Effects of Climate Change on Warming and Rainfall Patterns; Iran Case Study

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Abstract

The analysis investigates lasting climate trends underlying the importance of territorial coincidence of trend changes among temperature fluctuations, (minimum, average, and maximum) and precipitation observed in the past four decades at eight major meteorological stations in Iran. Applying the Mann–Kendall trend test indicated a steady increase in annual temperatures, while a general decline in annual precipitation in all territories of Iran. These dual trends vary across the study stations, strongly affected by altitude, latitude, and regional climate zones. In this case, high-altitude northern stations reached the highest rising trends in maximum temperature, as well as significant decrease in precipitation was observed. In contrast, lowland southern stations showed a weaker warming trend and also observed smaller changes in their precipitation. Only two stations, Tehran and Mashhad, with the highest urban density, showed sharper nighttime warming trend through an increase in minimum temperatures, which could highlight the role of local dynamics influenced by urbanization growth. Overall, the combined results of temperature and precipitation trends highlight that the mountainous regions located in the higher latitudes tend to be riskier concerning the increase in daily maximum temperature and decrease in precipitation amount. In general, these local differences in changes in temperature and precipitation are influenced by two main factors: altitude and latitude, which therefore emphasizes the need for climate adaptation strategies tailored to the geography and topography in each diverse ecosystem.

Keywords: Climate change, Precipitation, Temperature, Ecosystem Resilience, Adaptation Strategies, Iran.

1.Introduction

Climate change has emerged as a critical global challenge. Rising levels of carbon dioxide in atmosphere have been recorded for over five decades. Strong scientific evidence indicates that this issue has resulted increased global average surface temperature, along with with significant changes in precipitation patterns (IPCC, 2023). The latest report of IPCC indicates that the global warming trend will likely exceed 1.5°C during the 21st century. This milestone underscores that the 1.5°C target is no longer a

distant risk to be avoided, but a threshold already temporarily surpassed and at risk of becoming permanent (IPCC, 2023). The trends in temperature and precipitation as two of the most important indicators of climate change have become hot topics. Many studies carried out in different parts of the world for detecting possible climate trends and changes. The temperature variations especially for arid and humid climates have been observed in most regions of the planet. Arid and semi-arid regions such as Iran are particularly vulnerable, where climatic variability directly threatens water security, agricultural productivity, and ecological resilience (Daneshvar et al., 2019; Nasirian & Naddafi, 2025). Concerning the climate of Iran, several studies have been performed (Azizi and Roushani 2008). These studies pointed out significant variations in climate of Iran. Recent studies have consistently recorded warming trends throughout Iran country (Ghasemi, 2015; Tabari et al., 2012; Ranjbar-Saadatabadi, 2025). Temperature rises over Iran are most characteristic in high-altitude northern territories, with urban basins demonstrating an intensified nighttime warming trend (Sabohi & Soltani, 2009). Besides, climate change has also influenced rainfall in Iran, exacerbating hydrological stress and increasing ecological sensitivity in regional scales (Modarres & da Silva, 2007; Zohrabi et al., 2014). Recent analyses confirm that precipitation anomalies during 2024–2025 were strongly associated with atmospheric circulation changes, and have exacerbated ecological stress in northern parts of Iran (Ranjbar-Saadatabadi, 2025). In addition, climate projections of Iran using SDSM modeling indicate that future increases in maximum temperatures will disproportionately affect the arid climatic regions of Iran (Abbasnia & Toros, 2016). Moreover, new perspectives show that climate change in Iran not only alters hydrological cycles but also ecological vulnerability (Nasirian & Naddafi, 2025). In this regard, Shamsipour and Azizi (2024) have emphasized the importance of linking climate trends with ecosystem resilience in Iran to combat the adverse effects of climate change.

Despite numerous previous studies conducted at the local scale, a comprehensive research view that consider both analysis of temperature and precipitation trends have so far been limited in the study area especially in relation to changes in topographic, spatial, climatic factors. Therefore, this study has attempted to address this gap in scientific opinion by applying the Mann-Kendall trend test to long-term observational data collected from several major synoptic stations across Iran. By comprehensively examining the spatial overlap of changes in the trends of warming and precipitation patterns, this research highlights critical ecological vulnerabilities and provides practical insights for planning and adaptation strategies tailored to local climate, taking into account the diverse topographic and ecological characteristics of the main regions of Iran.

