Analysis of Long-Term Changes in Hydro-Climatic Components (Case Study: Maroun Sub-Basin)

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Abstract

This research investigates the trends and changes in the statistical distribution of climatic parameters (the warm days index, TX90p, and precipitation) and hydrological parameters (river flow discharge) in the Maroun basin over a 50-year period (1971-2020). The Mann-Kendall test was employed to identify trends, and the Pettitt test was used to determine the timing of abrupt changes. The results indicated that the TX90p index exhibits a statistically significant increasing trend (p-value = 0.018), with a change point in the year 1995, following which its mean value increased by 57%. Although the decreasing trends in precipitation and discharge were not statistically significant at the 95% level, the Pettitt test identified an abrupt change in both parameters in the year 2008. A comparison of the statistical distribution of the data before and after the change points, using Kolmogorov-Smirnov, analysis of variance, and location tests, confirmed that not only the central tendency but also the shape and dispersion of these parameters have changed significantly. Specifically, the mean precipitation and discharge decreased by 28% and 46%, respectively, while their standard deviations also decreased by 38% and 52%, respectively. These findings collectively indicate a shift in the regional climate pattern towards warmer and drier conditions, which has serious implications for water resources management.

Keywords: Extreme Temperature, Precipitation, Thermal Index, Trend Change.

1. Introduction

The Earth's climate system is a complex and dynamic entity, with its various components—including the atmosphere, hydrosphere, cryosphere, and biosphere—constantly interacting with one another (Krissek and John 2025). At the heart of this system lies the hydrological cycle, which acts as the driving force behind the distribution and river flow discharge. Key components of this cycle, such as precipitation, river flow discharge, and temperature, are vital indicators for understanding the climate behavior of a region. Examining these variables over a short timeframe provides only a snapshot, often influenced by natural fluctuations. However,

what is now a serious scientific and managerial challenge is the analysis of long-term changes in these components. It is through such analyses that sustainable trends, potentially influenced by human factors (such as increasing greenhouse gas concentrations) or larger-scale natural processes, can be revealed (Nazeri Tahroudi 2025).

Among all hydro-climatic variables, three parameters—precipitation, river flow discharge, and extreme temperature values—hold a special position, as these three represent a direct link between climate and water resources. Precipitation, as the primary input to the hydrological system, marks the beginning of the water cycle. Changes in its temporal and

spatial patterns, intensity, and duration directly impact the amount of water available. Streamflow discharge (such as river flow discharge) is the observable output of this system, influenced by precipitation, snowmelt, evapotranspiration, and watershed characteristics. This component translates precipitation into water that can be harnessed for agricultural, industrial, and drinking purposes. On the other hand, extreme temperature values (including heat and cold waves) not only directly affect the environment and human health but also, by influencing evaporation rates, plant water needs, glacier and snowmelt, and even water quality, indirectly exert a multiple pressure on the water resources system (Nazeri Tahroudi 2025). Examining these three parameters separately and independently of each other cannot provide a complete understanding of the complexities of a region's hydro-climatic system. Changes in one component can have cascading effects on others. For example, a decrease in winter precipitation combined with an increase in temperature can lead to a reduction in snowpack and, consequently, a decrease in river flow discharge during spring and summer, even if the annual precipitation has not changed significantly (Feng and Hu 2007; Ford et al. 2021; Nazeri Tahroudi 2025).

Furthermore, planning for sustainable water supply, flood management, and drought mitigation requires a comprehensive understanding of the relationship between precipitation (input), river flow discharge (output), and temperature (regulator of evaporation and transpiration). A simultaneous analysis helps managers identify critical points in the basin and develop more flexible strategies (Agarwal et al. 2025). Additionally, different basins, based on their physiographic and climatic characteristics, exhibit varying responses to climate change. Examining these parameters simultaneously allows for the specific identification of the effects of climate change in each basin and the assessment of its vulnerability to phenomena such as flash floods, prolonged droughts, and heat stress (Abdelkareem and Mansour 2023).

A review of research in this area highlights significant trends observed over several decades, demonstrating the effectiveness of the relationships between these weather variables and their implications for water resource management, disaster preparedness, and ecological health. For example, Box et al. (2019), by examining the hydrological cycle over 47 years in the Arctic, showed that increasing humidity and precipitation in the Arctic are associated with rising air temperatures, suggesting how climate change can alter hydrological patterns (Box et al. 2019). This finding reinforces the interconnectedness of precipitation, temperature, and runoff trends, emphasizing the need for comprehensive climate models that incorporate these long-term trends.

In the context of regional studies, Limsakul and Singhruck (2016) analyzed long-term trends in total precipitation and extreme precipitation in Thailand, revealing significant changes in both total and extreme precipitation. This research emphasizes the variability of precipitation patterns in different geographic regions and highlights the complexity of regional hydrological responses to global weather trends. Araya-Osses et al. (2020) demonstrated how increasing temperatures increase the atmosphere's water-holding capacity, leading to more frequent extreme precipitation events. Identifying regional flood hazard patterns provides insights into how long-term precipitation and runoff trends may evolve, informing water resource management strategies and disaster preparedness efforts. Donat et al. (2016) investigated long-term trends and variability associated with weather phenomena such as El Niño and the North Atlantic Oscillation. This study emphasizes the importance of extreme temperature events in understanding regional hydrological responses and further links temperature changes to precipitation trends.

Minaei and Irannezhad (2018) analyzed the spatiotemporal trends of precipitation, temperature, and river discharge in northeastern Iran during the period 1953-2013. The results showed that 12.5%, 19%, and 12.5% of stations exhibited a significant increasing trend in daily, monthly, and annual precipitation, respectively. Conversely, warming trends were observed in 38%, 23%, and 31% of stations for temperature at daily, monthly, and annual scales. Daily and monthly river discharge decreased in 80% and 40% of stations, respectively. These results indicate an

increase in precipitation and temperature but a decrease in river discharge, likely due to increased evapotranspiration rates resulting from warming. Khalili et al. (2016) also investigated the Precipitation Concentration Index (PCI) at 34 synoptic stations in Iran over a 50-year period (2010-1961). The results showed that the annual precipitation concentration had a similar trend in two 25-year sub-periods. Central and southern Iran exhibited very irregular and high precipitation concentration. At the annual scale, no station had a regular concentration (PCI > 10). Overall, 50% of stations showed an increasing trend in PCI, and 58% of stations experienced a decreasing trend in annual precipitation.

Toride et al. (2018) studied historical precipitation trends in the Shasta Reservoir watershed in California over 159 years (2010-1851) using dynamic downscaling and the WRF model. Trend analysis revealed a significant increase in total precipitation and the intensity of extreme events (such as 1- to 72-hour storms). The turning point for the increasing trend in annual precipitation was identified as 1940, and for extreme precipitation, the range was 1950-1960. A sharp increase in the variability of annual precipitation was also observed after the 1970s, indicating an increase in the occurrence of both very dry and very wet conditions.

