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Trend Analysis of Temperature, Precipitation, and the SPEI for Drought Assessment in the Salehiyeh Dust Source Region (Alborz–Qazvin Province)

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ABSTRACT

This study was conducted to investigate the role of climate change in intensifying dry conditions and facilitating the transformation of the Salehiyeh wetland into a dust source. Daily temperature and precipitation data from the synoptic stations of Karaj, Qazvin, Hashtgerd, Taleqan, and Buin Zahra for the 1990–2024 period were obtained from the Iran Meteorological Organization and analyzed after quality control, completion of missing data, and removal of outliers. Trends in climatic parameters were examined using the non-parametric Mann-Kendall test and Sen's slope estimator. In addition, the (SPEI) was calculated at 1-, 3-, 6-, 9-, 12-, and 24-month timescales to evaluate drought severity and frequency. The results indicated that nearly all temperature indices at the studied stations exhibited significant warming trends. Increases in mean temperature, extreme temperatures, summer days, and tropical nights, together with significant decreases in frost days and frost nights, indicate substantial regional warming, particularly during the cold season. In contrast, although most precipitation indices showed decreasing trends, these changes did not reach statistical significance. The SPEI analysis further demonstrated significant negative trends at all timescales, indicating an increase in the frequency and severity of cumulative and long-term droughts in the region. Overall, the findings show that the study area is experiencing a distinct climatic transition characterized by rapid warming, especially during the cold season, increased nighttime temperatures, reduced frost frequency, and intensified drought conditions. Even in the absence of a significant decrease in precipitation, these conditions may contribute to wetland desiccation and increased dust emission potential through enhanced evapotranspiration and reduced surface moisture. Furthermore, the magnitude of the observed warming relative to typical global trends suggests the possible influence of local factors, including increased atmospheric pollutants, enhanced greenhouse effects, land-use change, and urban expansion, in addition to regional climate change.

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1. Introduction

In recent decades, coinciding with the deterioration of air quality and the increasing frequency of dust events across large parts of Iran, several studies have been conducted to identify and map internal dust source regions. Including investigations by the Geological Survey and Mineral Exploration Organization of Iran (2015) and the Department of Environment of Iran (2022). In these studies, the Salehiyeh–Allahabad Wetland area was identified as one of the major dust-producing hotspots shared between Alborz and Qazvin provinces. Due to its proximity to densely populated areas, urban-industrial infrastructures, and its large extent, this region can pose very serious risks in terms of air quality degradation and public health problems.

The factors contributing to the degradation of the Salehiyeh–Allahabad Wetland and its transformation into a dust source may be either natural or anthropogenic. Climate change, global warming, and drought are considered natural causes, whereas increasing greenhouse gas concentrations, land-use change, disruption of the hydrological regime, destruction of vegetation cover, and similar processes are regarded as human-induced factors. According to previous studies, disruption of the hydrological regime of the Salehiyeh–Allahabad floodplain is considered the most important anthropogenic factor responsible for the degradation of the region (Shahandeh *et al*., 2025). Nevertheless, the present study focuses specifically on the role of natural drivers, particularly climate change, in the degradation of this ecosystem.

drought studies can generally be classified into four categories: (1) investigation of drought causes to better understand the climatic characteristics leading to drought occurrence; (2) assessment of drought frequency and severity to estimate the probability of drought events with different intensities; (3) description and evaluation of the economic, social, and environmental impacts and costs of drought; and (4) development of suitable strategies for drought mitigation and adaptation. In line with the first two categories, the present study investigates long-term climatic changes by analyzing trends in temperature, precipitation, and the (SPEI) over a 35-year period spanning 1990 to 2024.

The widespread application of the SPEI in climatological and drought studies stems from its ability to account for the effects of increased evapotranspiration under global warming conditions. According to (Vicente-Serrano *et al*., 2010), under climate change, only the SPEI and the self-calibrated Palmer Drought Severity Index (sc-PDSI) are capable of adequately representing drought intensification associated with increased atmospheric evaporative demand. The SPEI is a standardized index with an intensity scale in which both positive and negative values are calculated, allowing the identification of both wet and dry periods. Its monthly updating capability makes it suitable for continuous monitoring, and the reliability of the results increases with the length of the available time series (Vicente-Serrano *et al*., 2010).

In recent years, numerous researchers have applied trend analysis methods to evaluate climate change. Some of these studies are briefly reviewed below. Bolouki *et al*. (2021) investigated trends in temperature parameters, including minimum, absolute minimum, maximum, absolute maximum, and mean temperature, as well as precipitation parameters, including total precipitation, frequency of rainy days, and maximum daily precipitation on an annual timescale. They used the Mann-Kendall test and Sen's slope estimator for 15 synoptic stations located in the provinces of Sistan and Baluchestan, Bushehr, and Hormozgan during the statistical period 1987–2019. Their results showed significant increasing trends in minimum, maximum, and mean temperatures across most parts of the study region, whereas total precipitation did not exhibit a significant trend.

Farajzadeh and Elahi (2020), using the Mann-Kendall test, analyzed trends in minimum,

maximum, and mean temperature, wind direction and speed, as well as mean precipitation at the Sanandaj synoptic station during the period 1960–2017. They reported decreasing trends in mean temperature, minimum temperature, mean wind speed, minimum wind speed, and precipitation, while maximum temperature and maximum wind speed showed increasing trends.

Alijani *et al*. (2012) examined precipitation trends at 44 meteorological stations across Iran during the period 1976–2008 at both seasonal and annual scales using Sen's slope estimator. Their results, at the 95% confidence level, indicated that 33 stations did not show statistically significant decreasing trends in annual precipitation.

Ahmadi and Rademanesh (2014) studied trends in monthly and annual mean temperatures at 18 synoptic stations in northern Iran during the period 1961–2010 using the Mann-Kendall test and Sen's slope estimator. The results indicated that, at the monthly scale, the number of months with increasing temperature trends was greater than that with decreasing trends. At the annual scale, one station exhibited a significant negative trend, whereas 11 stations showed significant positive trends. Overall, the regional temperature increased by approximately 1.15°C during the last 50 years.

Arvin *et al*. (2016) investigated trends in mean, minimum, and maximum temperature as well as precipitation at annual and monthly scales in meteorological stations of Chaharmahal and Bakhtiari Province during the period 1986–2015. They reported that minimum, maximum, and mean temperatures in most parts of the region exhibited significant increasing trends in nearly all months except November and December, as well as on the annual scale. In contrast, precipitation generally did not follow a significant trend, although the stations of Kouhrang, Lordegan, and Yancheshmeh showed significant decreasing trends in March precipitation at the 99% confidence level.

Hosyni *et al*. (2020) examined annual trends in temperature and precipitation over the 30-year period (1986–2015) using data from synoptic stations in Iran and neighboring countries that have experienced severe drought and dust crises in recent decades. Using the Mann–Kendall test, Sen's slope estimator, and linear regression analysis, they found that precipitation generally exhibited decreasing trends, whereas temperature showed increasing trends. At several stations, these trends were statistically significant. They also reported that changes in precipitation were more pronounced than variations in temperature across the study region.

Mirzaei Hasanlou *et al*. (2020), through analysis of climatic data from stations within the Lake Urmia basin, showed that all stations in the basin experienced increasing temperature trends and decreasing precipitation trends. Furthermore, the monthly SPEI index demonstrated downward trends (indicating increasing drought conditions) at short-, medium-, and long-term timescales, with statistically significant trends observed in several months.

Ebrahimi-Khusfi *et al*. (2022) investigated trends in the SPEI index at synoptic stations in Kerman Province during the period 1990–2018 using the Mann-Kendall test and Sen's slope estimator. Their results indicated that annual SPEI variations followed an upward trend, reflecting increasing drought severity in Kerman Province during recent years.

Kheiri *et al*. (2021) evaluated drought conditions using the Palmer drought index (PDSI-sc) and the SPEI index at four temporal scales (3-, 6-, 12-, and 24-month) across 101 stations in Iran over 24 years (1992–2015). Their findings showed that severe and very severe droughts occurred even in regions that historically had relatively favorable precipitation conditions. According to the SPEI index, the onset of the drought period corresponded to the years 1999 and 2000.

Noroozi *et al*. (2023) analyzed climatic parameter trends in Khuzestan Province using the

Mann-Kendall test. Their results showed a significant decreasing trend in precipitation, while temperature, relative humidity, and evapotranspiration exhibited significant increasing trends.

Salmani *et al*. (2019) investigated long-term climatic and hydrological trends in the eastern part of the Gorganroud Basin and reported increasing trends in both precipitation and temperature at all stations.

Shakerian *et al*. (2019) studied river discharge in the Karun Basin and precipitation trends in the same basin using the Mann-Kendall method. Their results indicated decreasing trends in both precipitation and river discharge.

Abbasi and Rostami (2021), through analysis of climatic and hydrological data from the Ilam Dam watershed using the Mann-Kendall test and Sen's slope estimator, reported that precipitation fluctuations at the study station did not follow a stable trend. In contrast, mean and maximum temperatures exhibited increasing trends at most temporal scales, whereas minimum temperature showed a decreasing trend. In addition, homogeneity testing of the meteorological time series revealed abrupt changes in all studied climatic variables.

Berhane *et al*. (2020), by analyzing precipitation and maximum temperature trends in Western Tigray, Ethiopia, using the Mann-Kendall test and Sen's slope estimator, showed that precipitation had a decreasing trend, while maximum temperature exhibited an increasing trend.