2.Materials and Methods

Iran is geographically located in the middle latitudes and is widely rugged. Temperatures across Iran generally increase from north to south and from west to east (Abbasnia and Toros 2016), which is due to the characteristics of the mountains that are mainly located in the north and west of the country (Figure 1).
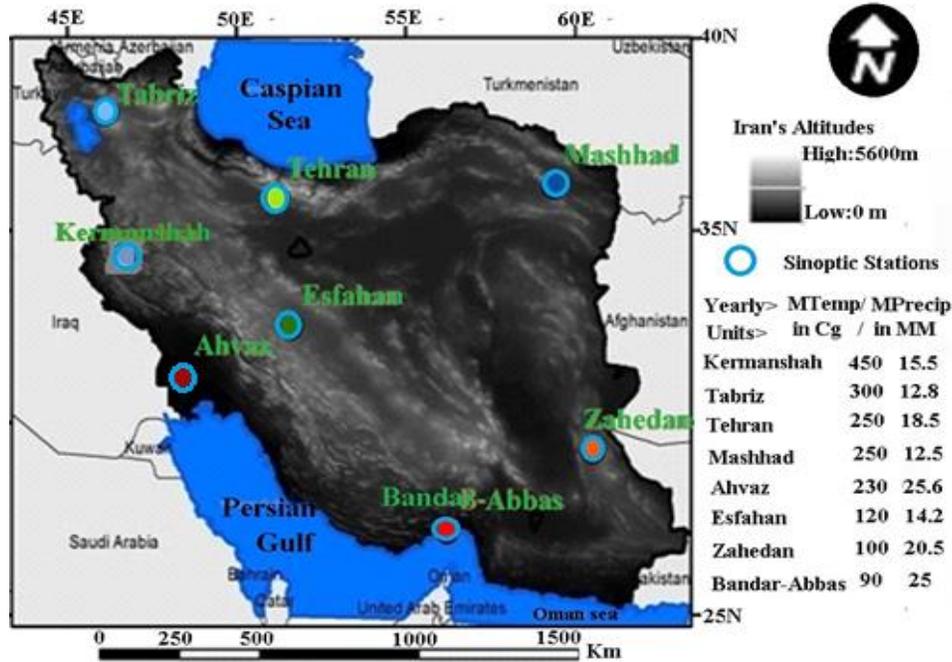
Figure 1- *Distribution of geographical areas in the study area*

In this study, monthly data on minimum, maximum, average of temperature and total average of precipitation parameters for eight synoptic stations during the period 1980 to 2017 were prepared from the Iranian Meteorological Organization. The study stations were selected from three main regions including mountainous areas, central interior plateau, and lowland areas, which can reflect all the characteristics of the topographic regions and geographical distribution within the vast country of Iran. After preparing the dataset, quality control was performed on all times series to ensure data validity. Next, long-term annual trends in these key climate variables were calculated using the Mann-Kendall trend test. This non-parametric trend test is widely known for detecting trends in long-term timeseries (see Mann, 1945; Kendall, 1975). In addition, the magnitude of trends was quantified using the Sen's slope estimator, which determines the rate of change in each time series. All statistical analyses were performed at the 95% confidence level ($p<0.05$) to ensure reliability in distinguishing true trend from its random. Finally, observational trends of the precipitation and temperature parameters are assessed at each station, regionally. This approach to selecting stations based on altitude and distance from water sources allows for the identification of spatially overlapping warming and precipitation trends, and thus, the climatic diversity of regions and their ecological vulnerability can be examined regionally throughout Iran.

3.Results and Discussion

The diverse topography and climatic zones across Iran lead to distinct responses to climate change. In this regard, long-term analysis of temperature and precipitation at eight synoptic stations highlights their altitude- and latitude-dependent patterns. Located in the northeast of Iran, the city of Mashhad represents the semi-arid region. The city, influenced by the effects of urbanization, experienced the highest increase in annual mean temperature among all stations. Kermanshah and Tabriz, situated in the mountainous territories of the northwest, also demonstrated a significant warming trend in daily mean temperature. While the average temperature increase in the cities was slightly less than Mashhad, the recorded maximum temperature was among the highest among all the stations examined. All these mentioned above indicate that reduced snow cover, increased solar energy absorption, and changes in atmospheric circulation intensify the daily warming in mountainous areas. On the contrary, Ahvaz, Bandar Abbas, and Zahedan, located in the low-land, and arid southern regions, with the weakest trends in mean daily temperatures,

have stable temperature regime due to their climate type, low vegetation cover, and minimal seasonal variation. However, warming trends remain statistically significant even in these regions, indicating that no region is protected against long-term temperature rises. In general, all stations experienced an increase in the annual mean temperature (Figure 2, first row). Kermanshah (+2.7°C) and Tabriz (+2.5°C) saw the most severe increases (Figure 2, second row) in maximum temperature, while Bandar Abbas experienced a more moderate temperature rise (+1.36°C). A statistically significant upward trend was observed in Aal studied stations. In this regard, Mashhad and Tehran showed the most severe increase in minimum temperatures compared to maximum temperatures, which exacerbates the nighttime warming. In contrast, Tabriz and Kermanshah recorded weaker increases in minimum temperatures despite intense daily maximum temperature. This result indicates a broadening of the daily temperature range in mountainous regions (Figure 2, third row). In this context, the findings of the temperature trends of the present study are confirmed by previous research conducted by Abbasnia et al. (2025) in identifying temperature anomaly trends across Iran. However, in the present study, all these temperature patterns are examined in a complementary and broader manner by simultaneously examining and matching them with precipitation trend patterns to assess spatial overlap.

