Desert Ecosystem Engineering Journal (2026) 14 (49), 93-111
Research Article

Identification of temperature hot spots in the Zagros natural habitat based on global standard indicators revealing climate change

Fatemeh Dargahian,[1]* Mehdi Pourhashemi,[2] Somayeh Hedarnezhad[3]

Received: 25/01/2026 Accepted: 03/02/2026

Abstract

One of the most important consequences of climate change is the reduction of forest area. The decrease in the area and the decline of oak forests in the Zagros ecosystem in western Iran, especially in the last two decades, is directly and indirectly affected by the occurrence of climate change, especially the increase in temperature This study investigates climate change impacts on the Zagros oak forest ecosystem in western Iran, focusing on warming trends and their spatial distribution. Using observational data from 34 synoptic stations and the ClimPACT software in R, we analyzed eight temperature indices (SU25, SU30, SU35, TN90p, TX90p, TX50p, WSDI2, WSDI6) standardized by the Expert Team on Climate Risk and Sector-Specific Climate Indices (ET-CRSCI). Results reveal a significant warming trend, with the most pronounced increases in warm temperature indices occurring at the highest latitudes of the northern Zagros and the highest elevations of the southern Zagros. Persistent hotspots were identified in northwestern Fars and southwestern Ilam provinces. Critically, the index representing prolonged warm spells (WSDI6) showed the strongest increase in the southern Zagros, an area coinciding with the highest frequency of wildfires in the past decade. This suggests that persistent heat accelerates ecosystem drying, thereby intensifying fire risk and damage. Identifying these thermal hotspots provides crucial insights for adaptive management and planning, enabling more resilient conservation strategies to mitigate climate change impacts on this vital ecosystem.

Keywords: ClimPACT, forest ecosystem, Decline of oak forests, Temperature hot spot, Warm Index.

---

1. Associate Professor, Research Institute of Forests and Rangelands, Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran; (Corresponding author), Email: dargahian@rifr-ac.ir
2. Prof., Research Institute of Forests and Rangelands, Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran; Email: doveyse@yahoo.com
3. Ph.D. in Desertification, Researcher at the Desertification Research Department of Lorestan Agricultural and Natural Resources Research and Education Center, Borujerd Agricultural and Natural Resources Research and Education Campus; Email: s.heydarnezhad@areeo.ac.ir

DO: 10.22052/DEEJ.2026.258289.1135

1. Introduction

The Zagros forests, spanning approximately six million hectares, constitute roughly 40% of Iran's total forest cover. These forests are predominantly composed of oak species, which represent about 70% of their composition. Over the past two decades, this region has experienced significant forest decline and dieback due to various interconnected factors. The phenomenon of oak decline is not unique to Iran and has been documented in over 40 countries. Between 2009 and 2010, approximately 100,000 hectares of Zagros forests were affected by oak decline, a figure that expanded rapidly to an estimated one million hectares by 2014 (Pourhashemi et al., 2017). Monitoring this decline across the vast Zagros ecosystem has been conducted through both field surveys and satellite imagery. Studies utilizing these methods have quantified substantial losses: change detection using object-based classification of multitemporal Landsat imagery in northern Ilam province revealed a 42% reduction in forest area (Rostam Zadeh et al., 2017). An analysis of forest cover change in the Romeshkan area, employing fuzzy object-based classification and CA-Markov modeling, indicated that forested area in 2017 was only one-third of its 1987 extent (Shehabi & Akbari, 2020). Monitoring in Lorestan Province using satellite imagery and the BFAST model showed a loss of over 42,804 hectares of oak forests to decline between 2000 and 2020 (Shiravand et al., 2020). Research on the spatial distribution of degradation in Ilam's Zagros forests reported a reduction of 5,311 hectares from a total of 733,349 hectares, with 2,125 hectares directly attributed to oak dieback (Jafari et al., 2020). A study in Dasht-e Boram, Fars province, demonstrated a decrease in oak canopy cover from the pre-drought to post-drought period using satellite images (Naseri et al., 2020). Drought and climate change are widely recognized as primary drivers of this oak decline (Clatterbuck & Kauffman, 2006). While numerous anthropogenic and natural factors contribute to the degradation of Zagros oak forests, research in the Kouhdasht region suggests human activities may play a more significant role than natural ones in deforestation (Ghasemi Aghbash & Falahi, 2017). Nevertheless, among natural factors, climate change and global warming have been extensively emphasized. Key findings linking climate to decline include reduced rainfall significantly affecting oak dieback in the Boram plain of Fars province (Hamzehpour et al., 2011), and the observation that in the arid Middle Zagros, precipitation positively and temperature negatively influenced the radial growth of Persian oak (Soosani et al., 2014). Factors such as average annual rainfall, temperature, evaporation, humidity, and dust were major contributors to oak decline in Ilam province, with significant rainfall reduction being a primary cause of drought stress (Azizi et al., 2015; Attarod et al., 2016). This pattern aligns with studies in the Mediterranean region, where climate change, alongside other biotic and abiotic stresses, is identified as a key factor in oak decline (Kim et al., 2017; Keča et al., 2018). Tree-ring analyses further corroborate this climatic influence, showing oak growth decline associated with delayed responses to climate, dependence on spring precipitation, and an inverse relationship with spring-summer temperatures (Di Filippo et al., 2010; Romagnoli et al., 2018). This global phenomenon of climate-induced forest decline particularly impacts drought-prone areas, increasing tree mortality (Colangelo et al., 2018). In the Zagros, models identify regions with higher temperatures, lower rainfall, increased altitude, and shallower soils as highly prone to severe forest drought (Kouh Soltani et al., 2018). Some studies also cite land-use change as a contributing factor (Moreno-Fernández et al., 2019; Hernández-Lambraño et al., 2019). Predicted increases in the intensity and duration of droughts and heat waves due to climatic warming are expected to exacerbate stem mortality and forest dieback globally, especially in semi-arid ecosystems like the