(Elzopi *et al*., 2020) likewise reported significant increases in mean temperature, whereas no consistent trends were detected in seasonal or annual precipitation in Ethiopia. (Touseef *et al*., 2020) reported declining precipitation in the Xiang River Basin, China. (Ekwueme & Agunwamba, 2021) found significant increasing trends in temperature and decreasing trends in precipitation in southeastern Nigeria, although the decline in precipitation was statistically significant in only three states. (Asgher *et al*., 2021) reported decreasing trends in precipitation and maximum temperature, together with increasing trends in minimum temperature, in the Middle Himalayas. Similarly, (Mondal *et al*., 2012) found significant increases in temperature accompanied by non-significant decreases in precipitation across different timescales in northeastern Bangladesh.

The recent desiccation of the Salehiyeh wetland, its transformation into an active dust source, and the associated environmental and public health consequences raise a fundamental question regarding the extent to which climate change has contributed to this process. Have significant climatic changes occurred in the study area over recent decades? If so, which climatic variables have been affected most substantially?

Based on previous studies, increasing temperature and decreasing precipitation trends are also expected in the study area. However, determining the statistical significance, magnitude, and rate of these changes, as well as clarifying their contribution to wetland degradation, requires a more comprehensive analysis. Therefore, the present study investigates trends in absolute maximum temperature, mean maximum temperature, mean annual temperature, absolute minimum temperature, mean minimum temperature, the number of frost days, the number of frost nights, the number of summer days, the number of tropical nights, maximum 24-h precipitation, monthly and annual precipitation, the number of precipitation days, and the (SPEI) over the period from 1990 to early 2025. The objective is to evaluate the significance and magnitude of climatic changes, determine the characteristics of drought conditions in the region, and clarify the contribution of climatic factors to the degradation of the Salehiyeh–Allahabad wetland. Furthermore, should anthropogenic factors be identified as contributing to the intensification of this process, the findings may provide a scientific basis for developing appropriate management strategies to mitigate its adverse impacts.

1.1. Study Area

The Salehiyeh–Allahabad wetland is a floodplain located between Alborz and Qazvin provinces (between latitudes 35°40′ to 36°05′ N and longitudes 50°05′ to 50°35′ E). The section situated within Alborz Province is known as Salehiyeh, while the part located in Qazvin Province is referred to as Allahabad. The floodplain covers approximately 46,500 ha, of which nearly 10,000 ha consists of wetlands and seasonally inundated areas (Shahandeh *et al*., 2025). The synoptic meteorological stations used in this study are located around the study area, as presented in Table 1. The geographical locations of these stations are also shown in Figure 1.

Table 1. Synoptic Stations around the Salehiyeh Wetland

Station	Statistical Period*	Climate Type
Karaj	More than 35 years	Cold semi-arid
Qazvin	More than 35 years	Cold semi-arid
Hashtgerd	19 years	Cold semi-arid
Buin Zahra	18 years	Cold arid
Taleqan	17 years	Cold Mediterranean
Abyek**	11 years (data gaps)	—
Payam Airport**	8 years	—
Nazarabad**	4 years	—

* Years with available records by the end of 2024.
** Due to incomplete statistical records, data from these stations were not used in the analysis.

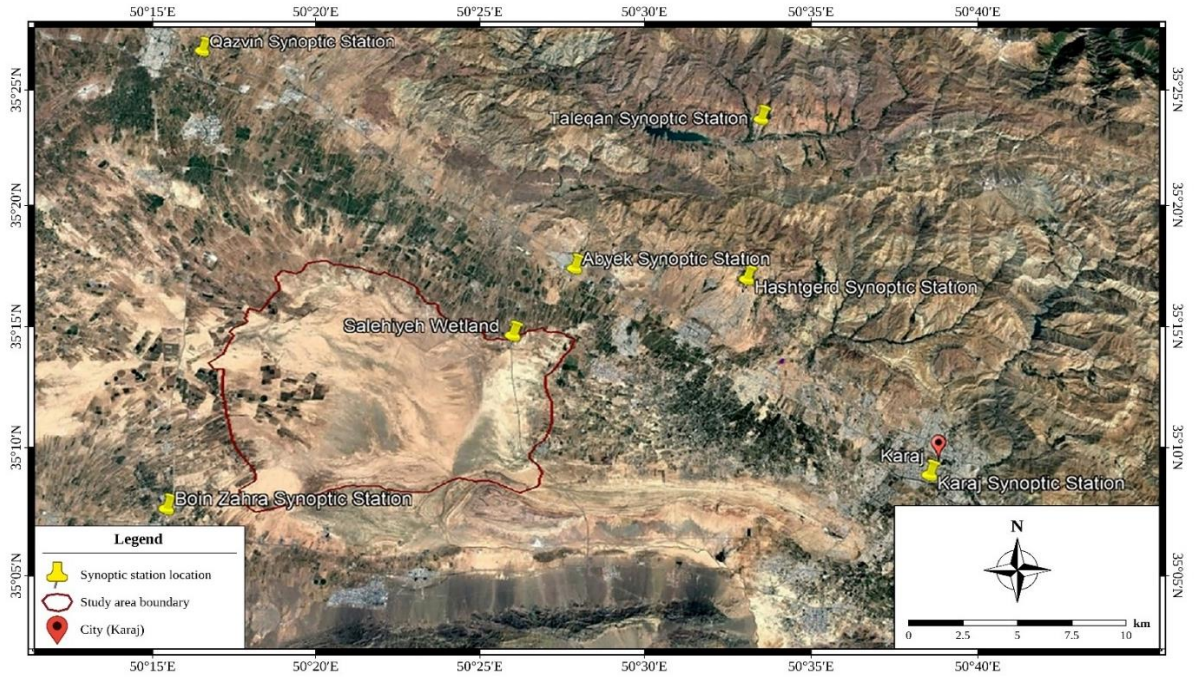


Figure 1. Geographical Locations of the Synoptic Stations around the Salehiyeh Wetland

2. Material and methods

2.1. Collection and Pre-processing of Climatic Data

In this study, daily meteorological data from the aforementioned stations were first obtained

from the Iran Meteorological Organization and subjected to quality control prior to statistical analysis. As a first step, the completeness of the datasets was assessed by examining the proportion of missing data at each station. The results showed that Nazarabad, Payam Airport, and Abyek stations contained 85.78%, 80.09%, and 68.72% missing data, respectively. Given the substantial proportion of missing observations and the resulting reduction in data reliability, these stations were excluded from the subsequent analyses.

Outliers were subsequently identified using the Interquartile Range (IQR) method. This approach is based on the interval between the first quartile (Q1) and the third quartile (Q3), with observations falling outside the predefined acceptable range being classified as outliers. The results indicated that the proportion of outliers in the precipitation time series ranged from 2.13% to 9.52% among the different stations (including the excluded station), whereas no statistically meaningful outliers were detected in the temperature records.

Following the quality-control procedure, the Karaj and Qazvin stations, which possessed relatively complete and consistent time series, were selected as reference stations. Missing observations at the remaining stations were reconstructed using a correlation-based reference-station approach. For each target station, the reference station exhibiting the highest correlation coefficient was selected; in all cases, the correlation coefficient exceeded 0.90. The missing values were then estimated using the statistical relationships established between the target and reference stations.

Finally, the climatic data were aggregated to monthly and annual temporal scales. In addition, several climatic variables and indices were derived and quantified from the daily records using the PivotTable function in Microsoft Excel (Table 2).

Table 2. Climatic Parameters of the Studied Stations

Station / Index	Karaj	Qazvin	Taleqan	Hashtgerd	Buin Zahra
Annual precipitation (mm)	230	286	393	332	189
Maximum 24-hour precipitation (mm)	46	42	48	50	36
Highest recorded temperature (°C)	42	42.4	37.9	39.4	46.4
Lowest recorded temperature (°C)	-16.6	-19.2	-21.3	-12.7	-23.6
Mean annual temperature (°C)	15.6	14.7	12.2	14.7	15.9
Mean maximum temperature (°C)	21.9	27.8	24.9	20	23.3
Mean minimum temperature (°C)	9.3	7.3	4.9	9.2	8.6
Number of rainy days	71	86	94	73	70
Number of days with precipitation ≤1 mm	34	40	40.6	28	37
Number of frost days*	3.5	3.1	5.5	5.4	1.5
Number of frost nights**	57	80	108	59	70
Number of summer days***	158.6	159.3	129.4	140.5	172.3
Number of tropical nights****	30.2	10.4	3.3	39.8	24

* Frost day: a day during which the maximum temperature does not exceed 0°C within 24 hours.
** Frost night: a night during which the minimum temperature is 0°C or lower.
*** Summer day: a day with maximum temperature equal to or greater than 25°C.
**** Tropical night: a night with minimum temperature equal to or greater than 20°C.

According to the data presented in Table 2, more than 45% of all precipitation days were associated with rainfall amounts of ≤1 mm, indicating a scarcity of effective rainfall events in the study area. Owing to its location in the mountainous region, Taleqan station recorded the highest precipitation, the fewest summer days, and the fewest tropical nights, while also experiencing the greatest number of frost days and frost nights. In contrast, Buin Zahra station,

located at a lower latitude, recorded the highest mean annual temperature and the highest absolute maximum temperature. It also exhibited the largest diurnal temperature range, reflecting the lower atmospheric moisture conditions prevailing at this station.

The number of tropical nights recorded at Karaj station was more than three times greater than that observed at Qazvin station. In addition to geographical differences, this contrast may also be associated with rapid urban expansion, extensive land-use change, and the development of urban heat island effects in Karaj relative to Qazvin.