Conversely, annual precipitation results analysis exhibited mainly declining trend across all study stations, pointing to a general a general progression towards drought and reduced precipitation across different Iranian regions over time. These reductions in magnitude varied significantly according to their spatial distribution and were affected by regional climates, altitude, and closeness to water sources. Under these circumstances, most severe annual precipitation decreases were recorded in Kermanshah and Ahvaz, with a value of -10.5 mm and -9.5 mm respectively, over the whole studied period (Figure 2, fourth row).

Situated in a mountainous region, Kermanshah, is becoming more sensitive to drought conditions because of greater decreasing trend in precipitation. Secondly, Ahvaz, located in the southwestern lowland region, had a significant decreasing trend, which may be followed by exacerbate water scarcity and water stress. A gradual increase in annual precipitation was only recorded in Isfahan station, which may be governed by local climate variability or convective precipitation anomalies in the central plateau of Iran. Nevertheless, this increase was slight and does not substitute a larger regional drought. The cities of Zahedan and Bandar Abbas representing arid regions exhibited a slightly stable precipitation trend, persistent with low baseline precipitation and restricted interannual variability in rainfall events. Oppositely, stations in the northern highlands, historically exposed to more precipitation because of closeness to humidity sources and ornithological elevation, are anticipated to be more prone to drought conditions.
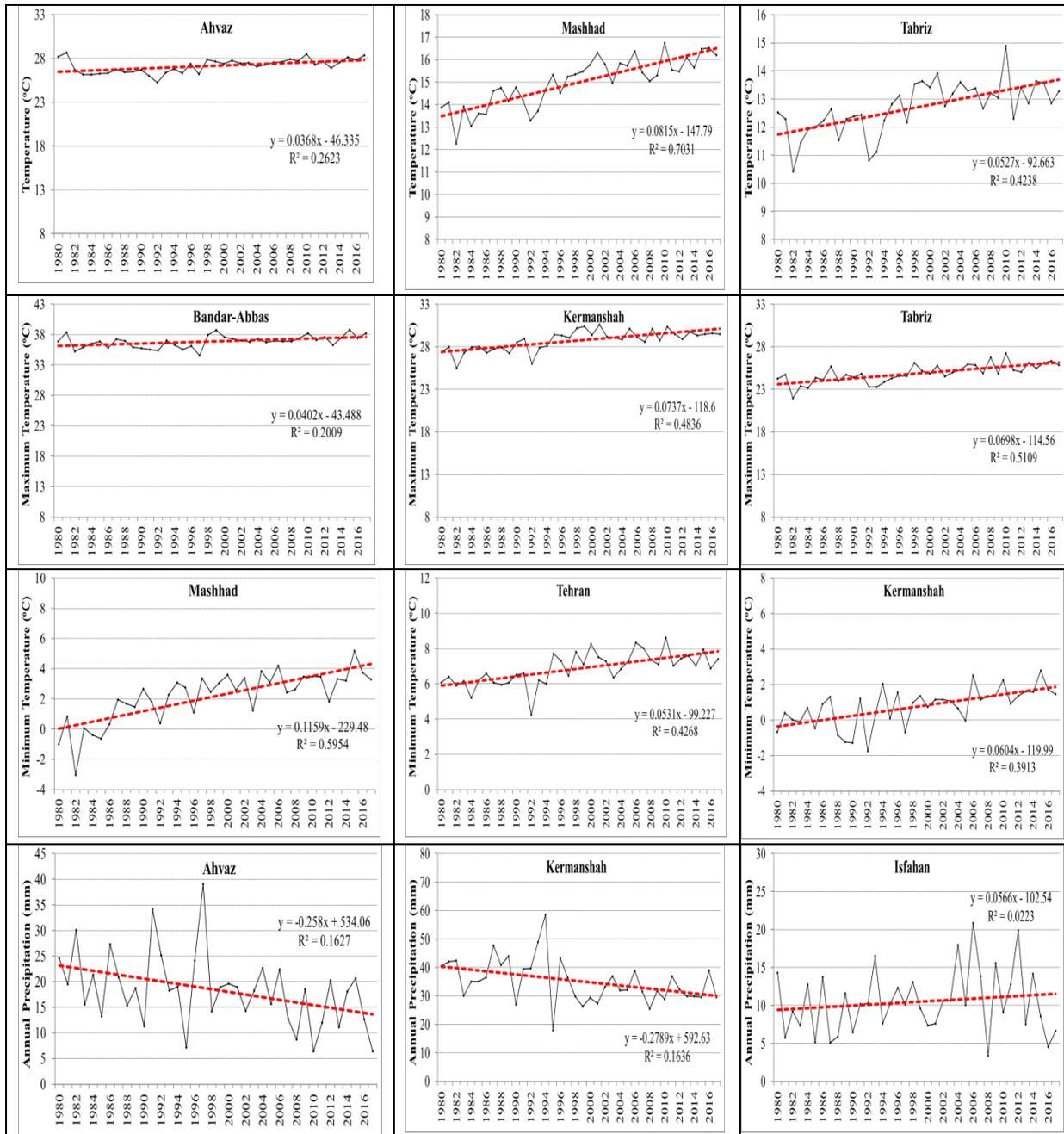
***Figure 2-** Selected annual climatic trends at representative synoptic stations in Iran;*
Row 1: Average temperature trend in Ahvaz, Mashhad, and Tabriz
Row 2: Maximum temperature trend in Bandar-Abbas, Kermanshah, and Tabriz
Row 3: Minimum temperature trend in Mashhad, Tehran, and Kermanshah
Row 4: Average Total Precipitation trend in Ahvaz, Kermanshah, and Isfahan