Dissanayaka and Rajapakse (2019) assessed the impacts of climate change on the hydrological regime of the Kalu River basin in Sri Lanka. Their findings indicate an increase in temperature and precipitation values while the average annual precipitation of the basin is decreasing. Projections using the CanESM2 model for different RCP scenarios suggested that temperatures may increase. This study simulated river flow discharge in future periods (2020, 2050, and 2080) using the HEC-HMS hydrological model to evaluate water resource management options for sustainable development under the influence of future climate change.

Sa'adi et al. (2013) examined the trend of seasonal and extreme precipitation changes in the Johor River basin in Malaysia during the period 1970-2015. The seasonal index indicated that the annual precipitation regime in this basin is relatively seasonal with a short dry season. Trend analysis of 11 extreme precipitation indices showed a significant increase in recurrent indices, particularly at the end of the northeast monsoon season. This increase in extreme precipitation is expected to exacerbate flood conditions in flood-prone areas. Mohammadi et al. (2024) used 14 empirical equations to estimate evaporation variations in cold regions. Their results showed that the default equations of Kohler (1955) and Papadakis (1961) were more suitable. Revising the equations with local data improved the performance of all equations, and the revised Kohler (1955) equation was introduced as the most accurate option. It was concluded that using revised equations with regional data increases the reliability of evaporation estimation.

Nazeri Tahroudi (2025) analyzed the spatiotemporal changes, stationarity, variance asymmetry, and distributional changes of global precipitation from 1891 to 2019. The results showed that 32% of global regions experienced a statistically significant increase and 21% a decrease in precipitation. Temporal regime changes primarily occurred between 1955 and 1987. Assessments indicated that 78% of the studied regions exhibited non-stationary behavior. Based on the PCI index, only 7% of global regions showed regular precipitation concentration. A significant shift towards irregular patterns was identified in recent decades. Statistically significant distributional changes were observed in 59% of cases, particularly in North Asia (increasing) and the Middle East and Africa (primarily decreasing).

Also, Mekuria et al. (2025) applied Modified Mann-Kendall, Sen's slope, and Innovative Trend Analysis (ITA) methods to the Upper Omo Gibe Basin and found an overall declining rainfall trend, though some stations showed increases. Temperature exhibited significant upward trends across all seasons, with the highest increase in spring (0.25°C/year). Streamflow trends varied by station and season, with both significant increases and decreases detected. Notably, the ITA method identified stronger significant trends in all variables (e.g., in 68% of streamflow cases) compared to the Modified Mann-Kendall test. The authors concluded that these shifts indicate a move toward warmer and drier conditions, with critical

implications for water resources, drought management, and agricultural planning in the basin.

The reviewed studies examined changes in meteorological and hydrological parameters worldwide, reporting both decreasing and increasing changes. In addition to precipitation and river flow discharge variables, this study also investigated the percentage of warm days with extreme temperatures. The aim of this study was to examine the trend of changes in precipitation values, river flow discharge, and extreme temperature index in the Maroun sub-basin. In essence, the objective of this analysis was to quantify changes in the frequency and intensity of hot days, precipitation values, and river flow discharge, and to provide evidence of climate change in the study area. In addition to examining changes in the aforementioned values and changes in the shape and location of the distribution before and after a significant break in the time series, the study also considered these aspects.

2. Materials and Methods
2.1. Study Area

The Maroun River basin is located as one of the important and vital sub-basins within the larger Karun River basin in Khuzestan Province and a portion of Kohgiluyeh and Boyer-Ahmad Province. This basin, with an area of approximately 6,200 square kilometers, is primarily fed by the Maroun River, which originates from the high Zagros Mountains. The Maroun River, flowing through deep valleys and steep slopes, eventually joins the Jarahi River near the Bend-e Qir region after merging with the Karkheh River.

It plays a crucial role in supplying water for irrigation of the fertile downstream plains (particularly the Ramhormoz and Hendijan plains) and supporting wetland ecosystems. The large Maroun and Dorudzan dams have

been constructed on this river, which, in addition to controlling destructive floods, play a key role in storing water for agricultural, industrial, and drinking purposes. From an environmental perspective, this basin is home to a diverse range of animal and plant species, but in recent years, it has faced challenges such as reduced precipitation, excessive water withdrawals, and pollution resulting from agricultural and industrial activities, making integrated and sustainable management of this river basin an undeniable necessity.

In this study, river flow discharge (m^3/s), precipitation (mm), and hot days index (TX90p) data from the period 1971-2020 at a monthly scale were used. The location of the Eydanak meteorological and hydrometric station is shown in Fig. 1. The statistical characteristics of the data studied are shown in Table 1.
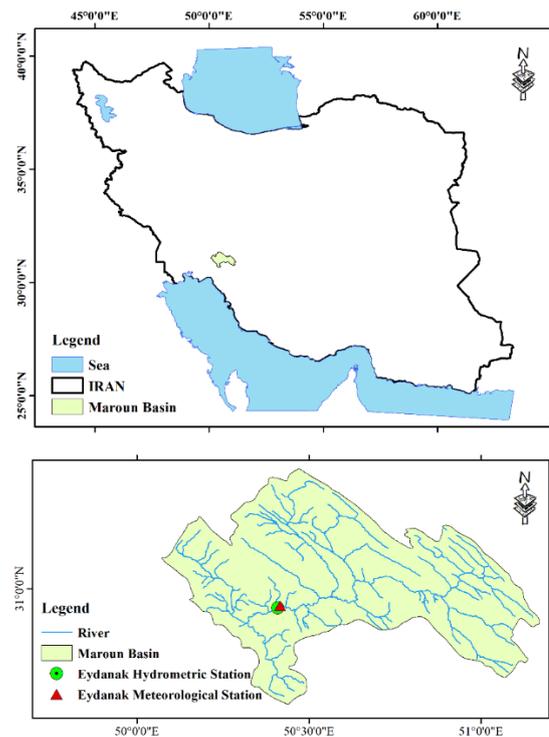

Fig. 1. Location of the Maroun station in Iran and the study area

Table 1. Statistical characteristics of the data studied

Parameter	Max	Min	Mean	St.D	Var
TX90p (%)	26.69	0.27	10.98	6.27	39.35
Precipitation (mm)	1213.80	0.00	595.25	230.51	53136.23
River flow discharge (m^3/s)	115.72	15.32	48.14	23.74	563.76

In addition to the parameters studied, a temperature extreme index was also investigated. This index measures the percentage of days on which the maximum air temperature (TX) exceeds the 90th percentile of the historical temperature for that day, denoted as TX90p. Simply put, TX90p indicates the frequency of hot days compared to a normal baseline period.