Zagros (Ogaya et al., 2020). Research consistently identifies climate change as the most significant factor in the drying of Zagros oak trees (Bedrood et al., 2021; Karamian & Mirzaei, 2020), with significant correlations found between climatic parameters and vegetation indices (Maroufzade & Attarod, 2021). The underlying mechanism is often linked to soil moisture dynamics: rapid loss of rhizosphere moisture and intensified water stress are critical factors in the decline of Persian oak (Zarafshar et al., 2020; Hosseinzadeh & Pourhashemi, 2017), and drought intensity shows a negative correlation with soil moisture and organic matter (Mozafari et al., 2019). Climatic factors such as drought indices, precipitation, temperature, and evapotranspiration are consistently the most impactful variables in models identifying drought-prone forest areas (Ghadirian et al., 2018; Goodarzi et al., 2019). A nationwide economic-climate study in Iran suggested a U-shaped relationship between deforestation and the ratio of rainfall to temperature (Saleh, 2021). Climate change poses a profound threat to forest ecosystems and their capacity to provide vital services in the coming decades (Sousa-Silva et al., 2018), potentially driving numerous species toward extinction (Valavi et al., 2019). Forecasts for the Zagros are concerning. Drought indices in the central Zagros (Lorestan) are projected to follow an increasing trend (Shiravand et al., 2019). Habitat modeling predicts the area suitable for Persian oak (Quercus brantii) in Chaharmahal and Bakhtiari province could decrease by 35.7% by 2050 under the RCP 4.5 climate scenario (Haidarian Aghakhani et al., 2017). Similarly, the habitat for wild pistachio species in the same province is forecast to decline by approximately 11-11.8% by 2050 under different climate scenarios (Naghipour Pour et al., 2019). However, implementing optimized management strategies to enhance adaptation to climate change impacts could allow Zagros forests to play a crucial role in mitigating global warming (Safari & Sohrabi, 2019).

2. Materials & Methods

2.1. Study Area

The Zagros forests, located in western Iran, span 11 provinces. Encompassing approximately six million hectares, these forests account for about 40% of Iran's total forest cover. Oak species dominate the forest composition, representing roughly 70% of the tree population (Figure 1). The climate of the region is semi-arid Mediterranean, characterized by cold winters. Precipitation exhibits a steep gradient, ranging from approximately 800 mm annually in the northern parts to about 300 mm in the southwest (Dargahian et al., 2025). Within Iran's total land area of 164 million hectares, forestland occupies approximately 14.3 million hectares. The Zagros forests, at six million hectares, represent the country's largest contiguous forest area and are a critical water source, contributing to an estimated 40% of the nation's water yield. Over the past two decades, this forest ecosystem has experienced significant tree decline and dieback. This degradation is attributed to a complex interplay of factors, including prolonged drought, climate change, particulate matter pollution, land-use change, over-extraction of groundwater, and large-scale construction projects (e.g., dams and roads) implemented without adequate environmental safeguards. Additional pressures include the decline of keystone animal species essential for forest regeneration (such as squirrels), and overgrazing by livestock in rangeland areas (Figures 2, 3).