An extensive and comparative analysis with spatial coincidence of rising temperature and precipitation trends in the explored area reveals critical environmental sensitivity. From this standpoint, mountainous regions such as Kermanshah and Tabriz have encountered severe daily warming besides reduced precipitation. This duality and variability observed in the precipitation and temperature fluctuations threatens the stability of mountain snowpack, groundwater recharge, and the resilience of regional

vegetation. In addition, Tehran and Mashhad cities, which are densely populated areas with further urban expansion, have exposed to more severe nighttime warming trends. Local climate dynamics has exacerbated the issue. Arid regions such as Ahvaz and Bandar Abbas, demonstrating less precipitation variability over the entire study period, can be exposed to water scarcities. Ultimately, Isfahan city recording a small increase in total precipitation among all regions, would not compensate for the broader drought trend.

The observed results suggest that environmental ecosystems in Iran are become increasingly vulnerable to climate change-induced stressors. Decreased precipitation combined with rising temperatures is likely to accelerate evapotranspiration, reduce groundwater recharge, and aggravate vegetation stress at local and regional scales. These processes endanger regional biodiversity, change hydrological cycles, and undermine ecosystem services for human well-being. Critically, the dual stressors of warming and drying show differences in magnitude or intensity, but also strongly dependent on altitude, latitude, and climate type. In term of management, mountainous areas need special strategies to handle lower snowfall, while densely populated urban areas require long-term actions to mitigate heat island effects and preserve ecological integrity of the environment. Arid regions, although showing less variability in rainfall, are vulnerable to groundwater depletion under the influence of global warming.

4. Conclusion

The results of Mann–Kendall trend test for temperature and precipitation parameters have revealed statistically significant warming and drying trends across Iran during an analyzed period of 1980 to 2017. In this regard, all studied stations have showed increasing trends in mean, maximum, and minimum temperatures, although the magnitude and spatial distribution of change varied regionally. The results of warming trends have showed the last decade of the previous century was substantially warmer than previous decades. Northern high-altitude stations such as Kermanshah and Tabriz have recorded the strongest increases in maximum temperature. This indicates intense daytime warming in mountainous areas compared to other regions. In contrast, southern low-altitude stations including Bandar-Abbas, Ahvaz, and Zahedan have showed more moderate warming in arid and hot climatic regions.

In other hand, precipitation trends were mostly negative during the whole studied period. The highest decreasing trend in precipitation has observed in Kermanshah which is located at higher latitudes and altitudes. Only Isfahan station among all studied stations has exhibited a slight positive trend in precipitation. In mountainous regions such as Tabriz and Kermanshah, increasing diurnal temperature range may accelerate snowmelt, reduce soil moisture, and disrupt temperature-sensitive biological cycles. This variation between day and night heating patterns will lead to the vital environmental consequences. Decreasing DTR range driven by increasing nighttime temperatures in more densely populated cities such as Tehran and Mashhad, may exacerbate heat stress, increase energy demand, and aggravate ecological vulnerability.

Combining data on warming and drying trends confirms that arid regions, particularly Iran, are exposed to a severe, dual-threat climate crisis. These findings emphasize that local ecosystems call for tailored, location-specific action plans, such as smarter water management, ecosystem-based conservation, and sustainable urban planning to adapt to these changes.

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