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A Comprehensive Analysis of Rainfall Trends and Climatic Breakpoints in Eastern Kermanshah Province: A Statistical Perspective on Climate Change

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ABSTRACT

Climate change, an escalating global phenomenon, presents significant challenges with diverse impacts, particularly in developing regions. This study conducts a detailed statistical analysis of long-term rainfall trends and climatic disruptions at six meteorological stations in Kermanshah Province, Iran, spanning 1951 to 2023. The analysis identifies significant trends and breakpoints in rainfall patterns using the Mann-Kendall test, Sen's slope estimator, and Pettitt's test. Results reveal a consistent decline in annual rainfall at five stations—Kermanshah, Ravansar, Songhor, Sahneh, and Bisotoon—while Harsin exhibits a slight increase. Bisotoon records the sharpest decline, with a 26.86% reduction in annual rainfall, equivalent to −5.38 mm per year, followed by Songhor with a 28.45% decline, reflecting heightened vulnerability in these areas.Conversely, Harsin demonstrates a 20.53% increase in annual rainfall after 1967, showcasing variable climatic responses within the region. Pettitt's test identifies the 1990s as the predominant period for abrupt rainfall shifts, coinciding with global phenomena such as El Niño and La Niña. These shifts significantly reduced mean annual rainfall in critical locations, including Bisotoon, where the mean declined from 540.9 mm to 395.61 mm after 1995. The findings emphasize the profound impact of climate change on regional hydrological dynamics, threatening water resources, agriculture, and livelihoods. The study underscores the urgency of adaptive water management strategies to address rainfall variability and recommends further research on the interaction between global atmospheric phenomena and local climatic shifts to inform effective mitigation and adaptation policies.

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1. Introduction

As a critical climatic variable, precipitation is pivotal in the hydrological cycle and water resource availability. Changes in precipitation patterns can result in widespread consequences for ecosystems, agriculture, and natural resources (WMO, 1988; Kundzewicz & Robson, 2000; Kundzewicz & Robson, 2004; IPCC, 2018), particularly in arid and semi-arid regions heavily dependent on the temporal and spatial distribution of rainfall (New et al., 2001; Cai et al., 2015).

Kermanshah Province, located in western Iran, is a semi-arid region highly susceptible to rainfall variability. Fluctuations in rainfall patterns can trigger extreme climatic events such as floods and droughts (Reduction, 2009), severely impacting human life, natural resources, and agricultural infrastructure (Antwi-Agyei et al., 2012; Atiah et al., 2020). Given the region's reliance on surface and groundwater resources, any reduction in annual rainfall or abrupt shifts in rainfall patterns can significantly impair agricultural productivity, biodiversity, and economic development in Kermanshah Province.

Global climate change has profoundly altered precipitation patterns in recent decades (Alley et al., 2003; UNDP & Ha, 2007; Dailidiene et al., 2011; Zhang et al., 2017). Some regions experience more intense rainfall events, while others face increasing droughts and water shortages, primarily due to global warming and its effects on meteorological systems (IPCC, 2018). Studies indicate that atmospheric phenomena such as El Niño and La Niña substantially influence weather patterns globally, including semi-arid regions. These phenomena, as components of the Southern Oscillation, often lead to significant variability in precipitation. In semi-arid areas such as the Middle East, El Niño and La Niña contribute to droughts and reduced water availability (IPCC, 2018). These climatic changes have intensified drought severity and diminished water resources (Chakraborty & Mandal, 2008; Jakhar et al., 2011).

Non-parametric statistical methods have been extensively used to analyse various regions' rainfall trends. For instance, Karaburun et al. (2011) examined temporal trends in annual, seasonal, and monthly temperatures in Istanbul during 1975–2006, using the Mann-Kendall test and Sen's slope estimator. Ceppi et al. (2012) investigated temperature trends in Switzerland from 1959 to 2008, identifying a mean annual warming rate of 0.35°C per decade with significant seasonal increases. Similarly, Gocic and Trajkovic (2013) analyzed meteorological variables in Serbia (1980–2010), finding significant increasing trends in minimum and maximum temperatures and notable changes in vapor pressure and wind speed. Kakkar et al. (2022) assessed rainfall trends in Sikkim, India, over 115 years, using the Mann-Kendall test, which revealed a significant decrease in monsoon rainfall. Nath et al. (2023) studied Indian states and linked reduced monsoon rainfall to higher summer temperatures, demonstrating adverse agricultural effects. Abdul Talib et al. (2024) identified significant declines in annual and seasonal rainfall through non-parametric analyses in several states in Malaysia.