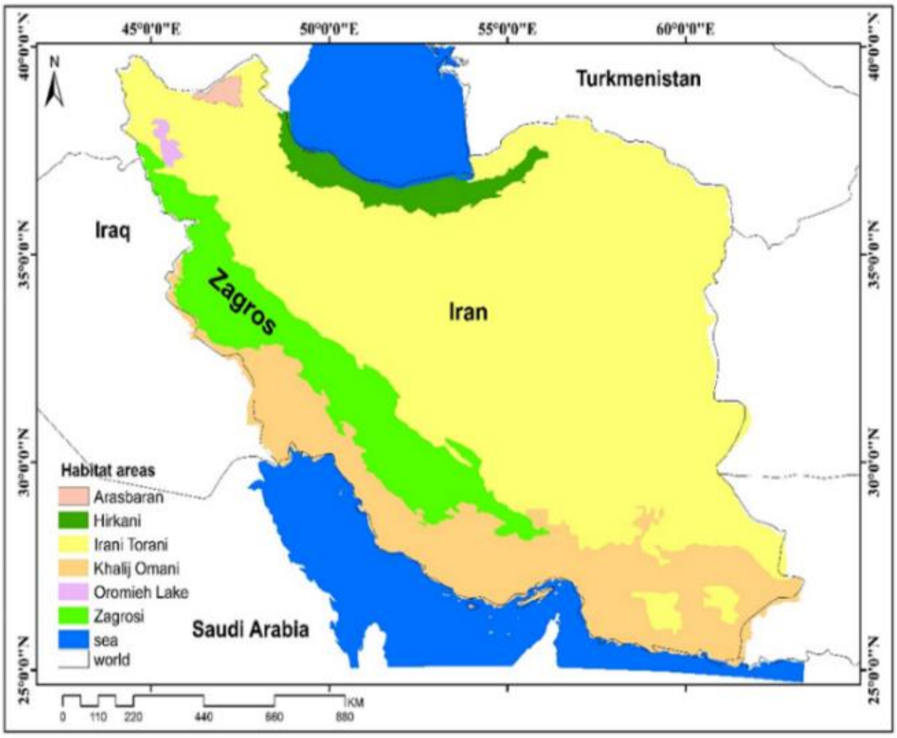

Figure (1): Location of Zagros forest ecosystem among natural habitats of Iran (Natural Resources and Watershed Management Organization 2020)

Figure (2): Zagros forest cover (oak)

Figure (3): Drying of oak species July 1401

2.2. Methods

The risks associated with global warming and climate change can be identified and managed through strategic planning. It is therefore essential to understand their potential consequences and develop effective adaptation and mitigation strategies. The Zagros forest ecosystem has undergone significant degradation under the influence of various stressors, including climate change.

To detect the occurrence of climate change within this ecosystem, this study analyzed the slope of the trend and the statistical significance of specific warm temperature indices. For this purpose, observational data from synoptic stations located within the Zagros forest ecosystem were utilized. Stations possessing a continuous 30-year statistical period were selected for analysis (Table 1).

Table (1): Synoptic stations used

Synoptic Station	province	Latitude	Longitude	elevation
Piranshahr	Azarbyjan	36.70	45.15	1443.50
Sardasht		36.15	45.49	1556.80
Mahabad		36.75	45.72	1351.80
Oshnaviyeh		37.06	45.14	1415.90
Thrush	Kordestan	36.22	46.31	1522.80
Sanandaj		35.25	47.01	1373.40
Marivan		35.50	46.15	1287.00
Baneh		36.01	45.90	1600.00
Kermanshah	Kermanshah	34.35	47.15	1318.50
Islamabad		34.12	46.47	1348.80
Ravansar		34.72	46.65	1380.00
Yasouj	Kahgiloueh_Boyerahmad	30.70	51.56	1816.30
Sisakht		30.84	51.47	2133.40
Darehshahr	Ilam	33.14	47.41	670.00
Dehloran		32.68	47.30	232.00
Ilam		33.59	46.40	1337.00
Ivan		33.76	46.36	1290.00
Ezeh	Khozestan	31.85	49.85	767.00
Kohrang	Chaharmahal_Bakhtiari	32.46	50.13	2365.00
Borujen		31.98	51.30	2260.00
Farsan		32.26	50.56	2062.00
Ardal		32.01	50.66	1873.00
Lordegan		31.50	50.83	1611.00
Kohdasht	Lorestan	33.52	47.65	1197.80
Delfan		34.05	48.00	1859.00
Alashtar		33.82	48.25	1567.10
Poldokhtar		33.15	47.72	713.50
Khorramabad		33.44	48.28	1147.80
Nyriz	fars	29.19	54.35	1632.00
Sepidan		30.23	52.00	2201.00
Noorabad		30.07	51.54	972.00
Doroodzan		30.21	52.42	1642.00
Zarghan		29.78	52.70	1596.00
Shiraz		29.56	52.60	1488.00
Kazeroun		29.60	51.65	840.00

