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Climate Change Impacts on Eco-Geotourism in Arid and Mountainous Regions: A Numerical and Empirical Analysis of Northern and Central Iran

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Abstract

Climate change has become one of the most urgent global issues, profoundly influencing multiple sectors, particularly ecotourism and geotourism. This study employs both numerical and empirical analysis to investigate the effects of recent climate change on ecotourism and geotourism in northern and central Iran, with a specific emphasis on elements impacted by climate variations over the past decade. The numerical analysis includes a functional modeling approach based on multiplicative and additive scaling. In addition, through an extensive review of existing literature and data, the research assesses how climate change has transformed local environmental conditions. The findings indicated that in central Iran and Alborz, there was an upward trend in the *p* variable (denoting precipitation), which was paired with a downward trend in the *t* variable (denoting temperature) over the last ten years. In contrast, data from the Caspian coast revealed a decrease in the *p* variable while the *t* variable exhibited an increase during the same timeframe. Consequently, this article highlights the challenges presented by increasing temperatures and diminishing precipitation, which jeopardize natural resources and biodiversity. It underscores the necessity for integrated ecotourism and geotourism strategies.

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Introduction

Research into the effects of climate change on ecotourism and geotourism has become increasingly vital, given the rising dangers posed to natural heritage sites and the pressing requirement for adaptive strategies. These sectors of tourism encounter a range of complex challenges that necessitate prompt academic investigation and policy intervention. Climate change intensifies geomorphological processes, posing significant risks to geoheritage assets located in coastal and mountainous areas. The rise in sea levels and instances of extreme weather events undermine not only the physical integrity but also the visual appeal of sites that are essential for geotourism, while simultaneously increasing the likelihood of natural hazards for visitors (Gordon, 2023). Coastal wetlands, which are critical for ecotourism, are experiencing habitat loss due to erosion and salinity intrusion, and the destruction of mangroves is further heightening the region's vulnerability to storms and rising sea levels (Salpage, 2022). Although ecotourism and geotourism provide considerable advantages, it is essential to address challenges such as the risk of habitat degradation and the necessity for effective governance in order to ensure their sustainable implementation (Patil and Pattanshetti, 2024; Rakhmonov, 2024). Such environmental degradation directly threatens the economic viability of tourism-dependent communities. Research has indicated that tourists are generally inclined to invest in mangrove restoration efforts, underscoring the significance of ecotourism in financing climate adaptation initiatives. Ecotourism not only generates jobs and supports local businesses, contributing to economic growth (Patil and Pattanshetti, 2024), but also raises awareness and funds for conservation projects. However, it is essential to manage ecotourism carefully to avoid potential negative impacts on the environment and local communities. However, climate-induced changes in visitor behavior—such as modifications in travel patterns and preferences for different destinations—pose a risk of undermining these economic advantages unless proactive management strategies are implemented (Gordon, 2023; Shakouri and Yazdi, 2014).

Recent climate change has begun to reshape the environmental landscape, posing challenges to the sustainability of these tourism sectors. Climate change, characterized by rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events, has far-reaching implications for ecosystems and biodiversity (Legg, 2021; IPCC, 2023). Recent studies indicate that Iran is experiencing an increase in mean temperatures by approximately 2.6 °C and a decline in precipitation by 35% over the coming decades (Mansouri Daneshvar et al., 2019). These changes have manifested in various ways, including droughts, desertification, and shifts in flora and fauna distributions (Zare et al., 2020). Iran, with its diverse landscapes ranging from lush forests and mountainous terrains to arid deserts and coastal regions, offers a unique setting for ecotourism and geotourism. These forms of tourism emphasize the appreciation of natural and geological features while promoting conservation and sustainable practices (Buckley, 2012). Recent research in the field of climate and environmental sciences has increasingly focused on understanding and mitigating the impacts of drought and urban heat on both natural and built environments. (Hajarian, 2025) has explored advanced machine learning techniques, specifically the Random Forest model, to monitor and zone meteorological drought risk. This approach has provided an insight into spatial patterns of drought, offering a robust framework for risk assessment and resource management in regions vulnerable to climate extremes. Concurrently, Mansourian and Askarzade (2025) have examined strategies to reduce the urban heat island effect, a pressing challenge in urban environments. Their study has identified both practical solutions and ongoing challenges, emphasizing the need for integrated urban planning and policy interventions. In addition, (Rahnama and Khadempour, 2025) have compared the effectiveness of gene expression programming methods with empirical relationships for predicting daily reference evapotranspiration across diverse climates. Their findings have contributed to the refinement of predictive models essential for water resource management and agricultural planning. Collectively, these studies reflect the dynamic interplay between technological innovation and environmental stewardship in addressing climate-related challenges. Ecotourism encourages environmental conservation and offers economic advantages to local communities, thus aligning with the principles of sustainable development. It acts as a mechanism for reconciling environmental challenges while enhancing the well-being of communities, especially in ecologically sensitive areas such as Iran (Seervi, 2023). Conversely, geotourism plays a vital role in fostering awareness of geological heritage and advancing geoconservation efforts, while simultaneously providing educational avenues regarding climate change (Dowling, 2024). This form of tourism can be experienced in both natural landscapes and constructed environments, thereby enhancing its attractiveness and prospects for sustainable tourism development (Newsome and Dowling, 2023). Research conducted on ecotourism branding within the Golestan protected area of Iran highlighted the critical necessity for sustainable ecotourism strategies that harmonize environmental conservation, community empowerment, and tourism development. This study illustrates the practical implementation of ecotourism principles in the Iranian context (Tajer and Demir, 2024).