2.2. Trend Analysis of Climatic Variables

To evaluate climatic changes in the study area over the study period, a set of precipitation- and temperature-related indices was selected and analyzed. The precipitation indices included annual maximum 24-h precipitation, total annual precipitation, total monthly precipitation, the number of precipitation days, and the number of days with precipitation ≤1 mm. The temperature variables comprised absolute maximum temperature, absolute minimum temperature, mean annual temperature, mean maximum temperature, mean minimum temperature, the number of summer days, the number of tropical nights, the number of frost days, and the number of frost nights.

The analyses were performed for the Karaj, Qazvin, Hashtgerd, Taleqan, and Buin Zahra synoptic stations, all of which possessed sufficiently long and reliable climatic records. Long-term trends and the magnitude of change were evaluated using the Mann-Kendall test and Sen's slope estimator.

2.2.1. Mann-Kendall Test

The Mann-Kendall test is a non-parametric statistical method used to detect the presence of a monotonic trend in a time series.

The test operates through pairwise comparisons of all values within the time series. The test statistic, denoted by SSS, is calculated as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\,(x_j - x_k)$$

Where:

- S = Mann-Kendall test statistic, indicating the presence or absence of a trend
- n = total number of observations
- x_j and x_k = data values at times j and k, respectively, where j>k

A positive value of S indicates an upward (increasing) trend, whereas a negative value indicates a downward (decreasing) trend.

Finally, using the S statistic and its variance, the standardized test statistic Z is calculated. If the p-value associated with the Z statistic is smaller than the selected significance level (commonly 0.05), the null hypothesis is rejected, confirming the existence of a statistically significant trend in the dataset.

2.2.2. Sen's Slope Estimator

After the Mann-Kendall test confirms the existence of a trend, Sen’s slope estimator is used to estimate the magnitude or slope of that trend. This method is also non-parametric and is resistant to outliers.

The slope between all possible pairs of points in the time series is calculated using the

following equation:

$$Q_{ij}=\frac{xj-xi}{j-i}$$

for i<j

where:

- x_i and x_j are the data values at times iii and j, respectively,
- j−i represents the time interval between the two observations.

Using this approach, a total of $N=\frac{n(n-1)}{2}$ slope values are obtained. These N slope estimates are then arranged in ascending order, and their median value is considered as Sen's slope estimator.

The resulting value represents the rate of change per unit time. The combination of the Mann-Kendall test and Sen's slope estimator provides a comprehensive trend analysis framework. The Mann-Kendall test determines whether a statistically significant trend exists, while Sen's slope estimator quantifies the rate at which the change occurs.

2.2.3. Calculation of the Standardized Precipitation Evapotranspiration Index (SPEI)

To evaluate the severity, frequency, and temporal trends of climatic drought, the (SPEI) was calculated using Python programming. Although the initial calculations were performed for eight meteorological stations, only the results from five stations were included in the final analysis because of data-quality and statistical limitations.

For the SPEI calculation, precipitation and potential evapotranspiration (PET) data, where PET was calculated using the Thornthwaite method, were used after preprocessing, including the identification, correction, and replacement of outliers and missing values using correlation-based and robust regression methods

The SPEI was computed at 1-, 3-, 6-, 9-, 12-, and 24-month timescales to characterize short-, medium-, and long-term drought conditions. During the standardization process, the Pearson probability distribution was used to model the cumulative distribution of the climatic water balance, and the entire available record (1990 to 2024) was adopted as the calibration period. Calculations were performed independently for each station to account for local climatic characteristics and to accurately represent the spatial variability of drought conditions.

Following the calculation of SPEI values at different timescales, the temporal patterns of drought and wet conditions across the study area were analyzed. Drought severity classes were then defined according to the standardized SPEI values (Table 3), and the frequency of occurrence of each class was calculated as a percentage of the entire study period. Finally, statistical comparisons among the different timescales were performed to evaluate drought variability and the consistency of the observed patterns.

Table 3. SPEI Classification Based on Index Values

SPEI Value	Classification
≥ +2.0	Extremely wet
+1.50 to +1.99	Severely wet
+1.00 to +1.49	Moderately wet
-0.99 to +0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
≤ -2.0	Extremely dry

To examine the temporal trends of the climatic variables, the Mann-Kendall test was applied to temperature, precipitation, potential evapotranspiration (PET), and the SPEI at all timescales. For each variable, the standardized *Z* statistic, *p*-value, and Sen's slope were calculated. The *Z* statistic and *p*-value were used to assess the statistical significance of the trends, whereas Sen's slope was used to quantify the rate of change.

2.2.4. Pettitt Test

To identify abrupt change points in the climatic time series, the non-parametric Pettitt test was applied at a significance level of 0.05. This test, originally developed by Pettitt (1979), is one of the most widely used methods for detecting abrupt shifts in the mean of time series. The Pettitt test is based on rank statistics and, without assuming any specific probability distribution, can identify the timing of a statistically significant structural change within a time series. This characteristic is particularly valuable in climate change studies, where the timing of shifts in the climatic regime is generally unknown. Therefore, the Pettitt test was employed as a complementary method to the Mann-Kendall test to investigate long-term climatic changes in the study area.

3. Results

3.1. Data Quality Assessment and Time-Series Reconstruction

The results of the data quality control procedure revealed a clear difference in the distribution of outliers between the precipitation and temperature datasets. While precipitation records at all stations contained a proportion of outlying observations, no statistically meaningful outliers were identified in the temperature time series. This finding reflects the inherently episodic and highly variable nature of precipitation compared with the relatively stable behavior of air temperature.

Correlation analysis among the meteorological stations further showed that all correlation coefficients exceeded 0.90. This indicates a high degree of climatic homogeneity across the study area and confirms the suitability of correlation-based approaches for reconstructing missing observations.

The reconstruction procedure successfully completed all missing data, and comparisons of descriptive statistics before and after gap filling indicated only negligible differences, demonstrating that the statistical characteristics of the datasets were preserved. Therefore, the final time series were considered sufficiently reliable for trend analysis and the assessment of long-term climatic changes.

3.2. Precipitation Trends

Trend analysis revealed that precipitation generally exhibited declining tendencies across most of the study stations during the study period. This pattern was more evident at stations with longer observational records, particularly Karaj and Qazvin.

The temporal evolution of precipitation (Figure 2) indicates that a noticeable decline became apparent at most stations from approximately 2010 onward. Although precipitation temporarily increased during 2019 and 2020 as a result of several major rainfall events, this increase was not sustained, and precipitation amounts declined again in the subsequent years. Thus, while interannual variability produced short-term interruptions in the downward trend, it did not alter the overall pattern of declining water availability in the region.

Overall, the results indicate that although the decreasing precipitation trend was not statistically significant at most stations, when considered together with increasing temperatures

and enhanced evapotranspiration, it is likely to have contributed substantially to intensified soil moisture deficits, reduced recharge of the Salehiyeh wetland, and an increased potential for dust emission.