In Iran, similar research has investigated climate change impacts on rainfall patterns (Modarres & Sarhadi, 2009; Tabari et al., 2011). These studies revealed that climatic shifts often manifest as gradual or abrupt changes in rainfall data, highlighting the need for accurate detection and analysis to guide water resource management and agricultural planning. Non-parametric statistical tools such as the Mann-Kendall test and Sen's slope estimator have proven effective in identifying climatic trends and breakpoints in rainfall time series (Longobardi & Villani, 2010; Shri Kant et al., 2014; Rangarajan et al., 2018; Panda & Sahu, 2019). Research consistently indicates that climate change has comparable effects on rainfall and water resources worldwide. Thus, detailed analyses of rainfall trends in Kermanshah Province could improve understanding of local climatic patterns and inform resource management strategies. Prompt identification of climatic changes enhances the effectiveness of monitoring systems

(Beaulieu et al., 2012).

This study aims to investigate long-term rainfall trends at six meteorological stations in Kermanshah Province from 1951 to 2023. Non-parametric statistical methods, including the Mann-Kendall test and Sen's slope estimator, were employed to identify and analyze trends and abrupt changes in rainfall. The Pettitt test was also applied to detect breakpoints in the rainfall time series. The results provide valuable insights into regional climate change and guide policymakers and water resource managers in effectively planning and managing water resources.

2. Materials and Methods

2.1. Study Area

Kermanshah Province is in the western part of the Iranian Plateau, along the Zagros mountain range. Covering an area of slightly over 25,000 square kilometers, the province is geographically positioned between 33°41′ and 35°17′ north latitude and 45°24′ and 45°1′ east longitude. It shares borders with Kurdistan Province to the north, Lorestan and Ilam Provinces to the south, Hamedan Province to the east, and Iraq to the west, with a 330-kilometer common border. The province has an average long-term precipitation of approximately 466 mm and an average annual temperature of 16.4°C. Kermanshah encompasses over 1.5 million hectares of natural resources, including forests and rangelands, and 942,077 hectares of agricultural land, of which 210,447 hectares are irrigated while the remainder are rain-fed (Figure 1).