2.2. Assessment of trends in the studied values

In this study, the modified Mann-Kendall test, which removes the effects of internal autocorrelation, was used to assess trends in the values studied (precipitation, river flow discharge, and hot days index). This test is particularly crucial for meteorological and hydrological data. This test has been extensively reviewed and validated in numerous studies for detecting trends in various meteorological and hydrological variables (Mann 1945; Kendall 1963; Hamed and Rao 1998; Ahmadi et al. 2018; Ali et al. 2019; Ashraf et al. 2021; Vani et al. 2023). In the Mann-Kendall test, the statistic is considered as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}\left(x_j - x_i\right) \qquad (1)$$

where x_j is the sequential data values, n is the length of the data set, and $\text{sgn}(\theta)$ is the sign function that defined as follows:

$$\text{sgn}(\theta) = \begin{cases} 1 & if \quad \theta > 0 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 0 \end{cases} \qquad (2)$$

Mann (1945) and Kendall (1963) research showed that when *n* is large ($n \geq 8$), the *S* statistic is approximately normally distributed, with its mean and variance as follows:

$$E(S) = 0 \qquad (3)$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5)}{18} \qquad (4)$$

where t_i is the number of data points that are the same in group *i*, and *m* is equal to the number of paired groups. The standardized test statistic *Z* is calculated as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \qquad (5)$$

A very useful index in the Mann-Kendall test is the slope of the trend line, or what is commonly known as the Sen's slope, which indicates the magnitude of the uniform trend (Tahroudi et al. 2019). The slope of the trend was estimated using the method presented by Thiel (1950) and later Sen (1968) with the following equation:

$$\beta = Median\left(\frac{x_j - x_i}{j - i}\right) \qquad \forall i < j \qquad (6)$$

where β is the estimator of the trend line slope, and x_i and x_j are the i-th and j-th observed values, respectively. Positive values of β indicate an increasing trend, while negative values indicate a decreasing trend. In this study, the modified Mann-Kendall test was used, a method described by Kumar et al. (2009). To investigate and identify the time of trend change in evaporation values, the Pettit test was used (Pettit 1979). The Pettit test operates based on ranks and is not sensitive to the distribution of the data. This feature makes it suitable for non-normal or skewed data. Also, since Pettit uses ranks, it is more resistant to outliers.

2.3. Two-Sample Kolmogorov-Smirnov test

The two-sample Kolmogorov-Smirnov (KS) test is a non-parametric test for comparing the distribution of two independent

$$D_{n,m} = \sup_x \left| F_{1,n}(x) - F_{2,m}(x) \right| \qquad (7)$$

where *n* is the size of the first sample with CDF function $F_{1,n}(x)$, *m* is the size of the second sample with CDF function $F_{1,m}(x)$, and $\sup_x$ is equal to the largest absolute difference between the two CDFs (Smirnov 1948; Massey 1951).

3. Results and Discussion

In this section, we first examined the trend changes in the studied parameters, including temperature, river flow discharge, and the hot

days index (TX90p), over the 50-year statistical period under study (2020-1971). To this end, the modified Mann-Kendall test, which removes the effects of internal autocorrelation of the data, was used. The results of the trend change analysis of the studied values are presented in Table 2.

According to Table 2, it can be observed that the TX90p parameter, which represents the percentage of days with maximum temperatures exceeding the 90th percentile of the baseline period (very hot days), exhibits an increasing trend. The Mann-Kendall statistic for TX90p values is positive (0.231) and its p-value (0.018) is less than the significance level of 0.05. This result clearly indicates a statistically significant increasing trend in the frequency of very hot days in the Maroun region. The trend line slope (0.165) also confirms this continuous increase. Considering the trend line slope and the 50-year statistical period, it can be observed that the frequency of hot days has increased by an average of more than 8% during the 2020-1971 statistical period.

Table 2. Results of trend analysis of studied values using the modified Mann-Kendall test

Parameter	p-value Mann-Kendall	Mann-Kendall's Tau	Slope of trend line
TX90p (%)	0.018	0.231	0.165
Rainfall (mm)	0.141	-0.144	-3.654
River flow discharge (m³/s)	0.089	-0.167	-0.320

For precipitation data, the Mann-Kendall statistic (-0.144) is negative according to Table 2, indicating a decreasing trend in annual precipitation. However, the p-value (0.141) is greater than 0.05, so this decreasing trend is not statistically significant. In other words, although the average precipitation has decreased during the study period, this decrease could be due to natural climate fluctuations and it cannot be confidently stated that a long-term climate change has occurred. The 50-year decrease in precipitation at this station, according to the trend line slope statistic, is approximately 180 mm.

With regard to Table 2, similar to precipitation, the Mann-Kendall statistic for river flow discharge is also negative (-0.167)

and its p-value (0.089) is greater than 0.05. This result indicates a decreasing trend in river flow discharge that is statistically at the threshold of significance but is not considered significant at the conventional 95% confidence level. The negative slope (-0.320) also indicates this decrease, meaning that, considering the 50-year statistical period under review, this decrease is approximately 16 cubic meters per second compared to the beginning of the statistical period.

An overall analysis of the Maroun station data reveals a cautionary but conventional pattern regarding climate change. While the region's temperature is significantly increasing (increasing very hot days), no clear and significant trend in decreasing precipitation is observed. However, the Maroun River's flow discharge is decreasing. This combination of findings suggests that the decrease in river flow discharge is not solely due to decreasing precipitation, but rather other factors, such as increasing temperatures and, consequently, increasing evapotranspiration, potentially play a significant role. Increasing temperatures increase the water needs of plants and evaporation from water and soil surfaces, which can lead to a decrease in water available for runoff and river flow discharge, even if precipitation remains constant. This phenomenon can exert a multiple pressure on the region's water resources, which are primarily reliant on the Maroun River for agriculture and drinking water.

The findings of this analysis are consistent with the results of broader studies at the national level in Iran and the Middle East region. For example, the increase in extreme temperature and precipitation indices across Iran, particularly in the southwestern regions, has been reported in Soltani et al. (2016). Khalili et al. (2016) and Nazeri Tahroudi (2025) also investigated and reported these changes across Iran. Ashraf Vaghefi et al. (2014) also showed that in many Iranian basins, including the Karun basins, runoff has been observed to decrease. The time series changes of the studied values, considering the trend parameter changes, are presented in Figs. 2, 3, and 4.