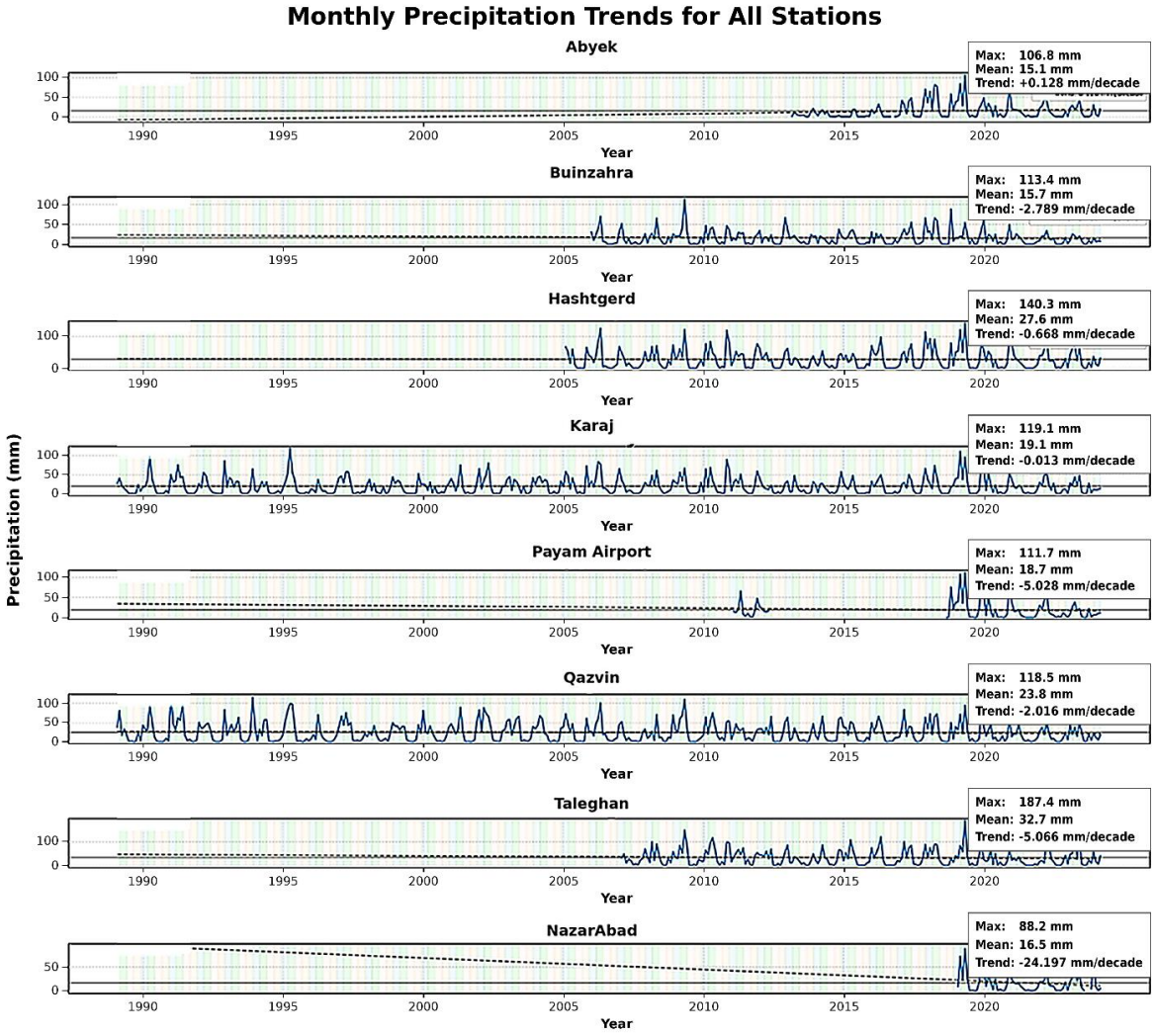


Figure 2. Monthly precipitation trend for all stations

3.3. Air Temperature Trends

The analysis of temperature indices indicates substantial warming across the study area during the study period. Nearly all temperature-related indices, including mean annual temperature, mean maximum temperature, mean minimum temperature, absolute maximum temperature, the number of summer days, and the number of tropical nights, exhibited increasing trends. In contrast, the numbers of frost days and frost nights showed decreasing trends at all stations.

The monthly temperature time series (Figure 3) demonstrate a nearly uniform warming trend across all stations. The more pronounced increase in minimum temperature relative to maximum temperature indicates warmer nights and a gradual decline in the frequency of cold events. This pattern is recognized as one of the most prominent signatures of climate change in many arid and semi-arid regions worldwide.

3.4. Analysis of the (SPEI) at Different Timescales

The temporal analysis of the SPEI revealed negative and statistically significant trends at all stations and across all investigated timescales. This finding indicates a progressive intensification of drought conditions in the study area over the past three decades. Moreover, the magnitude of the negative trends increased with increasing timescale. At short timescales, the rate of decline was generally less than 0.25 units per decade, whereas at the 24-month timescale it exceeded 0.60 units per decade at some stations. This pattern suggests that although short-term precipitation variability continues to occur, cumulative moisture deficits and long-term water stress have intensified progressively.

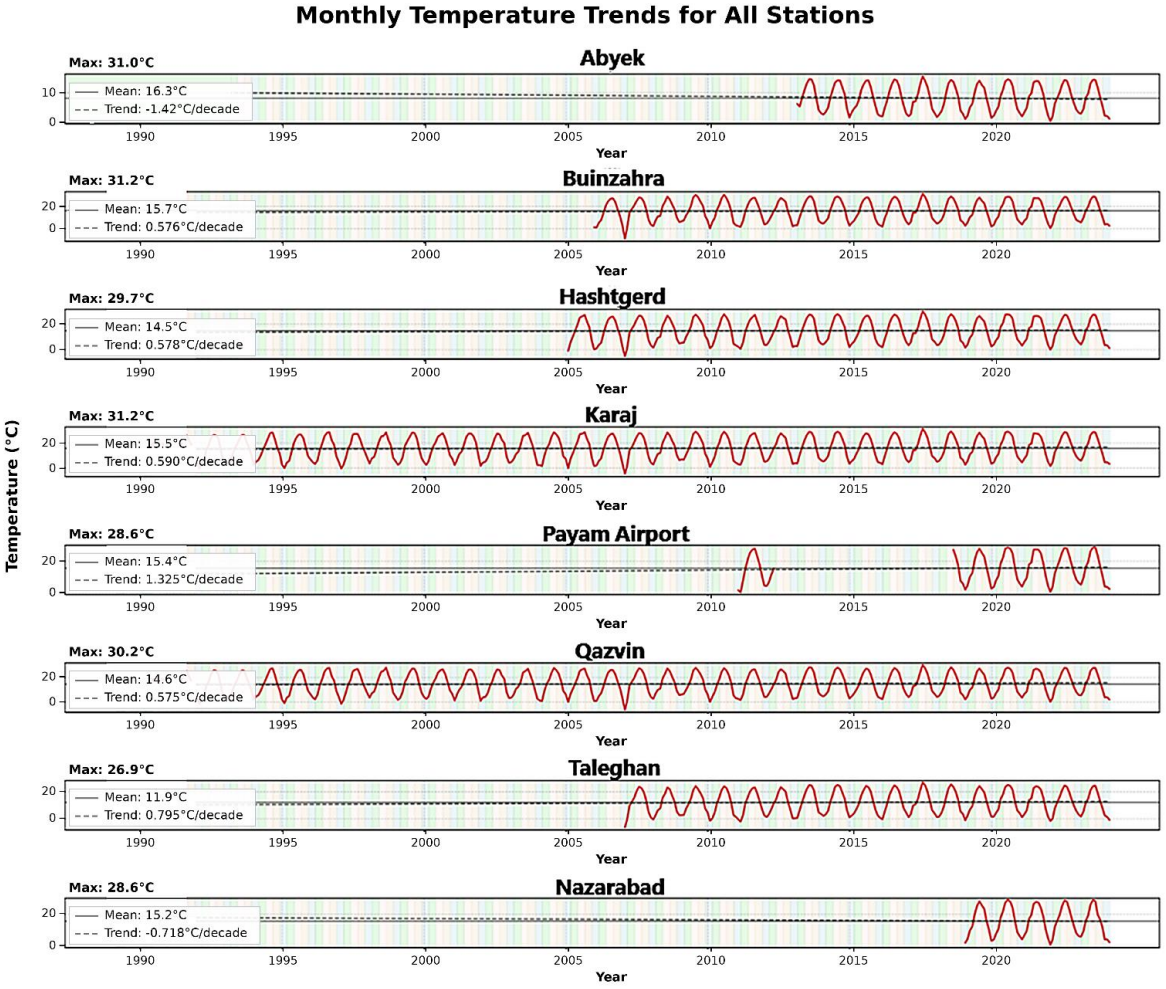


Figure 3. Monthly temperature trend for all stations

Comparison of the frequencies of drought and wetness classes across different timescales further demonstrated that, as the timescale increased, the proportion of normal conditions declined, whereas the frequency of moderate to severe drought increased. For example, the cumulative frequency of drought events at the 12-month timescale exceeded 20% of the total study period at some stations. This finding indicates that long-term droughts have become a more dominant component of the regional climatic regime than short-term drought events (Tables 4).

Correlation analysis among the different SPEI timescales showed that adjacent timescales were highly correlated, whereas the relationships between short- and long-term timescales were considerably weaker. This finding suggests that the processes controlling monthly and seasonal droughts are not necessarily identical to those governing multi-year droughts. Consequently, the simultaneous application of multiple SPEI timescales is essential for comprehensive drought monitoring and management.

Spatial comparisons revealed that Taleqan, owing to its higher elevation and greater precipitation, exhibited the most favorable moisture conditions among the study stations, although a declining SPEI trend was also observed at this station. In contrast, Buin Zahra, Qazvin, and the southern parts of the study area exhibited the greatest declines in SPEI, indicating greater vulnerability to drought and water scarcity.

Overall, the cumulative frequency of drought events (including moderate, severe, and extreme drought) increased from approximately 13.5% at the 1-month timescale (SPEI-1) to approximately 16.7% at the longer timescales. This result demonstrates that long-term SPEI indices are more effective in identifying cumulative water deficits and persistent drought conditions. Conversely, the frequency of extremely wet conditions decreased from 1.54% at the monthly timescale to values approaching zero at the longer timescales, indicating that most intense precipitation events in the region are short-lived and transient. This pattern suggests that the combined effects of regional warming and increased evapotranspiration have contributed more substantially to the development of long-term drought than reductions in precipitation alone (Table 4).

Table 4. Frequency table of drought categories based on SPEI index

Time scale	Extremely (%) wet	Severely (%) wet	Moderately (%) wet	Near normal (%)	Moderately (%) dry	Severely (%) dry	Extremely (%) dry
SPEI-1	1.5	3.9	9.3	71	8.1	3.7	1.7
SPEI-3	1.7	2.3	10.1	70	10.5	3.3	1.2
SPEI-6	1.5	3.8	7.9	70.5	9.8	5.4	0.3
SPEI-9	0.8	4.4	10.4	67.6	11	4.7	0.3
SPEI-12	0.7	3.7	10.5	66.5	13.9	3.4	0.3
SPEI-24	0.1	5.3	10.4	66.7	10.8	5.6	0.3

Correlation analysis also demonstrated that the correlation coefficients decreased as the temporal separation between SPEI timescales increased. For example, the correlation coefficient between SPEI-1 and SPEI-24 was only 0.312, whereas the highest off-diagonal correlation (0.89) was observed between SPEI-9 and SPEI-12 (Table 5).

Table 5. Correlations between different SPEI

	SPEI-1	SPEI-3	SPEI-6	SPEI-9	SPEI-12	SPEI-24
SPEI-1	1					
SPEI-3	0.648	1				
SPEI-6	0.466	0.747	1			
SPEI-9	0.383	0.605	0.841	1		
SPEI-12	0.367	0.557	0.735	0.898	1	
SPEI-24	0.306	0.468	0.601	0.711	0.795	1

These findings indicate that the mechanisms controlling short-term drought differ from those governing long-term drought, and that each timescale provides distinct information regarding the climatic conditions of the study area.