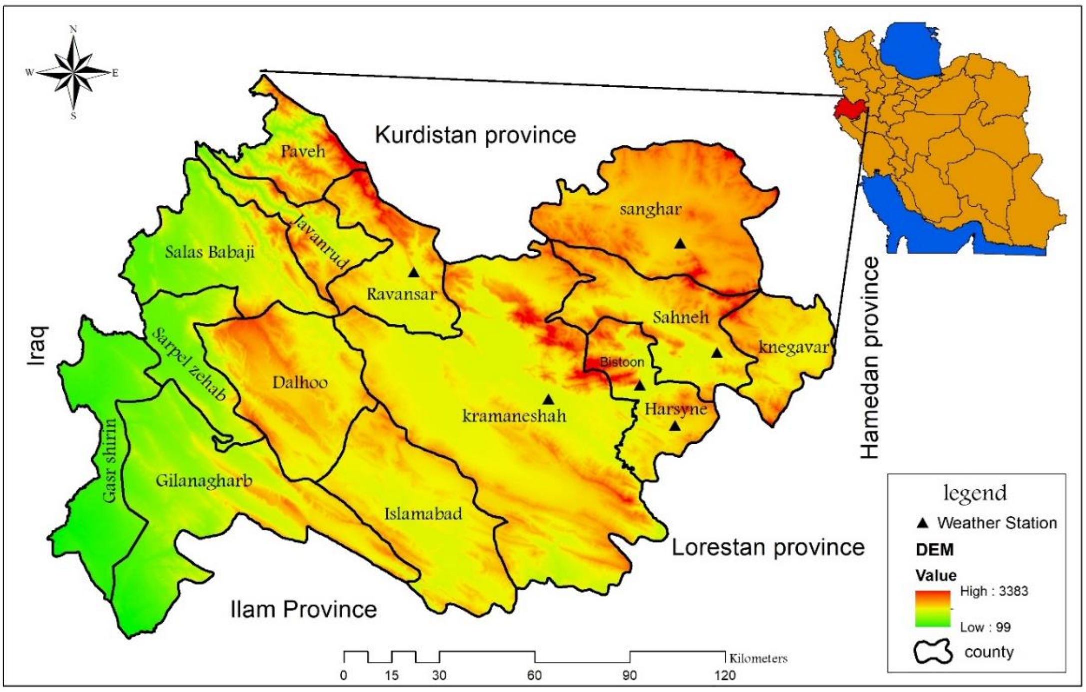

Fig 1. Map of Kermanshah Province, Iran, showing the location of six meteorological stations used in the study

2.2. Data Collection

This study analysed annual rainfall data from six meteorological stations in Kermanshah Province from 1951 to 2023. These stations were selected based on their long-term and continuous data records. The data were obtained from the Iranian Meteorological Organization and the Kermanshah Provincial Meteorological General Office. The profile of the selected stations is summarized in Table 1.

2.3. Missing Data Estimation

Due to gaps in rainfall data for specific years, missing values were estimated using the correlation method with reference stations (Wilks, 2019). This method relies on the correlation between datasets from various stations, selecting those with the highest similarity to the station with missing data. Stations demonstrating the strongest correlation with the available data were used to estimate and replace the missing values (Kumar & Jain, 2010).

Table 1. Profile of the Studied Meteorological Stations

No.	Station	Longitude	Latitude	Altitude (m)	Lowest annual rainfall (mm)	Highest annual rainfall (mm)	Average rainfall (mm)	Start of Record
1	Kermanshah	47°09′00″ E	34°21′00″ N	1318.8	205.60	747.10	433.10	1951
2	Ravansar	46°39′00″ E	34°43′00″ N	1380	274.60	1001.70	542.90	1954
3	Harsin	47°34′00″ E	34°16′00″ N	1546	188.70	720.40	387.20	1958
4	Sanqhor	47°35′00″ E	34°47′00″ N	1700	208.60	1329.00	465.00	1959
5	Sahneh	47°41′00″ E	34°28′00″ N	1382	213.20	824.00	479.90	1959
6	Bisotoon	47°24′00″ E	34°21′00″ N	2038	199.20	1022.00	485.50	1954

2.4. Methods

2.4.1. Mann-Kendall Test

The non-parametric Mann-Kendall test was employed to analyze long-term rainfall trends. This test is commonly applied to detect trends in climatic time series, mainly when the assumption of normality is not satisfied (Serrano et al., 1999). The Mann-Kendall test identifies whether a significant trend exists in a time series (Helsel et al., 2020). The null hypothesis assumes no trend, whereas the alternative hypothesis indicates the presence of either an increasing or decreasing trend (Yue et al., 2002). The test results are expressed as a Z-statistic, with a significance level of $\alpha = 0.05$. The test is conducted in the following steps:

a. The differences between each pair of observations are calculated, applying the sign function and determining the parameter **S**:

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

Where n is the number of observations in the series, and X_j and X_k are the j^{th} and k^{th} data points, respectively. The sign function is defined as follows

$$\operatorname{sgn}(x) = \begin{cases} +1 & if \quad (x_j - x_k) > 0 \\ 0 & if \quad (x_j - x_k) = 0 \\ -1 & if \quad (x_j - x_k) < 0 \end{cases} \tag{2}$$

b. To calculate the variance, the following relationships are applied:

$$Var(S)=\frac{n(n-1)(2n+5)-\sum_{t=1}^{m}t(t-1)(2t+5)}{18} \qquad n>10 \tag{3}$$

Alternatively, if there are ties in the data:

$$Var(S)=\frac{n(n-1)(2n+5)}{18} \qquad n\leq 10 \tag{4}$$

Where n is the number of observations, mmm is the number of tied groups, and t_i represents the frequency of data within each tied group.

c. The Z-statistic is calculated as follows, depending on the value of S:

The null hypothesis of no trend is accepted if the following condition holds:

$$\left|Z\right|\leq Z_{\alpha/2} \tag{5}$$

$Z_{\alpha/2}$ represents the critical value from the standard normal distribution at the significance level α, adjusted for the two-tailed nature of the test. For this study, $\alpha=0.05$.