Based on Fig. 2, an upward trend in the number of hot days is observable. This increase is not random but is likely influenced

by systematic factors such as climate change. In summary, this analysis indicates that the frequency of extremely hot days in the study area is significantly and consistently increasing. Figure 3 also shows a decreasing trend in precipitation values at the Maroun station over time. Based on the p-value results, although a general decreasing trend appears, it is not statistically significant. In other words, this decrease could be due to natural variations in the data, and we cannot statistically claim a real, systematic downward trend in precipitation. Figure 4 also illustrates a decreasing trend in river flow discharge values. This decrease could be part of the natural fluctuations of the hydrological system. For the statistical analysis and examination of the changes in the studied values, the results of the time of trend change analysis, stationarity, and homogeneity tests have also been investigated and are presented in Table 3.
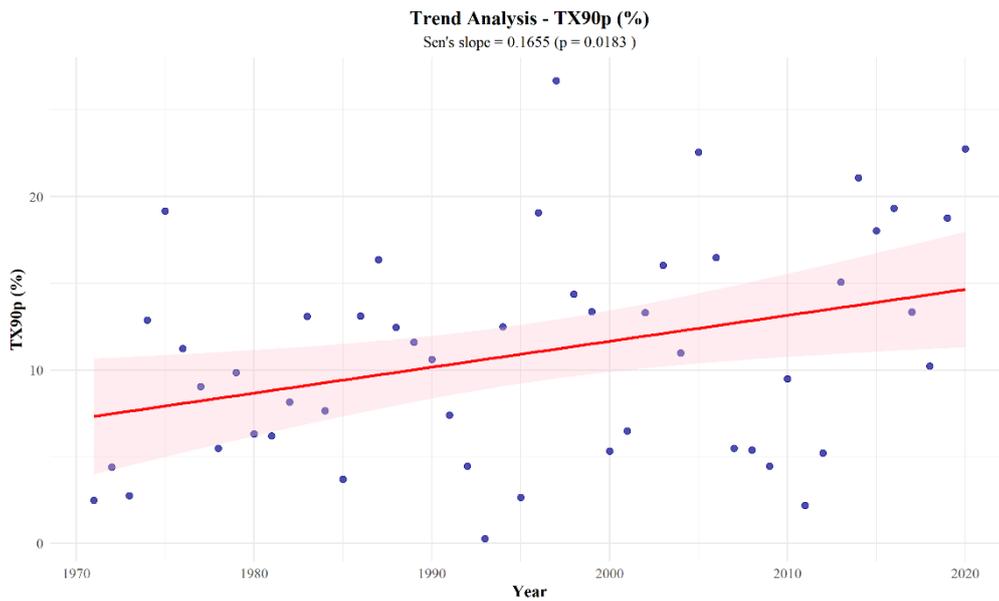

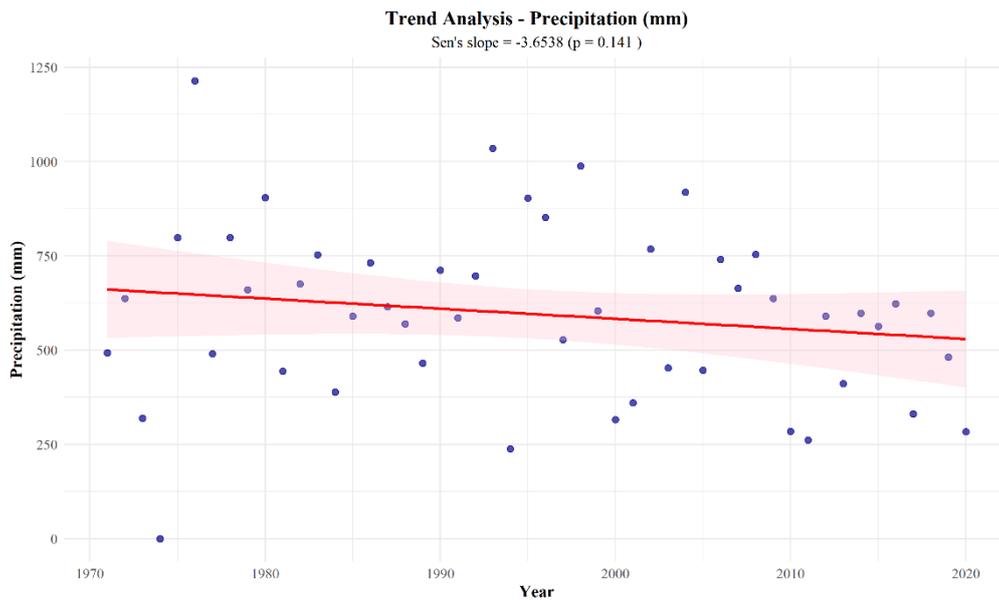**Fig. 2.** Results of the analysis of trends in TX90p (%) values

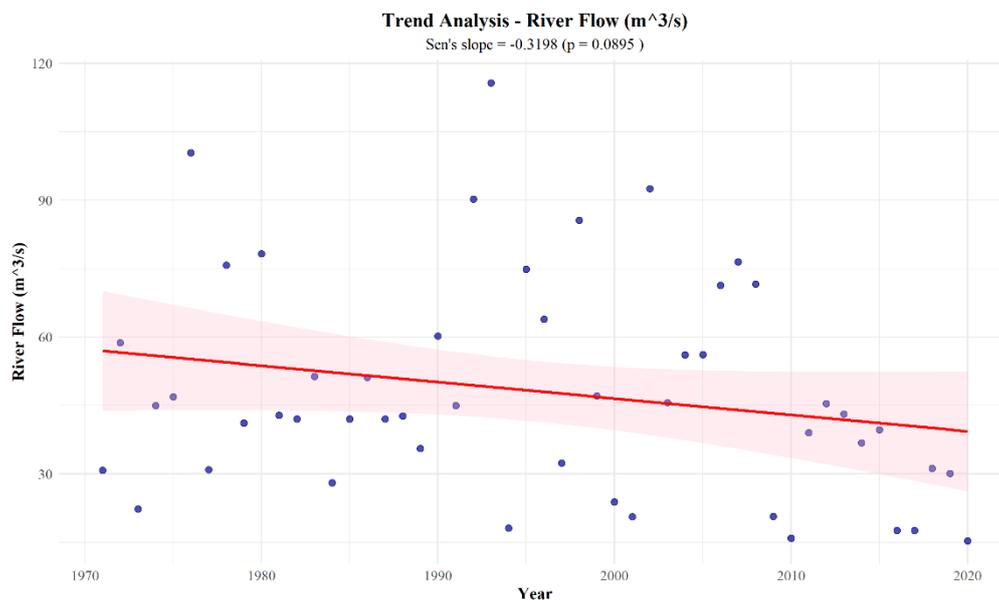**Fig. 3.** Results of the analysis of trends in precipitation (mm) values

Fig. 4. Results of the analysis of trends in river flow discharge (m³/s) values

Table 3 presents the results of three important statistical tests for three climatic and hydrological parameters (hot days index, precipitation, and river flow discharge) at the Maroun station: the Pettitt test for identifying the time of sudden change in the time series, the stationarity test for examining the constancy of statistical characteristics of the data over time (such as the mean), and the homogeneity test to ensure that the entire time series follows a uniform statistical distribution.