As climate change continues to alter weather patterns, biodiversity, and geological features, ecotourism and geotourism face significant challenges and opportunities. Ecotourism and geotourism are closely related concepts that often overlap, focusing on sustainable tourism practices and the appreciation of natural environments. While they share thematic elements, ecotourism emphasizes biodiversity and conservation, whereas geotourism specifically highlights geological features and heritage. Ecotourism has emerged as a vital sector in Iran, offering opportunities for sustainable development while promoting environmental conservation. However, climate change poses significant threats to this sector, affecting ecosystems and the livelihoods of communities dependent on tourism. Understanding these impacts is crucial for developing effective strategies to mitigate climate change effects and enhance ecotourism sustainability. Recent research suggests that escalating temperatures, alterations in precipitation patterns, and a heightened occurrence of extreme weather events are having detrimental effects on natural habitats and ecosystems, which serve as the foundation for ecotourism. (Pidcock et al., 2020) discussed the influence of climate change on extreme weather events. They highlighted that 74% of studied events were made more likely or severe due to climate change, with a focus on heatwaves, rainfall, and flooding. A study published in Nature in 2016 (National Academies of Sciences, 2016) was pivotal in establishing the field of extreme event attribution, calculating the human contribution to the 2003 European heatwave, which resulted in over 70,000 deaths. (Thomas and Nascimento, 2019) discussed how climate change, including temperature increases and altered precipitation patterns, threatens biodiversity and natural ecosystems. (Hannah and Dawson, 2018) examined how changing climate patterns, including increased frequency of extreme weather events, affect natural ecosystems and their resilience. (Vries et al., 2024) discussed how increasing variability in extreme precipitation is a significant factor contributing to the likelihood of record-breaking precipitation events. This research highlighted the implications of climate change on precipitation patterns and extreme weather events. There have been several studies exploring the impact of changing temperatures, precipitation patterns, and extreme weather events on natural habitats and eco-geosystems in Iran. (Sadeqi et al., 2024) investigated snowpack dynamics in Iranian mountain ranges, highlighting the effects of temperature changes on snow cover. (Zittis et al., 2022) discussed the increasing severity and duration of heatwaves, droughts, and torrential rain events, which hurt ecosystems. In addition, (Malaekeh et al., 2022) indicated an increase in hot climate extremes and a decrease in cold and precipitation extremes, impacting ecological conditions.

Recent studies have significantly advanced our understanding of species distribution models in relation to climate change impacts (Vaissi and Mohammadi, 2024). Additionally, research has delved into how climate change influences ecological footprints (Keshavarz and Farajzadeh, 2025), as well as the consequent reduction in water resources and the escalation of climate-induced migration within Iran (Rostami and Paski, 2024). Although research that collectively provides insights into how climate change is influencing Iran's natural habitats and ecosystems is useful for gaining an overview of the impact of global climate change on ecosystems and geosystems, it is important to note the significance and sensitivity of ecotourism and geotourism in Iran, which can be rapidly affected by climate change.

Therefore, this study aims to investigate the impacts of varying climate variables on ecotourism and geotourism resources across regions with diverse geological features in northern and central Iran. To address this inquiry, we proposed the following hypotheses: First, that accelerated geomorphological processes—such as erosion and extreme weather events—will markedly compromise the ecological and geological integrity of significant tourism sites, thereby diminishing their appeal and safety. Second, that environmental alterations driven by climate change will disproportionately jeopardize the economic stability of communities dependent on ecotourism and geotourism, leading to quantifiable declines in income and employment. Lastly, we anticipate that visitor preferences and travel behaviors are shifting in response to climate-related hazards, underscoring the necessity for adaptive management strategies to preserve the sustainability of tourism.