2.4.2. Sen's Slope Estimator

The non-parametric Sen's slope estimator was applied to estimate the annual rate of change in precipitation. This method is well-suited for irregular climate data due to its robustness against outliers (Yue et al., 2002). Sen's slope calculates the median rate of change between all pairs of data points (Helsel et al., 2020). A positive slope indicates an increasing trend, while a negative slope indicates a decreasing trend in precipitation (Sen, 1968). In this study, Sen's slope was calculated individually for each station to evaluate annual changes in precipitation quantitatively. The steps for calculating Sen’s slope include:

a. Calculating the slope between each pair of observed data:

$$Q=\frac{X_t-X_s}{t-s} \tag{6}$$

X_t and X_s are the observed precipitation values at t and s. From this equation, a series of slopes is obtained, and the median represents the slope of the trend line (Q_{med}), where positive values indicate upward trends and negative values indicate downward trends.

b. Determining $C\alpha$ at the confidence levels of the test:

$$C_\alpha=Z_{1-\alpha/2}*\sqrt{Var(s)} \tag{7}$$

where Z is the standard normal distribution statistic (e.g., 1.96 for a 95% confidence level and 2.58 for a 99% confidence level), and $N'$is the number of slope values calculated in step a.

c. Calculating the upper and lower confidence limits:

$$\begin{cases} M_1=\dfrac{N'+C_\alpha}{2} \\ M_2=\dfrac{N'-C_\alpha}{2} \end{cases} \tag{8}$$

where N' is the number of slopes calculated in step a.

d. Testing the confidence limits by extracting the M_1^{th} and $(M_2+1)^{th}$ slopes from the ordered slope values to verify statistical significance.

2.4.3. Pettitt Test

The Pettitt test detected abrupt change points in the rainfall time series. This non-parametric test is practical for identifying sudden shifts in the mean of time series data over long periods (Pettitt, 1979). The test does not require the assumption of normality and helps identify breaks in time series data (Broström, 1994). This study applied the Pettitt test to detect significant shifts in rainfall patterns and analyze the corresponding climatic breakpoints. The steps include:

The test statistic $U_{t,n}$ is calculated as:

$$U_{t,n} = \sum_{i=1}^{t} \sum_{j=t+1}^{n} \mathrm{sgn}(\chi_i - \chi_j) \quad t = 2,.....n \tag{9}$$

b. The Pettitt test evaluates the statistic K_t as:

$$k_t = \max_{1<t<n} \left| U_{t,n} \right| \tag{10}$$

c. For a two-tailed test or to identify changes in specific directions, the statistics are given by:

$$k_t^+ = \max_{1<t<n} U_{t,n} \tag{11}$$

The most significant change point is identified where $|U_{t,n}|$ reaches its maximum, and the associated significance level is calculated as:

$$k_t^- = \min_{1<t<n} U_{t,n} \tag{12}$$

The most significant change point is identified where $\left|U_{t,n}\right|$ reaches its maximum, and the associated significance level, k_t^+ , k_t^- is approximately determined $\rho = 2exp(-6k_t^2/(n^3 + n^2))$. If ρ is smaller than a specific significance threshold, such as 0.05, in this study, the null hypothesis is rejected. In other words, if a significant change point exists, the time series is divided into two parts at the change point $p = 1 - \rho$. The approximate significance probability for a change point is defined as (Liu et al., 2012).

All analyses were performed using R software. The Mann-Kendall and Sen's slope tests were used to detect trends and estimate change rates, while the Pettitt test identified breakpoints within the rainfall time series. A significance level of (alpha = 0.05) was applied to all tests.

3. Results and Discussion

The results of the non-parametric Mann-Kendall test, Sen's slope estimator, and Pettitt test for annual rainfall data at the studied stations were calculated. The findings, based on the significance level (p-value) and Z-statistic of the Mann-Kendall and Sen's slope tests, are summarized in Table 2. In this table, an asterisk (*) indicates a significant negative trend (Z < -1.96) or positive trend (Z > 1.96) at a 95% confidence level.