Table 3. Results of the Petitt trend change test and stationarity and homogeneity tests.

Parameter	p-value Stationary	p-value homogeneity	Change point (Year)
TX90p (%)	0.010	0.060	1995
Rainfall (mm)	0.010	0.209	2008
River flow discharge (m³/s)	0.237	0.022	2008

According to Table 3, for the TX90p (%) parameter, the trend change time is 1995, indicating a sudden and significant change in the average behavior of the time series in that year. The stationarity statistic (p-value=0.010) for this parameter is less than 0.05, so the stationarity hypothesis is rejected. This means that the TX90p data time series is non-stationary and its mean has changed over time, with the change point occurring in 1995. The homogeneity statistic (p-value=0.060) also showed that this value is at the threshold of significance (greater than 0.05 but close to it),

and it can be said that the data is heterogeneous, which heterogeneity is consistent with the sudden change in 1995. Based on Table 3, there is strong evidence that the frequency of very hot days (TX90p) at the Maroun station has experienced a sudden jump to higher levels in 1995 and has since stabilized in a new, warmer state.

Regarding precipitation values, according to Table 3, a sudden change was identified in 2008 based on the Pettitt test. Also, stationarity (p-value=0.010) is similar to the TX90p parameter, so the precipitation time series is also non-stationary and has experienced a structural change. The homogeneity statistic (p-value=0.209) is greater than 0.05, so the homogeneity hypothesis is not rejected. This creates an apparently contradictory conclusion with the Pettitt test. A possible explanation is that the trend change identified in 2008 is not strong enough to significantly affect the entire statistical distribution of the data. Therefore, the precipitation data shows a sudden change in 2008, but this change appears to be less stable and noticeable than the change observed in temperature.

According to Table 3, the Pettitt test for discharge also identified a sudden change in 2008. The stationarity statistic (p-value=0.237) is greater than 0.05, so the discharge time series is considered stationary statistically. This means that no significant trend or structural change has been identified in the long term in the data. The homogeneity statistic (p-value=0.022) is also less than 0.05,

so the discharge data is heterogeneous. This heterogeneity may indicate a change in variance or other statistical characteristics, even if the overall mean of the series (stationarity) has not changed significantly.

The combination of the results of this table with the previous table paints a much clearer picture of environmental changes in the Maroun region. The most important point is the identification of critical change years (1995 for temperature and 2008 for precipitation and discharge). The sudden and sustained temperature change in 1995 could be a climatic shift in the region, likely influenced by large-scale climatic phenomena. Approximately a decade later, this accumulated temperature change, along with natural or human-induced fluctuations in the system, led to a sudden change in the hydrological regime (precipitation and discharge) in 2008.

This timeline (first change in temperature and then in water) is entirely consistent with climate change theories in which increasing temperatures eventually affect the water cycle. The results for discharge indicate a high sensitivity of this parameter to changes, but also suggest that it may not yet have entered a completely stable new phase.

The findings related to the year of trend change are consistent with national and global studies that examine breakpoints in climatic time series. Shirvani et al. (2020) also reported a widespread sudden change in the temperature of some points in Iran in the mid-1990s. This finding directly confirms and strengthens the identification of 1995 as the change point for the TX90p index in Maroun.

Considering the time of trend change for the studied values in the 2020-1971 statistical period, the values of the hot days index, precipitation, and river flow discharge were divided into two statistical periods before and after the breakpoint. Finally, the changes in these parameters in the aforementioned two statistical periods are presented in Figs. 5, 6, and 7.
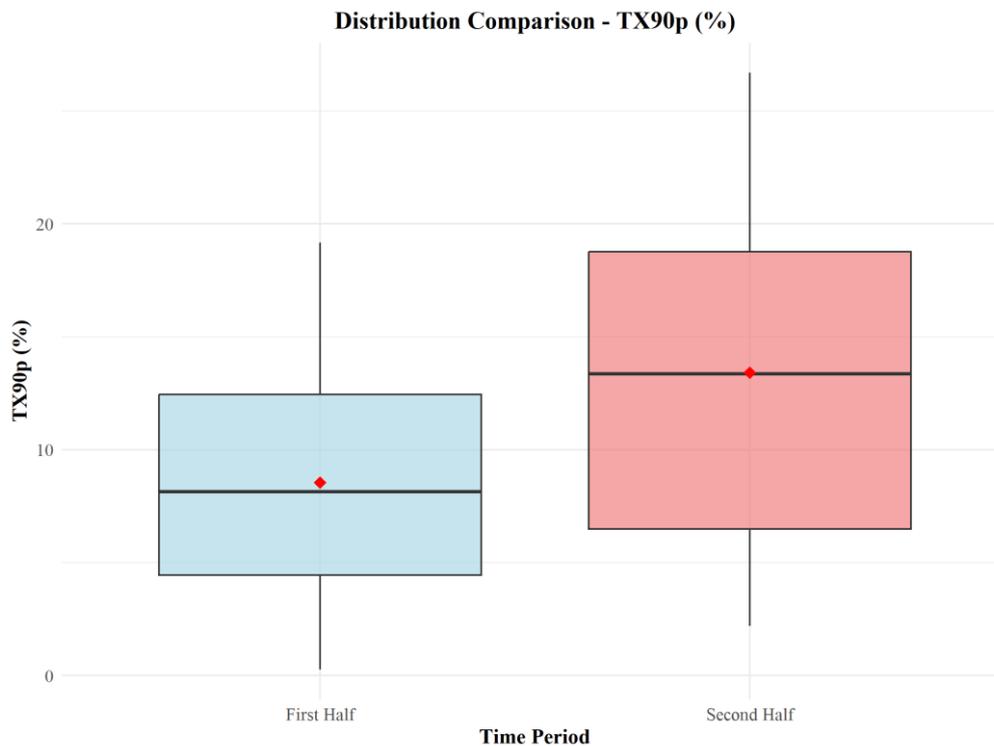