Overall, the SPEI analysis demonstrates that the study area experienced a statistically significant increase in both the severity and frequency of drought during the 1990–2024 period. The increasingly negative trends observed at longer timescales indicate intensifying cumulative water stress and a gradual decline in the resilience of the region's natural systems. Together with reduced precipitation and increasing atmospheric evaporative demand, these conditions have likely played a substantial role in the desiccation of the Salehiyeh–Allahabad wetland and the activation of regional dust source areas. The temporal evolution of the SPEI and the corresponding trend lines at different timescales are presented in Figure 4.

At the 1-month timescale (SPEI-1), the mean SPEI values at all stations were close to zero; however, the index exhibited substantial variability, with minimum and maximum values ranging approximately from −3 to +3. The significant negative trends detected at this timescale indicate that even short-term drought conditions have intensified over the study period. The greatest temporal variability at this timescale was observed at the Karaj and Buin Zahra stations.

At the 3-month timescale (SPEI-3), the negative trends remained persistent and became more pronounced at several stations. The highest rates of decline were recorded at Buin Zahra, Taleqan, and Qazvin, indicating an increasing frequency of seasonal droughts in these areas. In addition, the largest fluctuations in SPEI values were observed at the Hashtgerd and Qazvin stations.

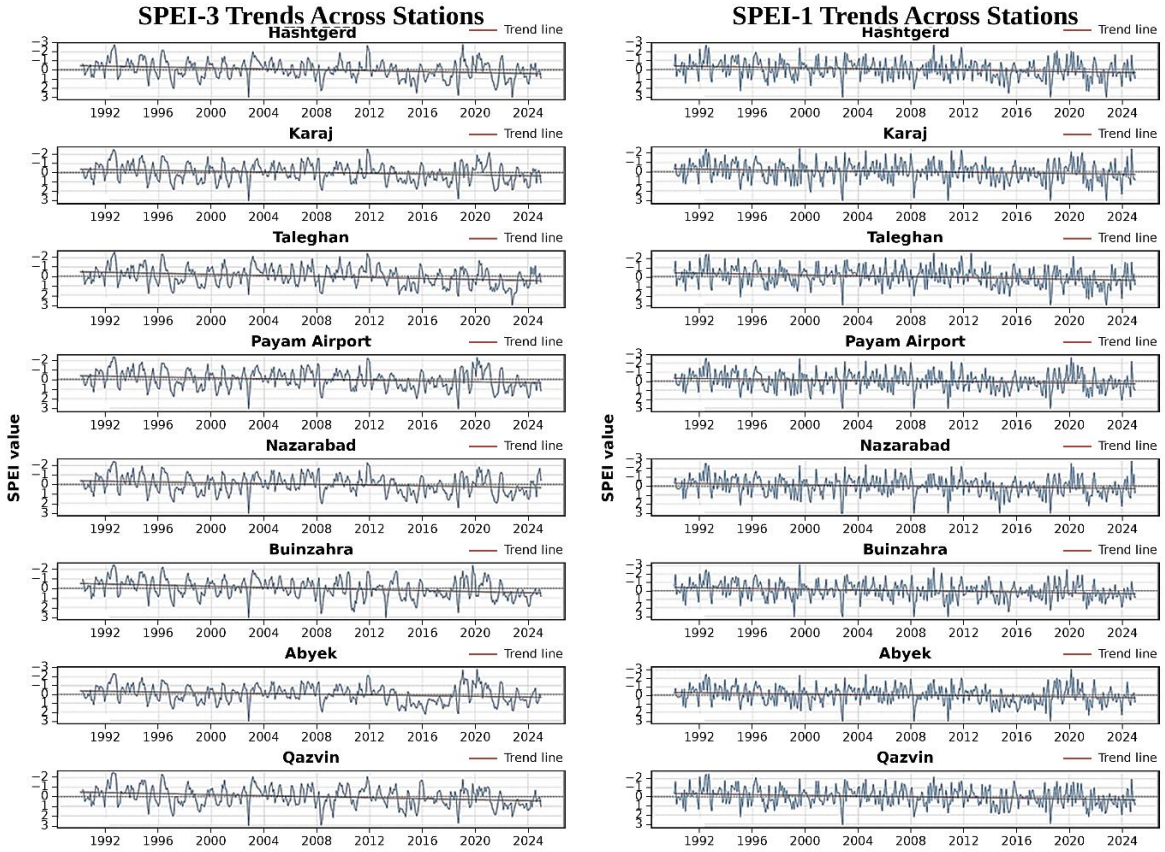


Figure 4. Temporal variations and trend lines of the (SPEI) from 1990 to early 2025 at different timescales.

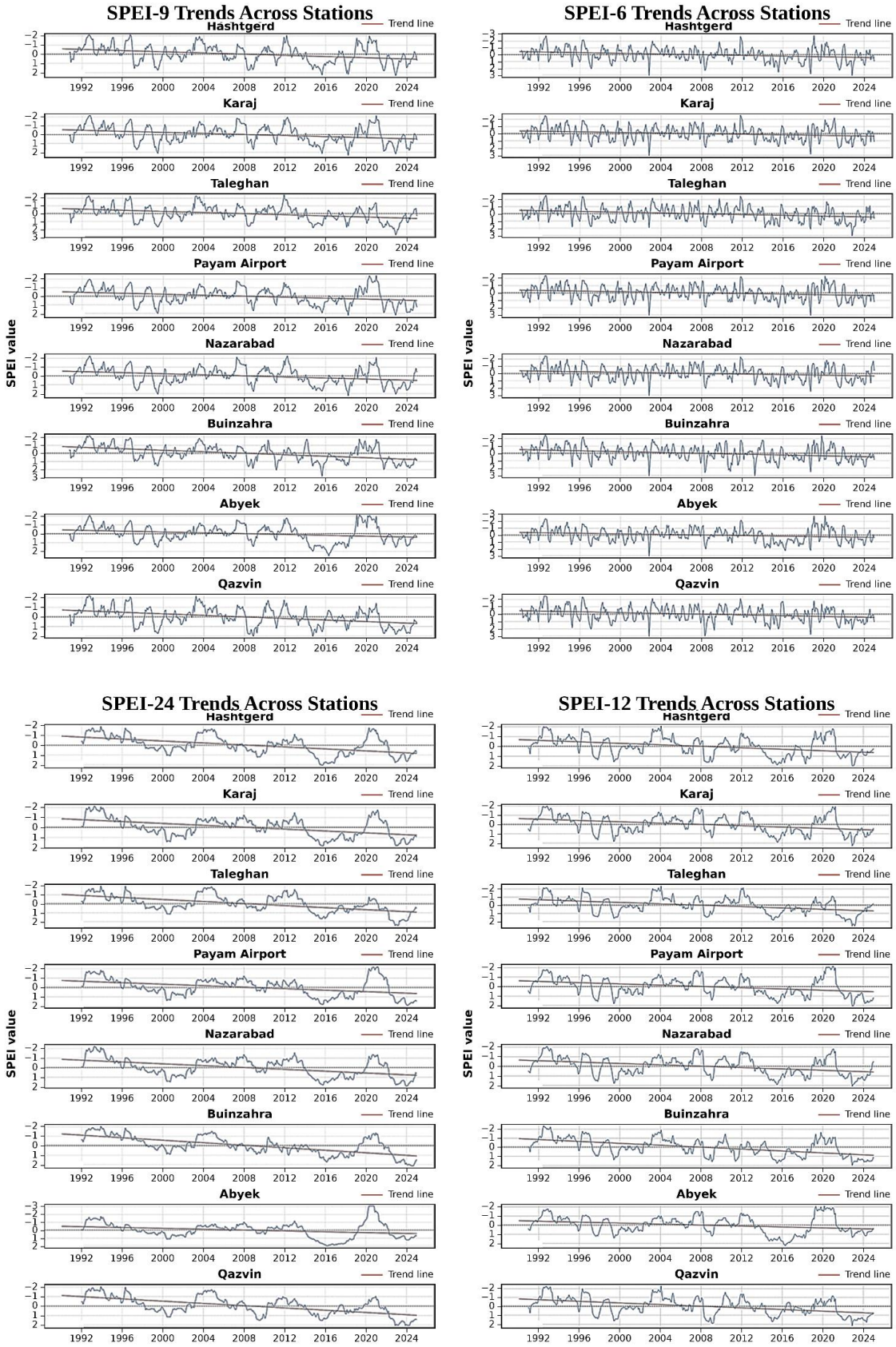


Figure 4. Continued

The SPEI-6 and SPEI-9 results indicate a further intensification of medium-term drought conditions. At these timescales, minimum SPEI values fell below −3 in some years, reflecting the occurrence of severe to extreme drought events. The strongest declining trends were observed at the Buin Zahra, Qazvin, and Taleqan stations.

At the longer timescales (SPEI-12 and SPEI-24), the negative trends reached their greatest magnitude. For SPEI-24, the rate of decline exceeded 0.60 units per decade at some stations. This finding indicates that, in addition to the increasing frequency of short-term droughts, cumulative moisture deficits and long-term hydrological droughts have also intensified across the region. The strongest negative trends at these timescales were observed at the Buin Zahra, Qazvin, and Taleqan stations, whereas Abyek station exhibited the greatest temporal variability.

The figure 5 illustrates the percentage of normal, drought, and wet conditions for each station in the study area according to the SPEI classification presented in Table 3.