3.1. Mann-Kendall Test

The Mann-Kendall test, recognized as a robust tool for analyzing non-normal climatic time series, was applied to assess precipitation trends in the eastern region of Kermanshah Province. The findings, calculated at a 95% confidence level, are shown in Table 2.

The test results indicate that precipitation in the region has predominantly decreased across most meteorological stations. The Z-statistics at the 95% confidence level for Kermanshah, Ravansar, Sahneh, Songhor, and Bistoon stations were -0.34, -1.32, -0.95, -2.69, and -5.17, respectively. These values demonstrate negative trends at all stations except Harsin.

The Bistoon station, with a Z-statistic of -5.17, and the Songhor station, with a Z-statistic of -2.69, exhibited statistically significant decreasing trends at the 95% confidence level. Conversely, with a Z-statistic of 0.78, the Harsin station showed a slight increasing trend, though this was not statistically significant at the chosen confidence level.

The observed decreasing trends in precipitation align with broader global climate change patterns. These changes can be attributed to rising global temperatures, altered atmospheric circulation, and climatic phenomena like El Niño and La Niña.

3.2. Sen's Slope Estimator

The results of Sen's slope estimator, calculated annually at a 95% confidence level, are presented in Table 2. The estimated slopes for Ravansar, Songhor, Sahneh, and Bistoon stations were -1.35, -2.50, -0.82, and -5.38 mm/year, respectively. These values confirm significant negative trends in annual precipitation at these stations.

Among the studied stations, the Bistoon station recorded the most significant annual decrease in precipitation, with a rate of -5.38 mm/year, followed by the Songhor station, with a decrease of -2.50 mm/year. These reductions underscore abrupt and pronounced changes in annual precipitation patterns, exceeding the 95% confidence threshold.

Conversely, the Harsin station showed a slight positive trend of +0.70 mm/year, indicating a minor increase in annual precipitation. However, this increase was not statistically significant.

The Sen's slope estimator results highlight substantial regional variations in precipitation trends and are visually represented in Figure 2. These findings emphasize the pressing need to consider localized climatic shifts in regional water resource management and planning.

Table 2 Results of Mann-Kendall Test and Sen's Slope Analysis for Annual Average Rainfall

No	Station	Period Length (Years)	Z-value	Sen's Slope
1	Kermanshah	73	-0.34	0.19
2	Ravansar	70	-1.32	-1.35
3	Harsin	66	0.78	0.70
4	Songhor	65	-2.69	-2.50
5	Sahnehh	65	-0.95	-0.82
6	Bisotoon	70	-5.17	-5.38

3.3. Pettitt Test for Determining Change Points

The annual rainfall trends at six meteorological stations were analyzed using Pettitt's test to identify abrupt change points. The results revealed that all stations experienced significant shifts in annual rainfall trends, as shown in Figure 3. The breakpoints for Kermanshah, Ravansar, Harsin, Songhor, Sahneh, and Bisotoon were identified as 1997, 1997, 1967, 1986, 1997, and 1995, respectively. These abrupt changes predominantly occurred during the 1990s, coinciding with global atmospheric fluctuations, as noted by the IPCC (2018).