To detect the occurrence of climate change in the Zagros ecosystem as a contributing factor to oak decline, the methodology of the Expert Team on Climate Risk and Sector-Specific Climate Indices (ET CRSCI) was employed. The climatic parameters required for the climate change detection model were selected, comprising daily precipitation, daily maximum temperature, and daily minimum temperature. Prior to index calculation, the daily input data underwent quality control and homogeneity testing. The indices for climate change detection were calculated using ClimPACT software, which operates within the R environment. ClimPACT is based on the RClimDEX software originally developed by the Expert Team on Climate Change Detection and Indices (ETCCDI) under the World Meteorological Organization (WMO) Commission for Climatology (CCl) Open Panel of Experts on Climate Information for Adaptation and Risk Management (OPACE 4). Following data entry into the software, the indices were computed and extracted. From the resulting suite of indices, specific warm temperature indices were selected for further analysis (Table 2).

Table (2): Warm temperature indicators indicating climate change in Zagros forest ecosystem (Lisa Alexander, 2015)

Row	ID	Indicator name	Definitions	UNITS
1	SU25	Summer days	Annual count when TX > 25ºC	days
2	SU30	Hot days	Annual count when TX >= 30ºC	days
3	SU35	Very hot days	Annual count when TX > = 35ºC	days
4	TN90p	Warm nights	Percentage of time when daily min temperature > 90th percentile	%
5	TX90p	Warm days	Percentage of time when daily max temperature > 90th percentile	%
6	TX50p	Above average Days	Percentage of days of days where TX>50th percentile	%
7	WSDI2	Warm spell duration indicator	Annual count of days with at least *n* consecutive days when TX>90th percentile where n>= 2 (and max 10)	days
8	WSDI6	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX>90th percentile	days

2.3. Warm Temperature Indices

- **SU25, summer days**: count of days where TX (daily maximum temperature) > 25°C

Let TX*ij* be the daily maximum temperature on day *i* in period *j*. Count the number of days where TX*ij* >25°C.

- **SU30, hot days**: count of days where TX > 30°C

Let TX*ij* be the daily maximum temperature on day *i* in period *j*. Count the number of days where TX*ij* >30°C.

- **SU35, very hot days**: count of days where TX > 35°C

Let TX*ij* be the daily maximum temperature on day *i* in period *j*. Count the number of days where TX*ij* >35°C.

- TX50p, above average days: count of days where TX > 50th percentile.

Let TX*ij* be the daily maximum temperature on day *i* in period *j* and let TX*ib*50 be the calendar day 50th percentile of daily maximum temperature calculated for a five-day window centred on each calendar day in the base period *b* (e.g. 1971-2000). Count the number of days where TX*ij* > TX*ib*50.

-TN90p, warm nights: count of days where TN > 90th percentile

Let TN*ij* be the daily minimum temperature on day *i* in period *j* and let TN*in*90 be the calendar day 90th percentile of daily minimum temperature calculated for a five-day window centred on each calendar day in the base period *n* (e.g. 1971-2000). Count the number of days where TN*ij* > -TX90p, warm days: count of days where TX > 90th percentile

Let TX*ij* be the daily maximum temperature on day *i* in period *j* and let TX*in*90 be the calendar day 90th percentile of daily maximum temperature calculated for a five-day window centred on each calendar day in the base period *n* (e.g. 1971-2000). Count the number of days where TX*ij* > TX*in*90.

-WSDIn2, user-defined warm spell duration index: count of days in a span of at least *n* days where TX > 90th percentile.

Let TX*ij* be the daily maximum temperature on day *i* in period *j* and let TX*ib*90 be the calendar day 90th percentile of daily maximum temperature calculated for a five-day window centred on each calendar day in the base period *b* (e.g. 1971-2000). Count the number of days where, in intervals of at least *n* consecutive days TX*ij* > TX*ib*90 where *n*<= 10.

- WSDI6, warm spell duration index: count of days in a span of at least six days where TX > 90th percentile.