Materials and methods

This research adopted a qualitative methodology, incorporating an extensive literature review and case studies to investigate the effects of climate change on ecotourism and geotourism in Iran. The study employed a functional modeling approach (FMA) for numerical analysis, utilizing both multiplicative and additive scaling techniques. The literature review encompassed scholarly articles, governmental reports, and pertinent publications from international organizations. The FMA describes complex systems by defining explicit relationships between variables. In this research, a function is a rule or mapping that assigns a unique output to each valid input based on the nature of the system being studied. The study encompassed three key types of variables, including input (independent), intermediate (dependent), and output (aggregated) variables. Data were gathered from multiple sources, including the Iranian Department of Environment, the World Tourism Organization, and institutions dedicated to climate change research. In addition, the case of specific ecotourism and geotourism sites in Iran was examined to illustrate the real-world implications of climate change. These sites included the Alborz Mountains region (Region A), Kashan region (Region B), and Caspian region (Region C), each representing different ecological and geological characteristics.

We established two climatic variables, denoted as t and p, which correspond to temperature and precipitation, respectively. By varying these variables, we observed corresponding changes in the tourism desirability variable, d, for three geographical locations identified as A, B, and C. We additionally introduced a new variable, denoted as s, to encapsulate the overall condition of the three locations. This variable is structured such that an increase in the value of d across all three locations corresponds to a corresponding increase in s, categorized into three levels: *low* (0), *medium* (0.5), and *high* (1). Consequently, in light of the provided explanation, the independent variables were defined as follows:

$t \in [\mathbf{0}, \mathbf{1}]$: temperature (normalized) (1)

$p \in [\mathbf{0}, \mathbf{1}]$: precipitation (normalized) (2)

Accordingly, the dependent and aggregated variables were defined as follows, respectively:

(3)

$the\ d_i \in [\mathbf{0}, \mathbf{0.5}, \mathbf{1}]$: tourism desirability for location $i \in [\boldsymbol{A}, \boldsymbol{B}, \boldsymbol{C}]$:

(4)

$s \in [\mathbf{0}, \mathbf{0.5}, \mathbf{1}]$: overall system condition or suitability

In an FMA framework, we aimed to define functions of the form:

(5)

$$d_i = f(t_i, p_i) \quad and \quad s = g(d_A, d_B, d_C)$$

where f and g are rule-based functions that capture the behavior and interactions among the variables based on logical rules, threshold conditions, and domain knowledge.

As illustrated in Figure 1, the study area was delineated to encompass segments from the Caspian coast to central Iran, and it was classified into three distinct regions, designated A, B, and C. This division facilitates the conduct of more thorough investigations within each respective region.

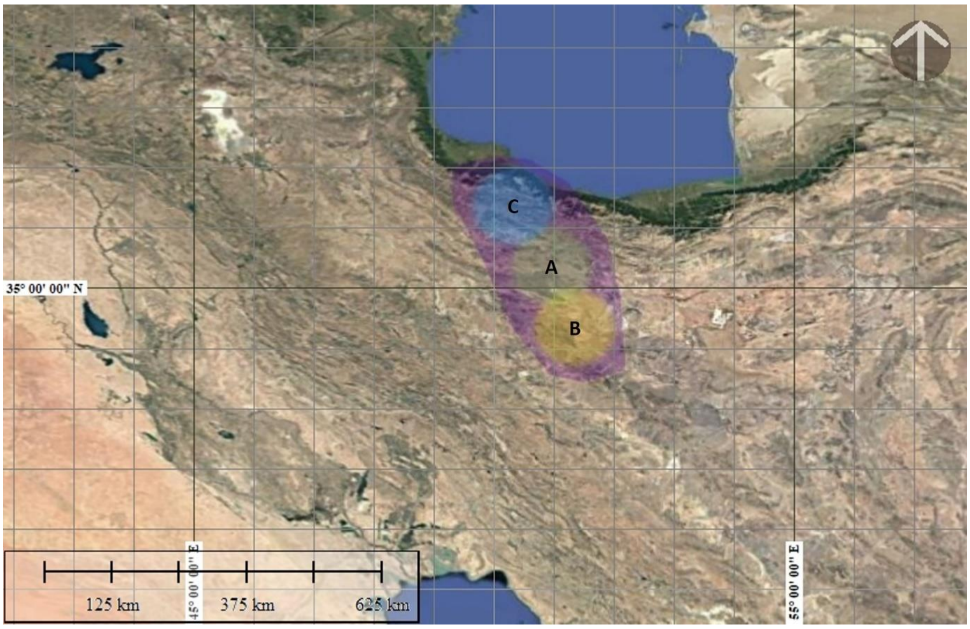

Fig. 1. GeoEye satellite image of the study area (pink area) including three regions (A, B, and C) marked in different colors.