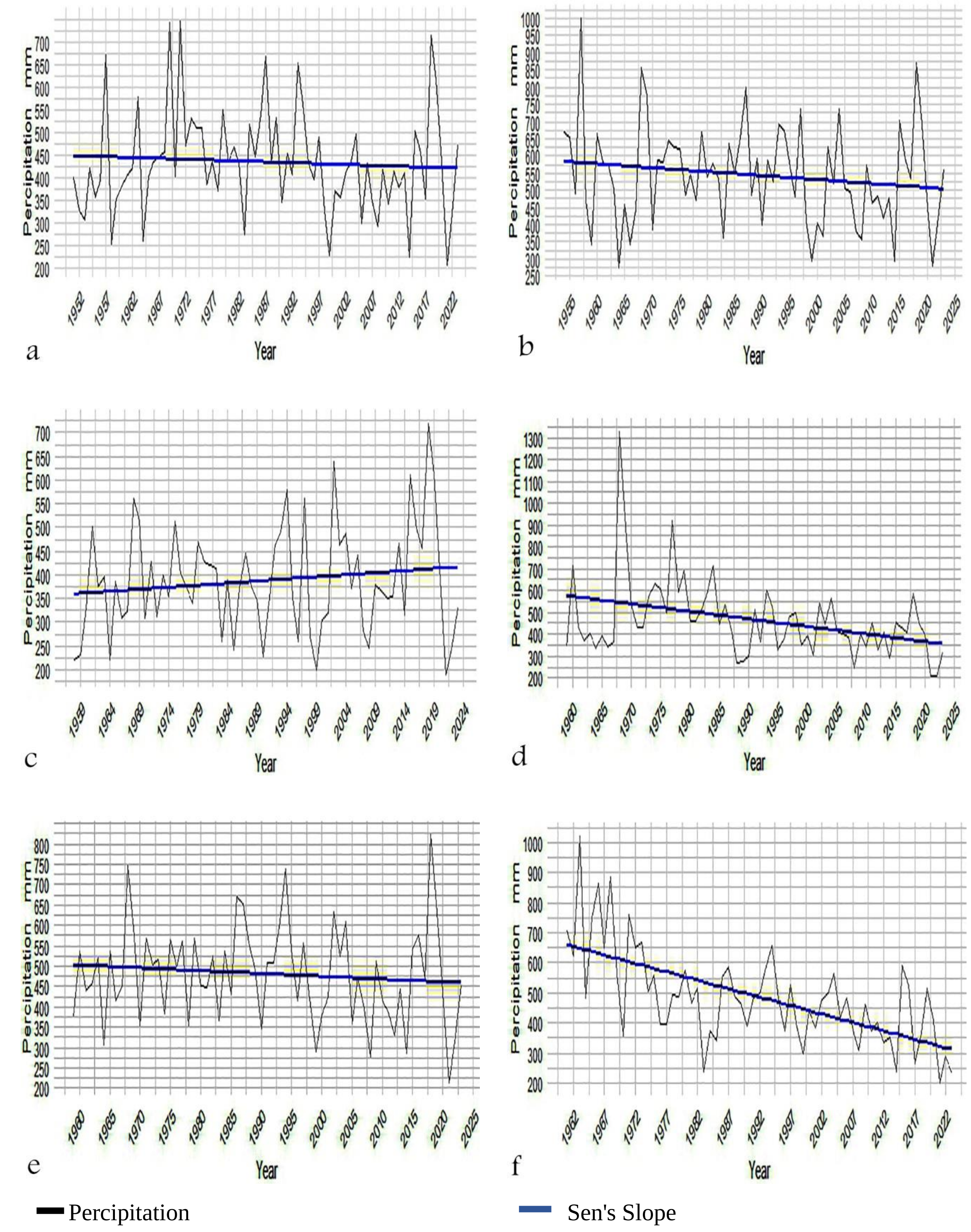

Fig. 2. Results of Sen's Slope Test for Mean Annual Rainfall over the Study Period for stations: (a) Kermanshah, (b) Ravansar, (c) Harsin, (d) Songhor, (e) Sahneh, and (f) Bisotoon.