Fig. 5. Box plot of changes in TX90p values in statistical periods before and after the time of change point
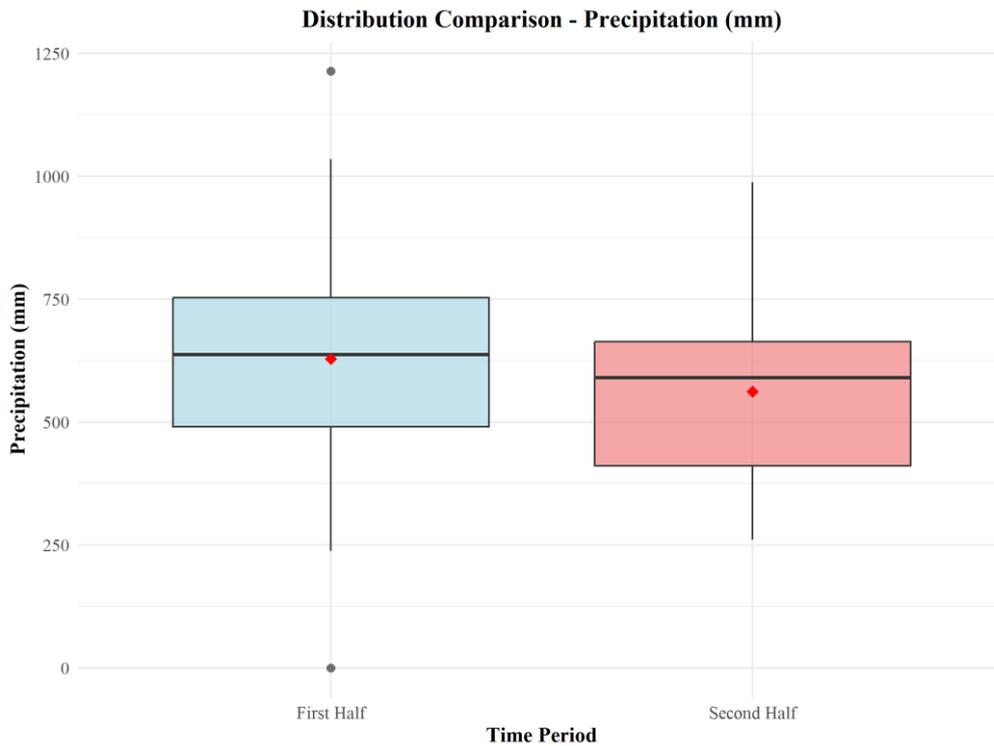
Fig. 6. Box plot of changes in precipitation (mm) values in statistical periods before and after the time of change point
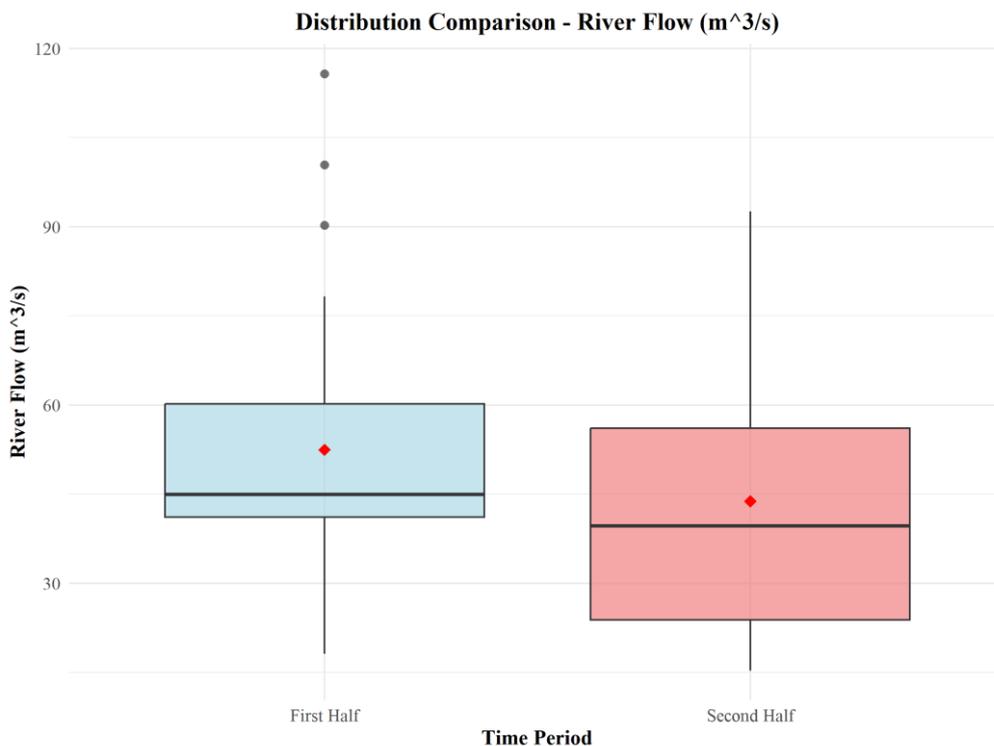

Fig. 7. Box plot of changes in river flow discharge (m³/s) values in statistical periods before and after the time of change point

According to Fig. 5 and regarding the very hot days index (TX90p%), comparing the distribution of this index between the first and second halves of the study period indicates a clear change in the pattern of hot days. The distribution curve in the second half of the period has shifted noticeably to the right (higher values). This shift clearly shows that not only has the average percentage of hot days increased, but the frequency of occurrence of extreme values of this index has also increased in the second half of the period. This pattern is

entirely consistent with the phenomenon of climate change and global warming. The increasing changes in the quartiles can be clearly observed in the second statistical period.

Regarding precipitation values, according to Fig. 6, the precipitation distribution diagram between the two halves of the period shows a different pattern. Although the overall range of the data is similar, changes in the shape of the distribution are observed. The first half of the period has a more stretched distribution and may have higher average values, while the second half of the period tends to decrease in central and median values. This change in pattern could indicate an increase in precipitation variability and a decrease in typical rainfall in the recent period, although the occurrence of heavy rainfall still seems likely.

Also, according to Fig. 7, comparing the distribution of river discharge between the two periods, a noticeable change in surface flow hydrology can be observed. The distribution curve in the second half of the period has clearly shifted to the left (lower values). This means a significant decrease in typical discharges and also a decrease in peak flow discharges. This decreasing pattern in river flow discharge could be due to a combination of factors, including reduced precipitation, increased temperature and, consequently, increased evapotranspiration, and also potentially changes in land use and water resource management.

The overall conclusion is that a clear climate change policy is occurring in the study area; the hot days index (TX90p) has significantly increased and its distribution has clearly shifted towards higher values. In contrast, although the precipitation trend is not statistically completely significant, its distribution pattern tends towards conditions with greater variability and potentially a decrease in typical rainfall. These climate changes have clearly impacted surface water resources and led to a noticeable decrease in river discharge.