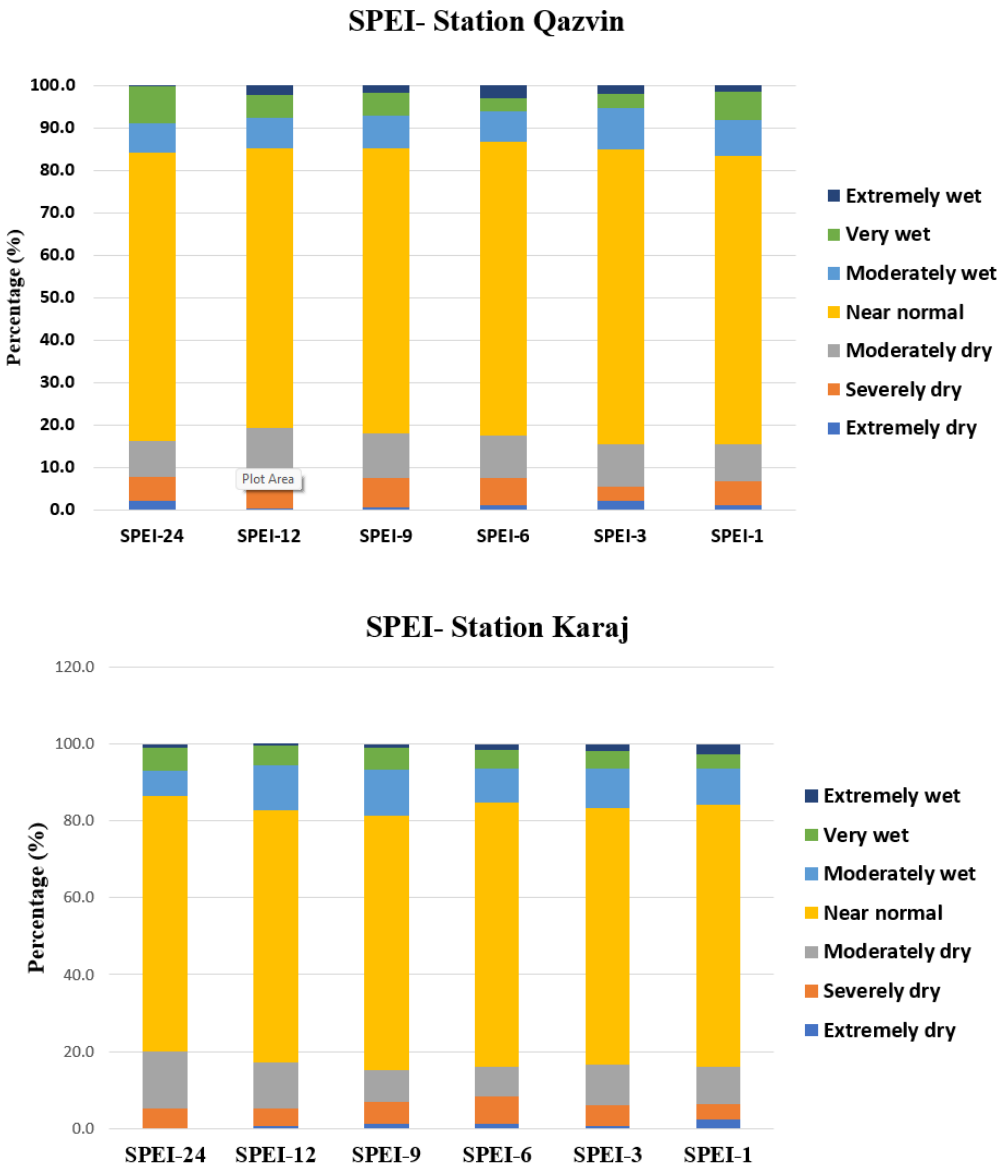


Figure 5. Percentage of normal, drought, and wet conditions at the study stations based on the SPEI classification.

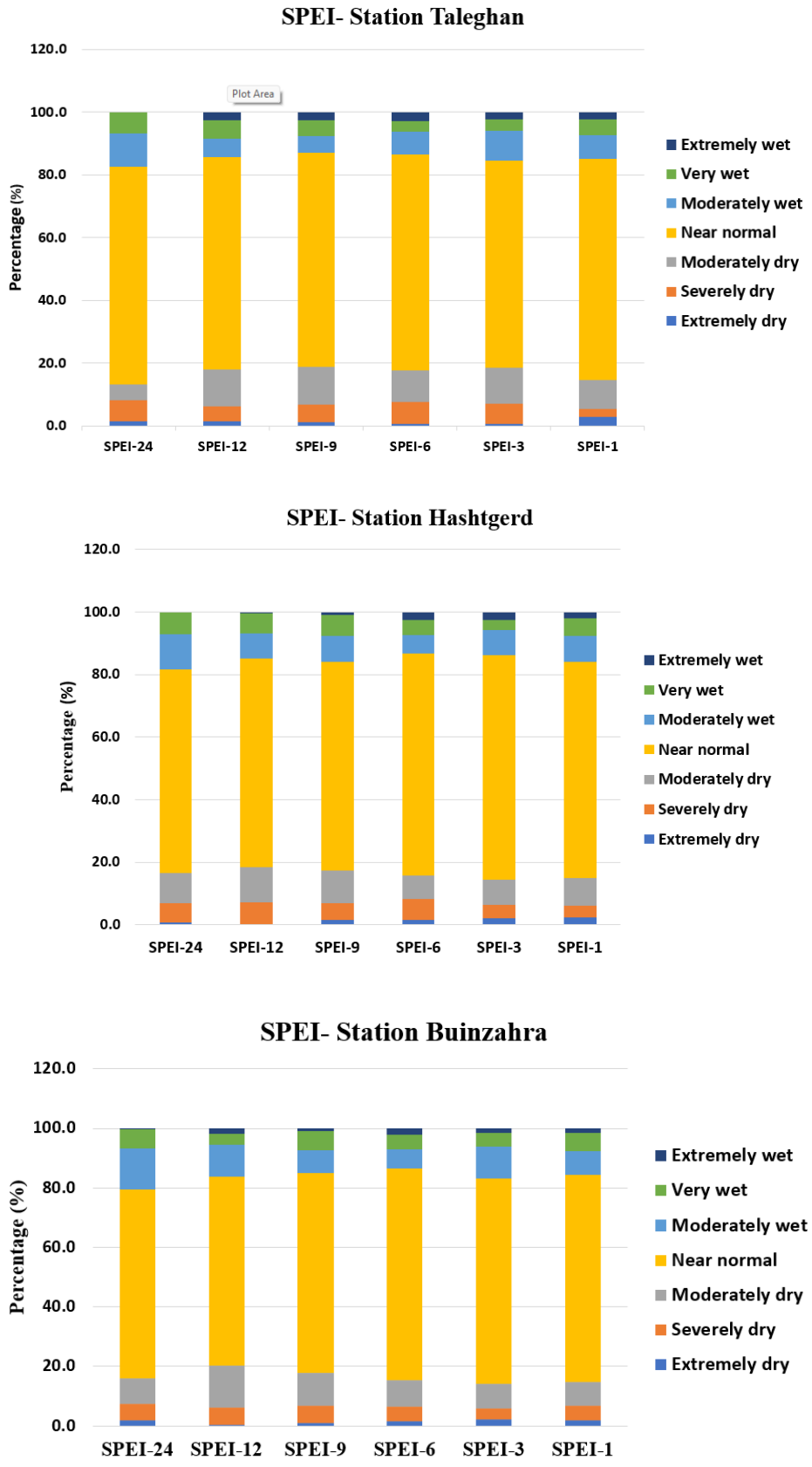


Figure 5. Continued

3.5. Trends in Climatic Variables Based on the Mann-Kendall Test

The results of the Mann-Kendall test indicate that the dominant pattern of climatic change in the study area is a transition toward warmer and drier conditions. Analysis of the temperature variables showed that most temperature-related indices, including mean annual temperature, mean maximum temperature, the number of summer days, and the number of tropical nights, exhibited increasing trends. Conversely, cold-related indices, including the numbers of frost days and frost nights, showed decreasing trends at most stations, indicating a gradual reduction in the frequency of cold events across the region.

In contrast, although most precipitation-related variables, including annual precipitation, monthly precipitation, the number of precipitation days, and maximum 24-h precipitation, exhibited decreasing trends, these trends were not statistically significant at most stations. Therefore, changes in precipitation alone cannot adequately explain the observed evolution of drought conditions in the study area.

The drought indices further revealed statistically significant negative trends in the SPEI at all investigated timescales, confirming increasing water stress and a growing frequency of cumulative drought events. These findings are consistent with the observed increases in temperature-related variables and atmospheric evaporative demand, highlighting the increasing influence of climate change on the regional hydroclimatic regime.

Overall, these results indicate that the desiccation of the Salehiyeh wetland has been driven primarily by rising temperatures, enhanced evapotranspiration, and the persistence of long-term drought, rather than by reductions in precipitation alone. The detailed results of the Mann-Kendall test and Sen's slope estimator for all climatic variables are presented in Table 6.

Based on the results presented in Table 4, the Mann-Kendall test and Sen's slope estimator indicate that the most prominent climatic signal across the study area during the 1990–2024 period is a statistically significant increase in temperature and the intensification of heat-related indices. In contrast, although decreasing precipitation trends were observed at most stations, they generally did not reach statistical significance. This pattern suggests that, under the current climatic conditions, the increasing atmospheric evaporative demand associated with regional warming is at least as important as declining precipitation in driving intensifying water stress.

The consistent increases in mean annual temperature and mean maximum temperature across all stations indicate progressive regional warming, accompanied by an increasing frequency and intensity of extreme heat events and a greater likelihood of establishing new temperature records.