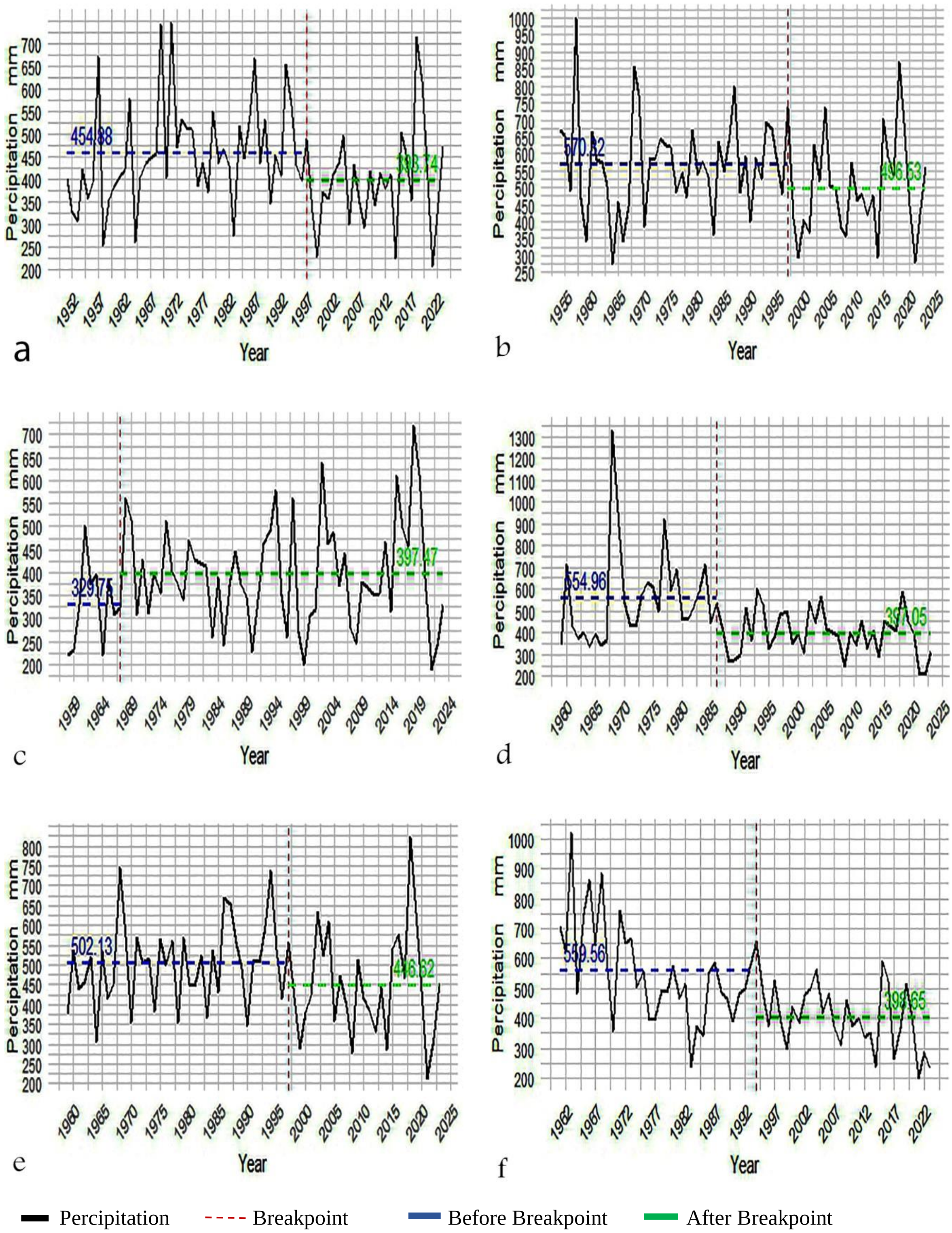

Fig. 3. Results of Pettitt's Test for Mean Annual Rainfall over the Study Period for stations: (a) Kermanshah, (b) Ravansar, (c) Harsin, (d) Songhor, (e) Sahneh, and (f) Bisotoon.

During this period, phenomena such as El Niño and La Niña profoundly impacted global rainfall patterns, including in the Middle East (Haktanir et al., 2004). Research suggests that climate change, driven by human activities such as increased greenhouse gas emissions, has also contributed to significant alterations in rainfall patterns in the region (Atiah et al., 2020; Bayram & Öztürk, 2021). The identified breakpoints in this study likely reflect these global climatic phenomena and their influence on local precipitation variability.

A comparison of average annual rainfall before and after the identified breakpoints demonstrated significant reductions at most stations. Specifically, the average annual rainfall decreased from 454.88 mm to 393.74 mm at Kermanshah, from 570.32 mm to 496.53 mm at Ravansar, from 554.96 mm to 397.05 mm at Songhor, from 502.13 mm to 397.05 mm at Sahneh, and from 540.90 mm to 395.61 mm at Bisotoon. These reductions represent downward trends in annual precipitation. Conversely, the Harsin station displayed an increase in average rainfall, rising from 329.75 mm to 397.47 mm after the breakpoint.

The percentage changes in average rainfall were calculated for each station and are summarized in Table 3. The Kermanshah, Ravansar, Songhor, Sahneh, and Bisotoon stations experienced reductions of -13.25%, -13%, -28.45%, -11.05%, and -26.86%, respectively. Songhor recorded the highest percentage decrease at -28.45.