Figure 2 represents an overview of the methodology proposed in this research.

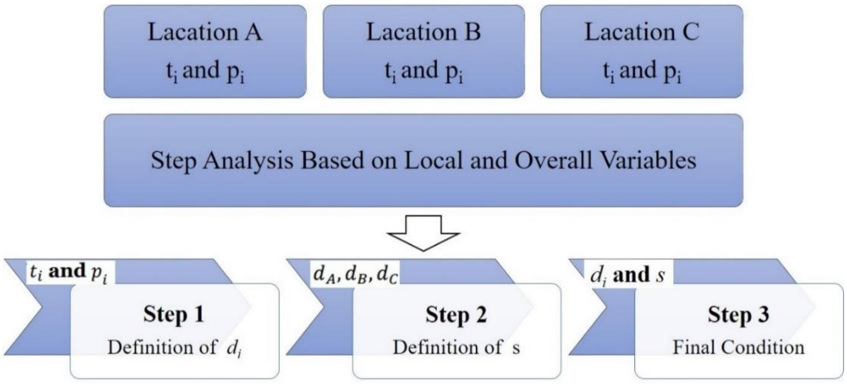

Fig. 2. The research methodology developed to establish the necessary numerical relationships for each case study through a three-step variable solution process. The variables t, p, d, and s represent temperature, precipitation, tourism desirability, and overall tourism conditions, respectively. The locations labeled A, B, and C correspond to the Caspian Sea region, the Alborz Mountains region, and the Kashan region, respectively.

To construct the required formulas for *d* (tourism desirability) and *s* (*overall tourism condition*), we defined the problem into three solving steps as follows:

Step 1: Definition d_i ***as a Function of*** t_i ***and*** p_i

We need to ensure that:

- d_i increases as t_i and p_i increase.
- $d_i = 0$ (*unfavorable*) if either t_i or p_i is **0 or close to 0**.
- $d_i = 1$ (very *favorable*) when both t_i and p_i are close to 1.
- $d_i = 0.5$ (*favorable*) for intermediate values.

Therefore, the function satisfying these conditions was suggested as:

$$d = (t_i . p_i) + \frac{t_i + p_i}{4} \quad (6)$$

where and denote temperature and precipitation for each region respectively.

Justification:

- The term $t_i . p_i$ ensures that if **either** t_i **or** p_i **is close to 0,** d_i **remains low**.
- The term $\frac{t_i + p_i}{4}$ helps smoothly transition between levels, ensuring intermediate values result in $d_i = 0.5$.

Step 2: Definition s ***as a Function of*** d_A, d_B, ***and*** d_C

The overall conditions should follow these rules:

- If all three locations have $d = 1$, then $s = 1$(*high*).
- If two locations have $d = 1$ and one has d = 0, then $s = 0.5$ (*medium*).
- If all three locations have $d = 0$, then $s = 0$ (*low*).

A simplified model for this behavior was suggested as:

$$s = \frac{d_A + d_B + d_C}{3} \quad (6)$$

Since d_i takes values in {0,0.5,1}, the function s naturally falls into the range {0,0.5,1}, ensuring it behaves as required.

Step 3: Final Condition

This step includes validation of the previous two steps. From equations (6) and (7), we have tourism desirability for each region ***i*** (A, B, C) and overall tourism condition**,** respectively**.** Let's check validation values:

t	***p***	***d***
0.0	0.8	**0.0** (*unfavorable*)
0.8	0.8	**0.8** (*very favorable*)
0.5	0.5	**0.375** (*between unfavorable & favorable*)
1.0	1.0	**1.0** (*very favorable*)

If $d_A = 1$, $d_B = 1$, and $d_C = 0$, then:

$$s = \frac{1+1+0}{3} = 0.5\ (Medium)$$

If $d_A = 1$, $d_B = 1$, and $d_C = 1$, then:

$$s = \frac{1+1+1}{3} = 1\ (High)$$

If $d_A = 0$, $d_B = 0$, and $d_C = 0$, then:

$$s = \frac{0+0+0}{3} = 0\ (Low)$$

Therefore, the relationships between defined variables behave exactly as required in this research. In tandem with the aforementioned findings, a comprehensive field and library study was undertaken to assess the effects of recent climate changes on ecotourism. This investigation, combined with the previously mentioned computational results, culminated in a conclusive outcome.