Let TX*ij* be the daily maximum temperature on day *i* in period *j* and let TX*ib*90 be the calendar day 90th percentile of daily maximum temperature calculated for a five-day window centred on each calendar day in the base period *b* (e.g. 1971-2000). Count the number of days where, in intervals of at least six consecutive days TX*ij* > TX*ib*90.

Given the size of the study area, the Zagros habitat was divided into three geographical sectors to examine the trend of time series changes across all indicators: North Zagros (NZ), Central Zagros (CZ), and South Zagros (SZ). For the purposes of this study: The Zagros regions within West Azerbaijan and Kurdistan provinces were designated as the NZ. The Zagros regions within Kermanshah, Ilam, and Lorestan provinces were designated as the CZ. The provinces of Khuzestan, Chaharmahal and Bakhtiari, Kohgiluyeh and Boyer Ahmad, along with parts of Fars province, were designated as the SZ. To represent each sector, one synoptic station was selected: Piranshahr station (West Azerbaijan) for the NZ, Ilam station for the CZ, and Borujen station for the SZ. The slope of the change trend, along with its P-value and statistical significance, was estimated and analyzed at a 95% confidence level. Eight warm temperature indices were extracted and spatially zoned across the entire study area. This zoning ultimately allowed for the identification of temperature hotspots within the Zagros habitat. Identifying these temperature hotspots provides valuable insight for planners and decision-makers, supporting the development of operational plans aimed at forest conservation, restoration, and adaptation to climate change in natural habitats.

3. Funding

SU25, Summer Days: This index counts the number of days where the daily maximum temperature (TX) exceeds 25°C. Analysis of the trend slope for this index revealed a significant increasing trend in the number of summer days across the entire Zagros ecosystem. The slope of the trend line was highest in the Northern Zagros, compared to the Central and Southern sectors (Figure 4).

Spatial zoning of the SU25 index indicated that the most pronounced increasing trend generally occurred at higher latitudes within the Northern Zagros and in the high-altitude regions of the Southern Zagros. Two additional temperature hotspots were identified in southwestern Ilam province and in the western and northwestern areas of Fars province. In these hotspot areas, the number of summer days has increased by 40 to 85 days (Figure 5).

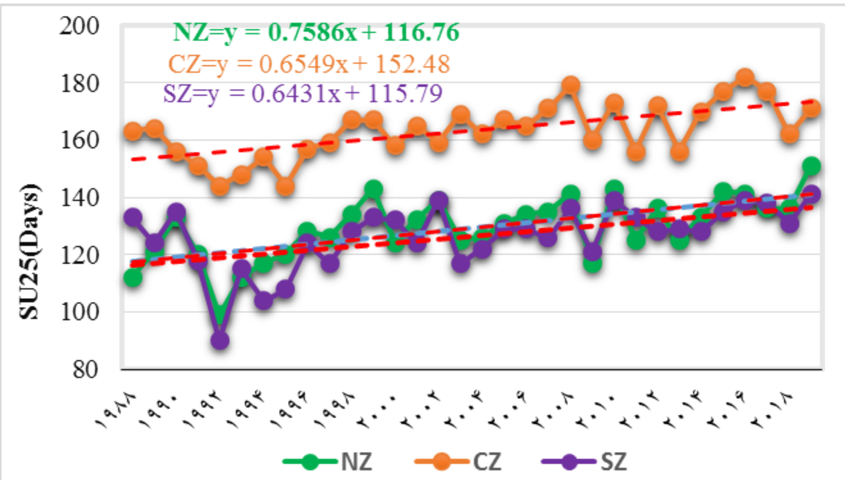

Figure (4): Liner trend slop, SU25 in Representative station in NZ, CZ and SZ

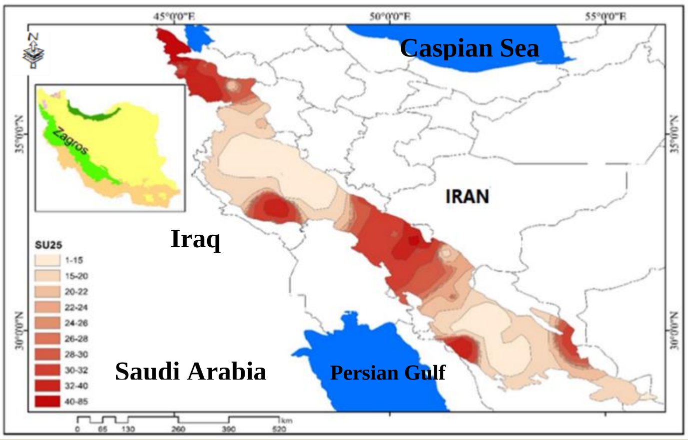

Figure (5): Trend of change SU25, summer day's index in Zagros forest ecosystem in Iran