Moreover, the statistically significant increase in mean minimum temperature, together with the pronounced decline in the number of frost nights at all stations, provides one of the strongest indicators of ongoing local climate warming. These changes may be associated with increasing greenhouse gas concentrations, reduced surface albedo, and enhanced heat retention within the lower atmosphere. Because nighttime warming is commonly linked to a strengthened greenhouse effect and reduced efficiency of nocturnal radiative cooling, these findings provide independent evidence of the intensification of climate warming in the region. The marked reduction in frost nights may also shorten the persistence of seasonal snow cover, accelerate snowmelt, and consequently reduce groundwater recharge. In addition, it reflects a shortening of the cold season, warmer winters, and a declining frequency of cold extremes.

Table 6. Changes in Different Climatic Parameters and Their Statistical Significance by Station

Climatic Parameter	Karaj (1990–2024)	Qazvin (1990–2024)	Hashtgerd (2006–2024)	Buin Zahra (2007–2024)	Taleqan (2008–2024)
Absolute maximum temperature	Highly significant increase	Highly significant increase	Significant increase	Significant increase	Non-significant increase
Change per decade (°C)	0.70	0.61	0.52	0.58	0.35
Mean maximum temperature	Highly significant increase	Highly significant increase	Significant increase	Significant increase	Significant increase
Change per decade (°C)	0.67	0.70	0.62	0.65	0.48
Mean annual temperature	Highly significant increase	Highly significant increase	Significant increase	Significant increase	Significant increase
Change per decade (°C)	0.59	0.56	0.55	0.57	0.42
Absolute minimum temperature	Significant increase	Significant increase	Significant increase	Significant increase	Stable trend
Change per decade (°C)	1.04	1.20	0.85	0.92	0.12
Mean minimum temperature	Significant increase	Highly significant increase	Significant increase	Significant increase	Significant increase
Change per decade (°C)	0.56	0.71	0.60	0.68	0.51
Frost days	Non-significant decrease	Significant decrease	Significant decrease	Significant decrease	Non-significant decrease
Change per decade (days)	-1.1	-1.4	-1.8	-2.1	-0.9
Frost nights	Highly significant decrease	Highly significant decrease	Highly significant decrease	Highly significant decrease	Significant decrease
Change per decade (days)	-7.3	-8.3	-6.5	-6.8	-4.2
Annual precipitation	Non-significant decrease	Non-significant decrease	Non-significant decrease	Non-significant decrease	Non-significant decrease
Change per decade (mm)	-12.4	-8.5	-15.2	-10.1	-18.3
Number of rainy days	Non-significant decrease	Non-significant decrease	Non-significant decrease	Non-significant decrease	Non-significant decrease
Change per decade (days)	-3.33	-2.86	-4.2	-3.1	-5.35
Summer days	Highly significant increase	Highly significant increase	Significant increase	Significant increase	Significant increase
Change per decade (days)	6.67	7.00	4.33	5.2	3.17
Tropical nights	Highly significant increase	Highly significant increase	Non-significant increase	Non-significant increase	Stable trend
Change per decade (days)	5.0	5.32	—	—	—

3.6. Breakpoints and Climatic Regime Shifts

The results of the Pettitt test at the 5% significance level indicate that climatic changes in the study area have not occurred solely as gradual trends but have also involved abrupt structural shifts in several temperature-related variables. This pattern was particularly evident at the Karaj and Qazvin stations, where most temperature indices exhibited statistically significant breakpoints between 2000 and 2010. These findings suggest that the regional climate entered a new warming regime during the first decade of the twenty-first century.

At the Karaj station, statistically significant breakpoints were identified in mean annual temperature and frost nights in 2008, in the number of summer days in 2004, and in the number of tropical nights in 2013. The occurrence of concurrent shifts across multiple independent temperature indices indicates that these changes are unlikely to reflect natural climatic variability alone; rather, they provide strong evidence of a structural transition in the regional thermal regime. The significance of this climatic regime shift is further reinforced by its temporal coincidence with the onset of the persistent decline in the SPEI and the subsequent intensification of long-term drought conditions, suggesting that regional warming has progressively altered the regional moisture cycle and water balance.

4. Discussion

The results of this study demonstrate that the dominant climatic pattern across the Salehiyeh–Allahabad wetland over the past three decades has been characterized by significant warming accompanied by the intensification of long-term drought conditions. While most temperature-related variables exhibited statistically significant increasing trends, the observed decline in precipitation did not reach statistical significance at most stations. These findings suggest that the recent climatic evolution of the region has been driven primarily by rising temperatures and the consequent increase in potential evapotranspiration rather than by substantial reductions in precipitation. In other words, the thermal component currently plays a more prominent role than precipitation in aggravating drought conditions. This interpretation is fully consistent with the theoretical framework of the (SPEI), which simultaneously incorporates the effects of precipitation and atmospheric evaporative demand in drought assessment.

The observed trends are in good agreement with several previous studies conducted in Iran and elsewhere. The statistically significant increases in temperature indices and the non-significant decline in precipitation are consistent with the findings of (Bolouki *et al*., 2021), (Farajzadeh & Elahi, 2020), (Alijani *et al*., 2012), (Ahmadi & Radmanesh, 2014), and (Arvin *et al*., 2016). Similar patterns of increasing temperature accompanied by declining or statistically insignificant changes in precipitation have also been reported by (Berhane *et al*., 2020), (Elzopi *et al*., 2020), (Touseef *et al*., 2020), (Ekwueme & Agunwamba, 2021), and (Mondal *et al*., 2012), further supporting the present findings.

Nevertheless, the results differ from those reported by (Hosyni *et al*., 2020), who concluded that precipitation changes were more pronounced than temperature changes in their study area. In contrast, the present study identified regional warming as substantially stronger and more statistically robust than changes in precipitation. This discrepancy may reflect differences in the spatial scale of the analyses, regional topographic characteristics, and local influences associated with urban expansion and land-use change.

One of the most important findings of this study is the statistically significant increase in temperature extremes and heat-related indices. The increase in absolute maximum temperature indicates an intensification of heatwaves and a greater probability of extreme high-temperature events in recent years. Concurrent increases in mean annual temperature, mean maximum

temperature, and mean minimum temperature further demonstrate that regional warming has affected virtually all components of the thermal regime rather than being confined to a particular season or period. The simultaneous increase in both maximum and minimum temperatures clearly indicates a progressive transition toward a warmer climate.

Another notable finding is that minimum temperatures have increased more rapidly than maximum temperatures. The rise in absolute minimum temperature, together with the marked decline in the number of frost nights, indicates that nighttime warming has been more pronounced than daytime warming. This phenomenon is widely recognized as one of the most robust indicators of contemporary climate change and is commonly associated with increasing greenhouse gas concentrations, higher atmospheric water vapor content, reduced surface albedo, and land-use change. According to (Safari, 2012), increasing greenhouse gas emissions resulting from fossil fuel consumption, rapid urbanization, and vegetation degradation are among the principal drivers of climate warming in arid and semi-arid regions.

The statistically significant decline in the numbers of frost days and frost nights represents another important outcome of this study. In addition to indicating a shortening of the cold season, these changes may have important implications for regional water resources. Reduced snow-cover persistence in the Alborz Mountains, earlier snowmelt, diminished groundwater recharge, and an increased risk of water shortages during the warm season are among the likely hydrological consequences. Furthermore, earlier spring warming may advance the onset of plant growth, thereby increasing vegetation vulnerability to late-spring frost events.

The Pettitt test further demonstrated that climatic changes in the study area have not occurred solely as gradual trends but have also manifested as abrupt shifts and transitions in the climatic regime. The occurrence of statistically significant change points in several temperature indices at the Karaj and Qazvin stations between 2000 and 2010 suggests that the regional climate entered a new warming phase at the beginning of the twenty-first century. This finding is consistent with the results of (Abbasi & Rostami, 2021), who also reported abrupt changes in climatic variables across Iran, and may reflect the intensification of climate change impacts in the region.

The SPEI analysis further revealed statistically significant negative trends across all investigated timescales, with the magnitude of these trends increasing progressively with longer accumulation periods. This pattern indicates that, in addition to more frequent short-term droughts, cumulative moisture deficits and persistent drought conditions have become increasingly severe. The marked intensification of drought at the 12- and 24-month timescales suggests a gradual decline in the resilience of natural ecosystems and regional water resources.

These findings are consistent with those reported by (Mirzaei Hasanlou *et al*., 2020), (Ebrahimi-Khusfi *et al*., 2022), and (Kheiri *et al*., 2021), who documented increasing climatic drought severity and a growing frequency of severe and extreme drought events across different regions of Iran. In the present study, the statistically significant decline in SPEI, despite the generally non-significant trends in precipitation, clearly highlights the critical role of increasing evapotranspiration in intensifying drought conditions.

From a management perspective, the findings of this study demonstrate that assessing water-resource conditions solely on the basis of precipitation variability may substantially underestimate the actual severity of drought. Under a warming climate, increasing evapotranspiration can intensify water stress even in the absence of statistically significant declines in precipitation. Consequently, the application of integrated drought indices such as the SPEI is essential for reliable drought monitoring and assessment. Furthermore, although previous studies have identified hydrological regime disruption as the principal anthropogenic

driver of the desiccation of the Salehiyeh–Allahabad wetland, the present results indicate that climate warming and increasing evapotranspiration have acted synergistically with human-induced disturbances to accelerate wetland degradation and enhance its susceptibility to dust emission. Therefore, sustainable water resources management, allocation of adequate environmental flows to the wetland, regulation of land-use change, mitigation of factors that intensify local warming, and the development of integrated climate and dust monitoring systems should be considered key priorities for reducing the vulnerability of this environmentally sensitive region.