It is evident that the statistical methodologies and techniques employed in this section comprised variable normalization and scaling, rule-based classification through threshold modeling, ordinal aggregation facilitated by weighted scoring, logical imputation and nonparametric design, and sensitivity considerations and robustness. Calculations and processing related to the proposed methodology were conducted using MATLAB programming.

Results and Discussion

3-1 Alborz Mountains Region

The Alborz Mountains, with elevations reaching up to 5,670 meters above sea level, exhibit a diverse climate that varies significantly with altitude. The region is characterized by a combination of alpine and continental climates, classified as Dfb and Dfc, depending on the specific location. In the lower elevations, average annual temperatures range from 10ºC to 15ºC (50ºF to 59ºF), while temperatures in the higher altitudes can drop below freezing for much of the year. Precipitation levels have been considerably higher than in lower regions, averaging around 1200 millimeters (47.24 inches) annually, with snowfall dominating the winter months. The Alborz Mountains region experiences approximately 100 to 150 days of precipitation each year, contributing to the lush vegetation and diverse ecosystems found in the area. Figure 3 illustrates the mean monthly temperature and precipitation patterns in the Alborz Mountains over recent years.

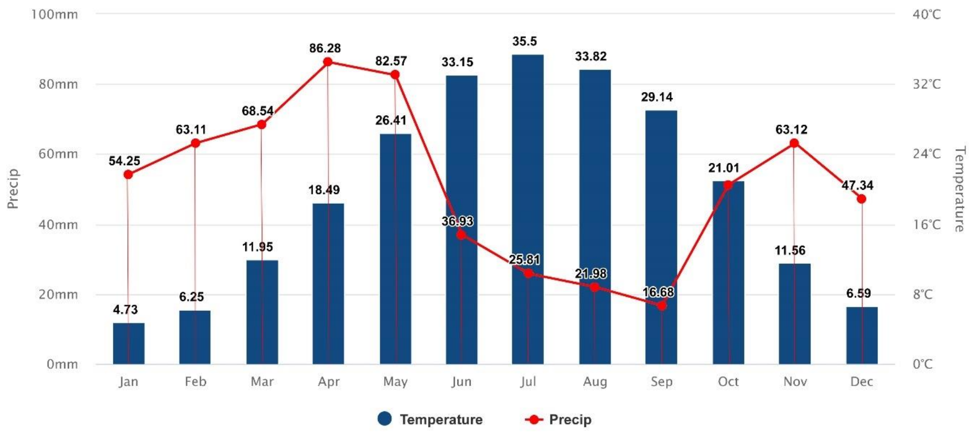

Fig. 3. Recent trends in monthly mean temperature and precipitation patterns in the Alborz Mountains region (based on W&C, 2025)

Kashsn Region

Situated at an altitude of 1,575 meters above sea level, Kashan exhibits a Mid-latitude steppe climate, classified as BSk. The average annual temperature in the district is 21.37ºC (70.47ºF), which is 2.94% above the national average for Iran. Each year, Kashan receives approximately 8.99 millimeters (0.35 inches) of precipitation, with an average of 25.78 days of rainfall, accounting for about 7.06% of the year. Figure 4 shows the mean monthly temperature and precipitation of Kashan in recent years.

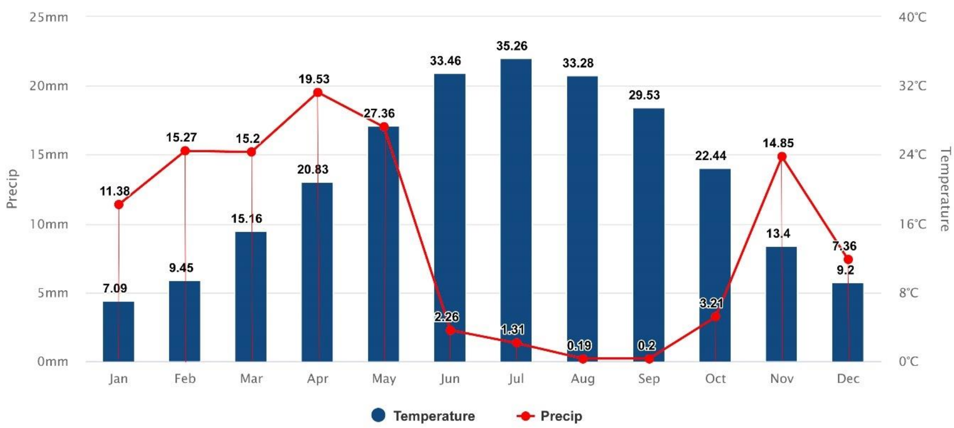

Fig. 4. Recent trends in monthly mean temperature and precipitation patterns in kashan region (based on W&C, 2025)