In the next step, the changes in the statistical distributions of the studied data were investigated. To this end, the Pettitt test was used to divide the data into periods before and after the time of trend change. The statistical distributions of the studied data before and after the Pettitt test are presented in Figs. 8, 9, and 10, and a summary of the results is presented in Table 4.
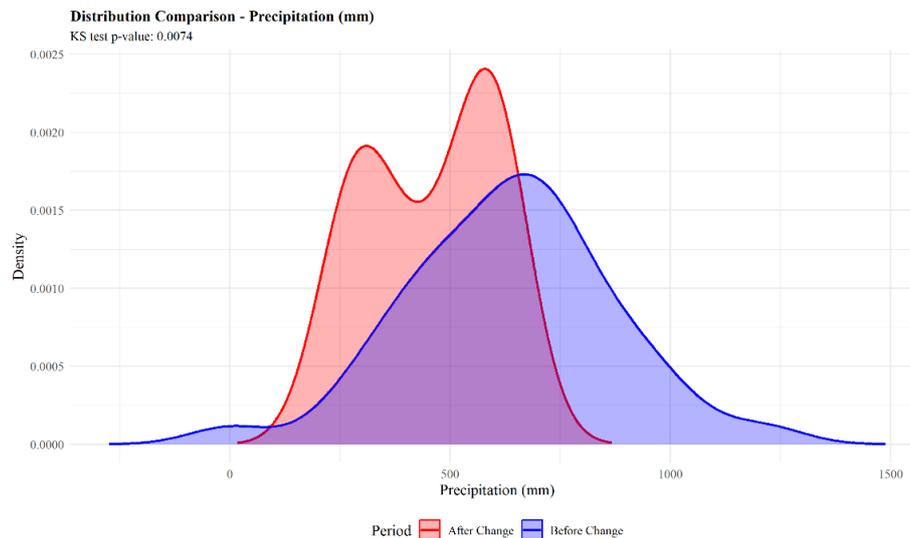

Fig. 8. Analysis of the statistical distribution of precipitation (mm) data before and after the Pettitt test
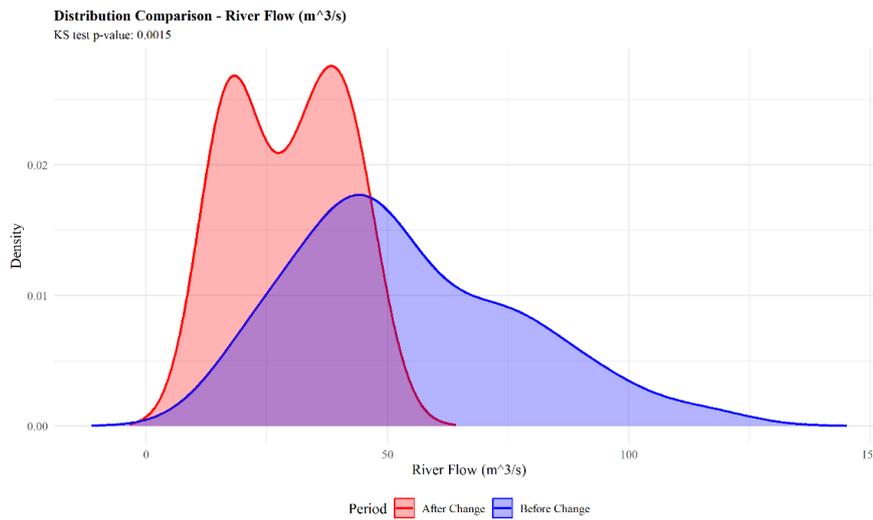
Fig. 9. Analysis of the statistical distribution of river flow discharge (m³/s) data before and after the Pettitt test
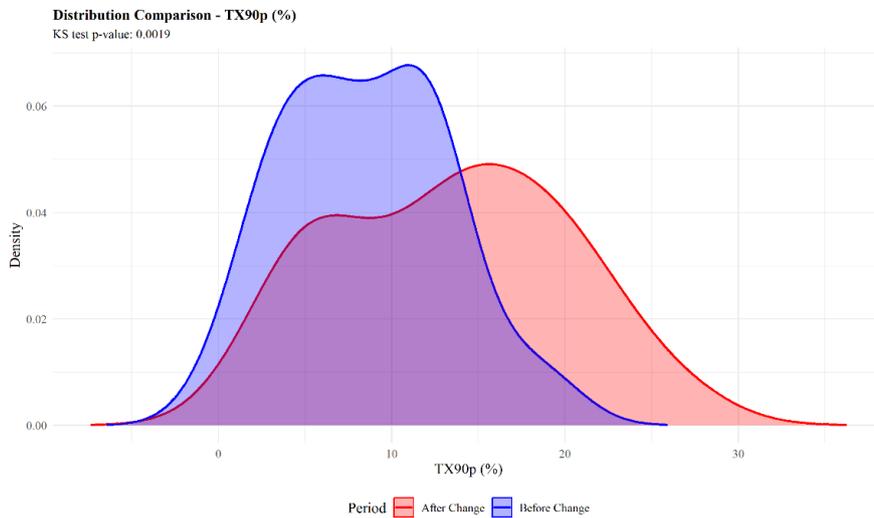

Fig. 10. Analysis of the statistical distribution of TX90p (%) data before and after the Pettitt test

Table 4. Summary results of the analysis of significant changes in the statistical distribution of the studied data with respect to the time of change point

Parameter	TX90p (%)	Precipitation (mm)	River flow discharge (m³/s)
KS_Test Statistic	0.5200	0.5385	0.5965
KS_Test Pvalue	0.0019	0.0074	0.0015
Variance_Test Pvalue	0.0935	0.1063	0.0134
Location_Test Pvalue	0.0051	0.0093	0.00001
Location_Test Name	t-test	Wilcoxon test	t-test
Mean Before Change point	8.5491	634.3436	54.0739
Mean After Change point	13.4197	456.6455	29.3607
Mean Change (%)	56.9700	-28.0100	-45.7000
SD Before Change point	4.7515	236.1789	23.6071
SD After Change point	6.7382	145.9760	11.4190
SD Change (%)	41.8100	-38.1900	-51.6300
Distribution Change Significant	Yes	Yes	Yes

According to Table 4, the Kolmogorov-Smirnov test was used to examine the difference between the two statistical distributions before and after the time of trend change. According to this test, the p-values indicate that the shape of the distribution has changed significantly in the two sub-periods under investigation, confirming the change in distribution shape. The analysis of variance (ANOVA) test was also used to compare the dispersion of the two statistical periods under investigation. According to the p-values of this test, the results indicate a significant change in the variability of the data in the two sub-periods under investigation. To compare the mean or median of the two statistical periods, the location test was examined, which used a t-test for normal data and a Wilcoxon test for non-normal data. P-values less than 0.05 indicate a significant change in the center of the data distribution in the two sub-periods. Examining the changes in the mean before and after the time of trend change showed that the mean of the TX90p, precipitation, and river flow discharge parameters changed by approximately 57%, -28%, and -46%, respectively, after the time of trend change, and these changes are significant according to the tests examined. Changes in the standard deviation before and after the time of trend change also showed that the standard deviation of the TX90p, precipitation, and river flow discharge parameters changed by approximately 42%, -38%, and -52%, respectively, after the time of trend change. Overall, the analysis of the statistical analyses performed in Table 4 showed that these tests complement each other and, together, provide a complete picture of the changes, all confirming the change in the statistical distribution of the data over the 50-year period.