Table 3. Results of Pettitt's Test Analysis for Mean Annual Rainfall over the Study Period

No	Station	Overall Average of Rainfall (mm)	Break Year	Mean Rainfall Before Break (mm)	Mean Rainfall After Break (mm)	change in precipitation %	Trend
1	Kermanshah	433.1	1997	454.88	393.74	-13.25	Decreasing
2	Ravansar	542.9	1997	570.32	496.53	-13	Decreasing
3	Harsin	387.2	1967	329.75	397.47	+20.53	Increasing
4	Songhor	465.0	1986	554.96	397.05	-28.45	Decreasing
5	Sahnehh	479.9	1997	502.13	446.62	-11.05	Decreasing
6	Bisotoon	482.8	1995	540.90	395.61	-26.86	Decreasing

%, underscoring its vulnerability to declining rainfall. In contrast, the Harsin station exhibited a significant increase of 20.53%, the only positive trend observed among the stations.

These findings highlight considerable shifts in rainfall patterns over recent decades, predominantly reflecting a general downward trend across the region. Such changes underscore the impacts of climate change on precipitation and its potential consequences for water resources, agriculture, and ecosystems in Kermanshah Province.

The decline in rainfall in Kermanshah Province aligns with findings from similar studies conducted globally in other arid and semi-arid regions. For instance, Kakkar et al. (2022) reported declining monsoon rainfall in India, which increased the risk of natural disasters, paralleling the reductions observed in Kermanshah. In Africa, research by Kwawuvi et al. (2023) demonstrated that rising temperatures and declining rainfall have reduced water resources and negatively impacted agriculture, a trend confirmed in West Africa. Similarly, studies in Turkey by Erlat and Türkeş (2013) documented rising heatwave frequencies alongside reduced rainfall, mirroring patterns observed in Kermanshah Province.

These comparisons indicate that rainfall variability in Kermanshah is not merely a local phenomenon but a broader global trend linked to climate change.

4. Conclusion

This study examined long-term precipitation trends in the eastern region of Kermanshah Province from 1951 to 2023. Non-parametric statistical analyses revealed significant decreases in precipitation across five of the six studied stations, consistent with global climate change trends. The Mann–Kendall test and Sen's slope estimator identified the Bistoon station as experiencing the most pronounced decline in precipitation, with a rate of -5.38 mm per year, followed by the Songhor station, with a decline of -2.50 mm per year. In contrast, the Harsin station exhibited a slight upward trend, with an increase of 0.7 mm per year.

The Pettitt test results indicated that breakpoints in rainfall trends predominantly occurred during the 1990s, aligning with significant global climatic fluctuations. The test highlighted substantial changes in mean precipitation before and after the identified breakpoints. For instance, with 73 years of recorded rainfall data, the Kermanshah station showed a reduction in annual mean precipitation from 454.88 mm before the 1997 breakpoint to 393.74 mm afterward—a decline of 13.5%. Similarly, the Songhor station experienced the steepest decline, with a 28.45% reduction in mean precipitation, while the Bistoon station recorded a 26.86% decrease. Conversely, the Harsin station demonstrated a 20.53% increase in precipitation, with mean annual rainfall rising from 329.75 mm before the breakpoint to 397.47 mm after it.

Given that the statistical records for the studied stations span over six decades, and the pre- and post-breakpoint periods each extend beyond 30 years, with differences in mean precipitation ranging from 11% to 28%, these shifts can be attributed to the impacts of climate change. The statistically significant findings of the Mann–Kendall test and Sen's slope estimator, at a 95% confidence level, provide robust support for these conclusions.

These findings underscore the substantial impact of climate change on precipitation patterns in the region. Declining rainfall poses significant challenges, including reduced surface and groundwater resources, increased water scarcity, heightened risks of drought, and subsequent threats to agriculture, biodiversity, and socioeconomic stability. These results highlight the urgent need for adaptive water resource management and mitigation strategies to address the ongoing and future challenges of climate change in Kermanshah Province.

Author Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

"Not applicable"

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Ethical considerations

The authors avoided from data fabrication and falsification.

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Conflict of interest

"The authors declare no conflict of interest."

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