Caspian Sea Region

Situated at an elevation of 2.06 meters above sea level, Gilan experiences a humid subtropical climate characterized by the absence of a dry season (Climate Classification: Cfa). The city's average annual temperature was recorded at 18.79°C (65.82°F), which was 0.36% above the national average for Iran. Gilan receives approximately 104.23 millimeters (4.1 inches) of rainfall each year, with precipitation occurring on an average of 123.1 days, accounting for 33.73% of the year. Figure 5 illustrates the mean monthly temperature and precipitation patterns in the Caspian Sea region over recent years.

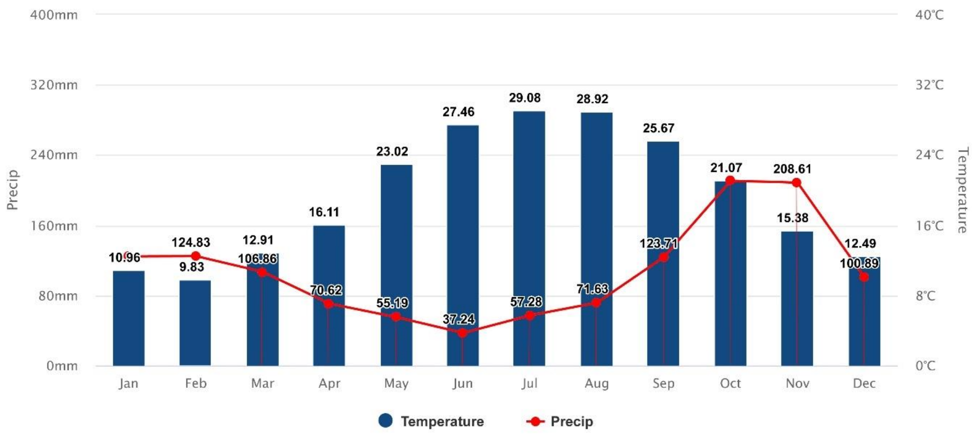

Fig. 5. Recent trends in monthly mean temperature and precipitation patterns in the Caspian Sea region (based on W&C, 2025)

Table 1 presents the recent and previous decadal temperature (*t*) and precipitation (*p*) values as of May 2015, along with the calculated reference and normalized values for comparative analysis.

Table 1. Recent and previous decadal *t* and *p* values as of May 2015.

Location	*p* (mm)	Ref. *p*[a] (mm)	*p*[b] (0 – 1)	*t*[c] (°C)	Ref. *t*[d] (°C)	*T*[e] (0–1)
A (Alborz Mtn.)	82.57	31–141.28	0.46	26.41	26.40–31.72	0.99
B (Kashan Region)	17	6.04–62.14	0.19	27.36	27.36–33.2	1
C (Caspian Region)	55.19	53.0–409.6	0.01	23.02	19.9–24.06	0.25

[a] Reference *p* from the last decade according to W&C, 2025
[b] Normalized value of *p*
[c] Average maximum
[d] Reference *t* from the last decade, including Min and Max values according to W&C, 2025
[e] Normalized value of *t* selected based on the work of Scott et al. (2007).

A comparative analysis of the climate change data presented in Table 1, in conjunction with the findings illustrated in Figures 3 through 5, reveals that for locations A and B, there is an increase in the *p* variable accompanied by a decrease in the *t* variable over the past decade. Conversely, for Region C, the data indicate a decline in the *p* variable and a rise in the *t* variable during the same period. The results presented in Table 2 are obtained by solving for *d* using Equation (1) followed by Equation (2).

Table 2: Values of *s* obtained by solving for *d* using Equations (6) and (7).

Location	p^b (0 – 1)	t^d (0–1)	d_i (0 – 1)	s (0 – 1)
A (Alborz Mtn.)	0.46	0.99	0.81	
B (Kashan Region)	0.19	1	0.48	0.43
C (Caspian Region)	0.01	0.25	0.00	

[a] Normalized value of *p*
[b] Normalized value of *t* selected based on the work of Scott et al. (2007).