5. Conclusions

The findings of this study demonstrate that the study area has entered a new climatic regime during the past three decades, characterized primarily by significant warming, a marked decline in cold-related events, and the intensification of long-term drought. Trend analysis using the Mann-Kendall test and Sen's slope estimator revealed statistically significant increasing trends in most temperature-related variables across all study stations, whereas precipitation generally exhibited negative trends that, in most cases, did not reach statistical significance.

Analysis of the rates of change showed that the mean annual temperature increased by approximately 0.54 °C per decade, corresponding to an overall increase of about 1.6 °C during the study period. This warming rate is substantially higher than the global average reported in the IPCC Sixth Assessment Report and by the World Meteorological Organization (IPCC, 2023) (WMO, 2024) & (WMO, 2025), which is estimated at approximately 0.20–0.25 °C per decade. The magnitude of warming observed in the Salehiyeh wetland therefore exceeds the global average and suggests the combined influence of regional climate change and local environmental drivers (Table 4).

The increases in mean temperature, temperature extremes, the number of summer days, and tropical nights, together with the statistically significant decreases in frost days and frost nights, collectively provide compelling evidence of intensified regional warming. Furthermore, the Pettitt test identified significant regime shifts at several stations, particularly Karaj and Qazvin, indicating that many temperature-related variables entered a new warming phase beginning in the early 2000s.

Analysis of the (SPEI) at multiple timescales revealed statistically significant negative trends at all stations and across all accumulation periods. The magnitude of these trends increased with increasing timescale, reaching its maximum at the 12- and 24-month timescales. These findings indicate that, in addition to more frequent short-term droughts, cumulative and persistent long-term drought has intensified throughout the region. Moreover, the results demonstrate that increasing temperature and potential evapotranspiration can substantially intensify effective drought conditions even when precipitation declines are not statistically significant.

Overall, the findings indicate that rapid regional warming, enhanced evapotranspiration, and the increasing persistence of long-term drought have created favorable conditions for the desiccation of the Salehiyeh wetland, reductions in surface moisture, depletion of water resources, degradation of vegetation cover, and ultimately the activation of regional dust source areas. Nevertheless, because the observed warming rate substantially exceeds the global average, it is likely that, in addition to the regional climate change signal, local factors—including urban expansion, land-use change, increasing atmospheric pollution, vegetation degradation, and disruption of the hydrological regime—have also contributed to accelerating these processes. Quantifying the relative contributions of these drivers will require further investigations integrating remote sensing observations, land-use datasets, air-quality

measurements, and climate modeling.

Based on these findings, sustainable water resources management, restoration of the natural hydrological regime supplying the wetland, conservation of vegetation cover, regulation of land-use change, establishment of long-term climate and dust monitoring systems, and the implementation of climate change adaptation strategies should be considered key priorities for reducing the vulnerability of the region. Future research should also quantitatively investigate the roles of temperature inversion frequency, air pollution, land-use change, and the urban heat island effect in amplifying regional warming and promoting the activation of the Salehiyeh dust source.

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Author Contributions

Reza SHahandeh: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Mohamad Rahimi And Hassan Khosravi: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing.

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Competing interests

The authors declare that they have no competing interests.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical considerations

Not applicable

References

Abasi, S., & Rostami, N. (2021). Long-term trend analysis and the relationship between meteorological and hydrological series (Case study: Ilam Dam watershed). *Extension and Development of Watershed Management, 33*(9), 30–38. (In Persian). https://www.magiran.com/p2300998

Ahmadi, F., & Radmanesh, F. (2014). Trend analysis of monthly and annual mean temperature of the northern half of Iran over the last 50 years. *Water and Soil*, *28*(4), 855–865. (In Persian). https://www.magiran.com/p1348631

Alijani, B., Mahmoudi, B., & Chougan, A. (2012). A study of annual and seasonal precipitation trends in Iran using a nonparametric method (Sen's slope estimator). *Journal of Climate Research*, *9*(3), 23–42. (In Persian). https://www.magiran.com/p1160558

Asgher, S., Ahmad, M., Kumar, N., & Kumari, M. (2021). Trend analysis of temperature and rainfall using Mann–Kendall test and Sen's slope estimator in Bhaderwah Tehsil of Doda District. *Research Journal of Agricultural Sciences, 12*(3), 1021–1026. https://www.researchgate.net/publication/352371578

Berhane, A., Hadgu, G., Worku, W., & Abrha, B. (2020). Trends in extreme temperature and rainfall indices in the semi-arid areas of Western Tigray, Ethiopia. *Environmental Systems Research, 9*, Article 3. https://doi.org/10.1186/s40068-020-00165-6

Bolouki, H., Fazeli, M., & Sharifzadeh, M. (2021). Investigating the trend of some climatic parameters in three south coast provinces of Iran and identifying the areas most affected by climate change. *Climate Change Research, 2*(6), 47–62. https://doi.org/10.30488/ccr.2021.284727.1044

Ebrahimi-Khusfi, Z., Mirakbari, M., Ebrahimi-Khusfi, M., & Soleimani-Sardoo, M. (2022). Evaluation of drought temporal changes using Mann–Kendall test and Sen's slope in Kerman Province for the period 1990 to 2018. *Desert Ecosystem Engineering, 11*(36), 1–16. (In Persian). https://civilica.com/doc/1934502

Ekwueme, B. N., & Agunwamba, J. C. (2021). Trend analysis and variability of air temperature and rainfall in regional river basins. *Civil Engineering Journal, 7*(5), 816–826. https://doi.org/10.28991/cej-2021-03091692

Elzopi, K., Chaturvedi, A., Madhava, K., Gopinath, G., Naveena, K., & Surendran, U. (2020). Trend analysis of long-term rainfall and temperature data for Ethiopia. *South African Geographical Journal*. https://doi.org/10.1080/03736245.2020.1835699

Farajzadeh, M., & Elahi, S. (2020). Climatic analysis in western Iran (Case study: Sanandaj synoptic station). *Climate Change Research, 1*(3), 52–64. (In Persian). https://doi.org/10.30488/ccr.2020.236090.1006

Hosyni, S. A., Majidi, L., Baly, A., & Shyravnd, H. (2020). Regional variations of temperature and precipitation in Southwest Asia. *Journal of Climate Research, 11*(42), 155–167. (In Persian). https://www.magiran.com/p2228237

Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report*. https://www.ipcc.ch/report/ar6/syr/

Kheyri, R., Mojarrad, F., Masompour, J., & Farhadi, B. (2021). Evaluation of drought changes in Iran using SPEI and SC-PDSI. *Spatial Planning (Modares Human Sciences), 25*(1), 175–206. (In Persian). https://sid.ir/paper/966698/en

Mirzayi Hasanlo, A., Abghari, H., & Erfanian, M. (2020). Evaluation of SPEI drought index and trend analysis using nonparametric methods in the selected stations of Urmia Lake Basin. *Journal of Watershed Management Research, 11*(22), 175–187. (In Persian). https://doi.org/10.52547/jwmr.11.22.175

Mondal, A., Kundu, S., & Mukhopadhyay, A. (2012). Rainfall trend analysis by Mann–Kendall test: A case study of the north-eastern part of Cuttack district, Orissa. *International Journal of Geology, Earth and Environmental Sciences, 2*(1), 70–78. https://doi.org/10.13140/RG.2.2.12822.06726

Noroozi, A. A., Homaei, M., & Torkaman, M. (2023). Analysis of the trends of climate parameters using the Mann–Kendall test (TFPW-MK) in Khuzestan Province. *Journal of Environmental Science Studies, 8*(2), 6510–6521. (In Persian). https://doi.org/10.22034/jess.2022.174474.1130

Safari, B. (2012). Trend analysis of the mean annual temperature in Rwanda during the last fifty-two years. *Journal of Environmental Protection, 3*(6), 538–551. https://doi.org/10.4236/jep.2012.36065

Salmani, H., Sheykh, V. B., Salmanmahini, A., Onagh, M., & Fathabadi, A. (2019). Long-term trend analysis of climate and hydrological series using autocorrelation removal statistical methods in the eastern Gorganrood Basin, Golestan Province. *Journal of Watershed Management Research, 10*(19), 58–72. (In Persian). https://www.magiran.com/p2017457

Shahandeh, R., Rahimi, M., & Khosravi, H. (2025). Environmental impact assessment of drainage construction in the Salehiyeh Wetland region with an explanation of climate change effects. *Management of Natural Ecosystems, 4*(3), 36–49. (In Persian). https://doi.org/10.22034/emj.2025.730109

Shakerian, S., Torabi Poudeh, H., Shahi Nezhad, B., & Naghavi, H. (2019). Investigation of the rainfall and river flow trends in the Great Karun Basin using the trend-free pre-whitening Mann–Kendall (TFPW-MK) test. *Iran-Water Resources Research, 15*(3), 272–282. (In Persian). https://www.magiran.com/p2068739

Touseef, M., Chen, L., Yang, K., & Chen, Y. (2020). Long-term rainfall trends and future projections over the Xijiang River Basin, China. *Advances in Meteorology, 2020*, Article 6852148. https://doi.org/10.1155/2020/6852148

Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate, 23*(7), 1696–1718. https://doi.org/10.1175/2009JCLI2909.1

World Meteorological Organization. (2025). *State of the climate in Asia 2024*. WMO.

World Meteorological Organization. (2025). *State of the global climate 2024*. WMO.