Also, according to Fig. 8, the precipitation density plot for the two periods "before change" and "after change" shows that the shape of the precipitation distribution differs significantly between the two periods. It appears that in the "after change" period, the probability of occurrence of heavier rainfall has increased. The 38% decrease in the standard deviation of precipitation in the second range compared to the first range indicates a decrease in precipitation variability and potentially a lengthening of dry periods.

This pattern could indicate a change in atmospheric patterns or an exacerbation of phenomena such as drought in the region (Nazeri Tahroudi 2025).

According to Fig. 9, the results also indicate a clear difference between the two periods. The discharge distribution in the "after change" period has shifted towards higher values. The reduction in the standard deviation by 51.6% indicates a significant decrease in river flow discharge variability. This decrease could be due to reduced precipitation, increased water withdrawals, or changes in snowmelt patterns. Fig. 10 also shows a distinct difference in the density plot for the two periods for TX90p values. The increase in TX90p values in the "after change" period indicates an increased frequency of very hot days, which could be indicative of climate change in the region. The average TX90p index has increased from 55.8% to 42.13% (an increase of 57%), indicating the occurrence of hot days with approximately double the frequency. The standard deviation of TX90p values has also increased by 41.8%, indicating greater variability and potentially more intense and frequent heat waves. These changes are consistent with the phenomenon of global warming and can have significant impacts on ecosystems, agriculture, and energy consumption.

The presented dataset for the three parameters of precipitation, river flow discharge, and the TX90p temperature index all indicate the occurrence of significant changes in the "after change" period compared to the "before change" period. These changes could be due to natural or human factors, including climate change, changes in precipitation patterns, water resource management, or urbanization. These changes could indicate the beginning of a new period of warmer and drier conditions in the region. The simultaneous decrease in precipitation and river discharge is a serious warning for water resource management and long-term planning.

The findings of this research regarding the change in the shape of the precipitation distribution (increased probability of heavier rainfall) and the significant increase in the TX90p index (very hot days) are entirely consistent with patterns reported in the context of climate change. Global studies by the

Intergovernmental Panel on Climate Change (IPCC) have repeatedly emphasized that global warming not only increases average temperatures but also changes the probability and intensity of extreme heat and precipitation events. For example, the results of the Donat et al. (2016) study showed that globally, both the frequency and intensity of extreme hot days are increasing. This results in fewer cold days and more hot days, and the 57% increase in TX90p observed in this study is a prominent and quantified example of this global phenomenon at the regional scale.

On the other hand, the 28% decrease in average precipitation and the 46% decrease in average river flow discharge observed in this research indicate an exacerbation of hydrological drought in the study area. This pattern is particularly concerning in arid and semi-arid regions of the world, including the Middle East. Numerous studies in Iran, such as Parchami et al. (2023), Aghelpour et al. (2021), Nazeri Tahroudi et al. (2022), Azarakhshi and Farzadmehr (2022), Ahmadi et al. (2022), Porhemmat and Altafi Dadgar (2023), Tahroudi et al. (2023), Modabber-Azizi et al. (2023), Salarijazi et al. (2023), Khozeymehnezhad et al. (2025), have reported similar decreases in river runoff, resulting from reduced precipitation and increased temperatures.

Climate change does not affect all parameters uniformly. The increase in temperature variability (TX90p) indicates that the region is not only getting warmer but is also facing greater instability in temperature and potentially more intense and frequent heat waves. In contrast, the decrease in precipitation variability and discharge could indicate the dominance of longer dry periods with concentrated but potentially less effective (due to increased evaporation) rainfall events. This drier pattern, along with heavier rainfall, has also been reported as one of the characteristics of climate change in many regions in global studies, including the Westra et al. (2013) study.

4. Conclusion

Analysis of half-century data from the Maroun basin, Iran reveals a clear structural shift in the region's hydro-climatic regime. Key evidence includes a significant increase in very hot days (TX90p) with a 1995 change point, followed by a 2008 breakpoint where both precipitation and streamflow declined markedly (by 28% and 46%, respectively). The sharp reduction in streamflow variability (-52%) indicates flow homogenization and diminished capacity for natural flood generation and reservoir replenishment. This temporal sequence—warming first, then hydrological drying—aligns with climate change mechanisms where increased evapotranspiration reduces runoff. The most important indicator of the changing climate regime in the Maroun basin is the significant and remarkable increase in very hot days (the TX90p index). The sudden turning point (breakpoint) for this indicator occurred in the year 1995. This index not only signifies an increase in average temperature (by 57% after the breakpoint) but also indicates an intensification and increased frequency of heat waves, which have a more direct and immediate impact on the environment, agriculture, public health, and energy demand. The temporal sequence of this change (1995), which occurred before the abrupt shift in hydrological parameters (precipitation and streamflow in 2008), clearly illustrates the driving mechanism of climate change in the region: warming first, followed by hydrological drought

The convergence of evidence from multiple statistical tests underscores the urgency for adaptive water and agricultural management. Declining surface water coupled with rising temperatures places severe pressure on resources, mirroring trends observed in Mediterranean and Middle Eastern basins. This local case reflects a global challenge, necessitating a shift in water allocation, crop patterns, and the development of integrated basin-level adaptation strategies to address the projected warmer and drier future. The reduction in water resources, coupled with rising temperatures, will intensify competition for water among agriculture, industry, and drinking water sectors, threatening crop yields, industrial operations, and public water supply. To address this, adaptive management is essential, including revising water allocation policies, shifting agriculture toward drought-resistant crops and efficient irrigation, promoting water conservation across all sectors, and exploring alternative sources such as managed aquifer recharge and treated wastewater reuse. This requires an integrated basin-level approach involving all stakeholders to

build resilience against the emerging drier and warmer regime. These significant shifts towards warmer and drier conditions, particularly the abrupt changes in 1995 and 2008, are discussed in the context of regional anthropogenic climate change and local water management practices, which have serious implications for water resources.

5. Conflict of interest

No potential conflict of interest was reported by the authors.

6. References

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