Locations A (Alborz Mountain), B (Kashan Region), and C (Caspian Region) are classified as "*very favorable*," "*favorable*," and "*unfavorable*," respectively, with d_i values of 0.81, 0.48, and 0.00. The overall condition of the study area, encompassing all three regions, was determined to be at a "*medium*" level with an *s* value of 0.43. Of particular significance is the significant impact of climate change on Region C (Caspian Region), as its *d* value decreases from "*very favorable*" to "*unfavorable*" in the past decade. This serves as a warning signal for the management of environmental changes. According to the methodology presented, both library and field evidence from Region B demonstrate the impact of climate change on ecotourism over the past decade as follows:

- Water scarcity: Based on some research (Jamshidzadeh and Mirbagheri, 2011; Khorasanizadeh et al., 2023; Haghighi and Motagh, 2024) in recent years, groundwater in Region B has experienced significant declines. The aquifer storage volume was decreased by over 35 MCM, with an average annual groundwater level drop of about 0.44 meters. In addition, the total groundwater level declined by approximately 15.29 meters over 28 years, averaging 0.54 meters per year. These significant water shortages due to prolonged droughts, which are exacerbated by climate change, affect not only the agricultural practices that sustain local communities but also the lush gardens that attract tourists. The Fin Garden, a UNESCO World Heritage site, relies on traditional qanat irrigation systems, which are becoming less reliable as water tables drop.
- Increased temperatures: Rising temperatures make the already hot desert climate even more extreme. This can deter ecotourists during peak summer months when temperatures can exceed 40°C, leading to a decline in visitor numbers during crucial seasons.

- Biodiversity loss: The changing climate affects local flora and fauna, potentially diminishing the biodiversity that is a key attraction for ecotourism. Species that are sensitive to temperature changes may migrate or decline, reducing the ecological richness that draws visitors to Region B.
- Cultural heritage at risk: The impacts of climate change threaten not only the natural environment but also the cultural heritage sites in Region B. Increased erosion, extreme weather events, and changes in vegetation can affect the integrity of historical sites, which are integral to Kashan's appeal as an ecotourism destination.

The same type of assessment is also conducted for Region C, as outlined below:

- Decrease sea levels: The Caspian Sea, once a thriving ecosystem, experiences declining water levels, impacting local biodiversity and tourism activities (Ghasemi et al., 2019). Based on some researches (Chen et al., 2017; Leroy et al., 2022; Samant and Prange, 2023; UNEP, 2025), the Region C experiences a significant decline in water levels in recent years, with a reported decrease of approximately 6.07 cm per year, and more recent satellite data indicating a decline of about 8.81 cm per year since 2005. This decline resulted in a loss of around 15,000 km² of sea area. The decrease in the Caspian Sea water level adversely affects ecotourism by disrupting key ecosystems and reducing marine protected areas, which are crucial for biodiversity. Additionally, the loss of coastal areas and wetlands can diminish the natural attractions that draw tourists, impacting local economies reliant on ecotourism.
- Biodiversity threats: Region C is home to unique species, including the endangered Caspian seal and various fish species. Climate change impacts such as temperature fluctuations, changes in salinity, and habitat loss threaten these species. Declines in biodiversity reduce the appeal of ecotourism activities like birdwatching, fishing, and wildlife observation.
- Altered ecosystems: Climate change leads to shifts in local ecosystems, affecting the flora and fauna that attract tourists. For example, changes in precipitation patterns impact the lush green landscapes of Gilan, which are known for their beautiful rice paddies and forests. Deforestation and changes in land use, driven by climate change, are disrupting these ecosystems even further.
- Increased extreme weather events: Region C is experiencing an increase in extreme weather events,

such as heavy rainfall and flooding. These events can damage infrastructure, disrupt travel plans, and deter tourists from visiting. For instance, flooding can affect coastal resorts and access to natural attractions, leading to temporary closures and economic losses for local businesses reliant on ecotourism.

The data gathered from the Iranian Department of Environment, the World Tourism Organization, climate change research institutions, and related studies (Dinpashoh et al., 2011; Zahraei et al., 2018; Kazemzadeh et al., 2020; Rahimi et al., 2020; Darand et al., 2025) highlight significant insights into climate dynamics and water management in Iran. The results revealed notable variations that influence local climate patterns, indicating shifts in climate zones, as classified by the Köppen–Geiger system, suggesting a trend towards more arid conditions in certain regions. Furthermore, the estimation of evaporation from the Caspian Sea provides critical temporal and spatial data, indicating significant variability influenced by climatic factors. In conclusion, the examination of trends in reference crop evapotranspiration throughout Iran highlights the growing demand for water resources in agriculture. This situation calls for adaptive management strategies to address the shifting climatic conditions. Collectively, these studies illustrated the intricate relationship between climate change, water management, and agricultural practices in Iran.

However, it appears that these factors are largely applicable to other regions of the country as well. In general, the recent changes in temperature and precipitation have significant implications for biodiversity, water resources, and overall ecological health, as outlined below:

- Environmental changes: Recent climate change led to significant environmental alterations in Iran. Increased temperatures have resulted in prolonged droughts, particularly in the central and southern regions of the country (Zare et al., 2020). These changes adversely affected water resources, leading to reduced vegetation cover and increased desertification.
- Impact on biodiversity: Biodiversity is a cornerstone of ecotourism and geotourism. However, climate change disrupts ecosystems, leading to shifts in species distributions and increased extinction risks (Legg, 2021). In Iran, endemic species such as the Persian leopard and the Caspian seal face heightened threats due to habitat loss and changing climatic conditions (Zare et al., 2020). The decline in biodiversity not only affects

ecological balance but also diminishes the attractiveness of ecotourism destinations.

- Tourist behavior and preferences: Climate change also influences tourist behavior and preferences. As environmental conditions change, tourists may seek alternative destinations or activities that align with their values regarding sustainability and conservation (Buckley, 2012). In Iran, there is a growing awareness among tourists about the impacts of climate change, leading to increased demand for eco-friendly and sustainable tourism options. This shift presents an opportunity for the development of new ecotourism initiatives prioritizing environmental stewardship.
- Economic implications: The economic implications of climate change on ecotourism and geotourism in Iran are profound. The tourism sector is a significant contributor to the national economy, providing jobs and supporting local communities (World Tourism Organization, 2020). However, as climate change impacts natural attractions, there is a risk of decreased tourist arrivals, leading to economic losses. Conversely, new economic opportunities can be created through the promotion of sustainable tourism practices, fostering resilience in local economies.
- Adaptive strategies: To mitigate the adverse effects of climate change on ecotourism and geotourism, stakeholders must adopt adaptive strategies. These include implementing sustainable land-use practices, enhancing conservation efforts, and promoting community engagement in tourism development. In addition, raising awareness among tourists about the importance of sustainable practices can contribute to the resilience of these sectors.

The results highlight the need for adaptive management practices that can respond to these environmental changes. In the end, the findings suggest that successful ecotourism strategies in Iran must incorporate climate resilience measures. This includes promoting sustainable practices among local communities, enhancing conservation efforts, and leveraging technology to monitor environmental changes. Furthermore, collaboration between the government, NGOs, and local stakeholders is essential to create a cohesive approach to ecotourism development that aligns with climate adaptation goals. In this regard, it is clear that conservation and community involvement, drawing on recent research and case studies from UNESCO-designated sites in Iran, are prioritized.

Conclusion

This study has underscored the significant impact of climate change on ecotourism and geotourism in northern and central Iran, revealing critical insights into the vulnerabilities of various regions. A comparative analysis with the framework defined in the FMA reveals that for locations A and B, there has been an increase in the *p* variable accompanied by a decrease in the *t* variable over the past decade. Conversely, for Region C, the data indicate a decline in the *p* variable and a rise in the *t* variable during the same period. The findings indicate that while the Regions A (Alborz Mtn.) and B (Kashan Region) maintain *favorable* conditions for ecotourism, the Region C (Caspian Region) has experienced a marked decline in its ecological viability, transitioning from "*very favorable*" to "*unfavorable*" status over the past decade. This shift highlights the urgent need for adaptive management strategies that can effectively address the challenges posed by climate change. In addition, the overall condition of the study area, including all three regions, is ranked at a *medium* level with an *s* value of 0.43. Field and library studies also indicate that the most common items affected by climate change for northern and central Iran are water scarcity, increased temperatures, biodiversity loss, cultural heritage at risk, decreased sea levels, biodiversity threats, altered ecosystems, and increased extreme weather events. The study shows a complex interplay between environmental shifts and the tourism sector. As climate change continues to alter weather patterns, biodiversity, and geological features, both ecotourism and geotourism face significant challenges and opportunities. The practical implications of this research emphasize the necessity for integrating climate resilience measures into ecotourism strategies, which can enhance the sustainability of local economies while preserving natural heritage.

Given the sensitive nature of this topic, it is recommended that further research be undertaken to explore decision-making processes across different regions of Iran. This investigation should be supported by a robust dataset that incorporates a diverse array of variables and spans multiple time periods, particularly considering the influence of additional factors, such as human activities, to enhance future analyses.

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