SU30, Hot Days: This index counts the number of days where the daily maximum temperature (TX) exceeds 30°C. Analysis of the hot day's index showed a significant and increasing trend across the entire Zagros ecosystem. The slope of the trend line was steeper in the Northern Zagros compared to the Central and Southern sectors (Figure 6). The spatial zoning map for hot days revealed that the distribution of hotspots for this index aligns precisely with the pattern observed for the summer days (SU25) index. Four primary hotspots were identified: The northern Zagros plateau, Western Ilam province, The central Zagros highlands within Chaharmahal and Bakhtiari and Kohgiluyeh and Boyer-Ahmad provinces, and Northwestern Fars province (Figure 7).

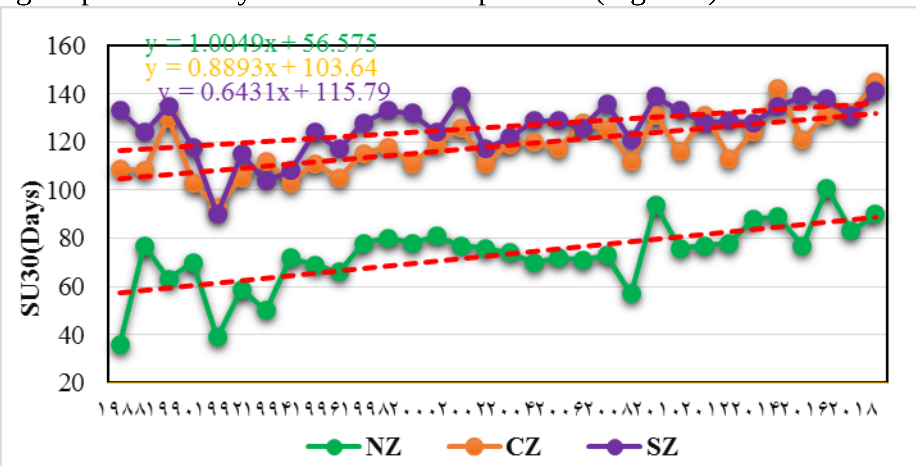

Figure (6): Liner trend slop, SU30 in Representative station in NZ, CZ and SZ

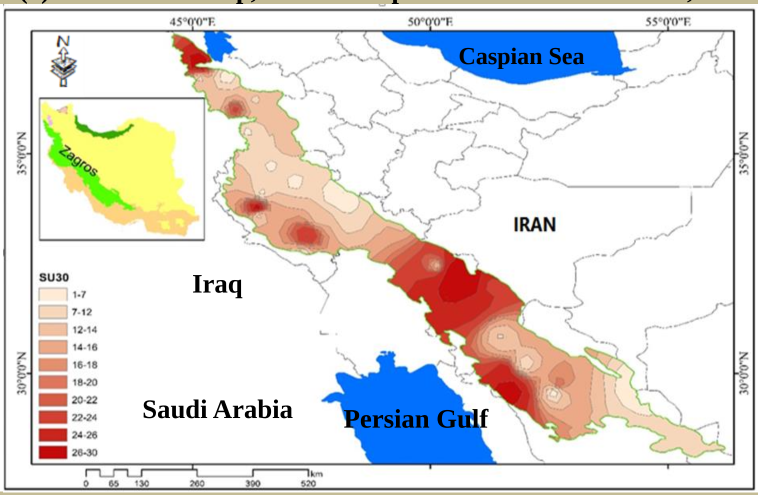

Figure (7): Trend of change, SU30, hot days' index in Zagros forest ecosystem in Iran

SU35, Very Hot Days: This index counts the number of days where the daily maximum temperature (TX) exceeds 35°C. Analysis of the very hot days' index revealed a significant increasing trend across the entire Zagros ecosystem. Notably, the slope of the trend line was highest in the Central Zagros, exceeding the rates observed in the Northern and Southern sectors (Figure 8). The zoning map for the very hot days' index showed that three primary hotspots coincide with those identified by the previous two indices (SU25 and SU30). The most significant hotspots based on the SU35 index are located in the northern Zagros, western Ilam province, and northwestern Fars province (Figure 9).

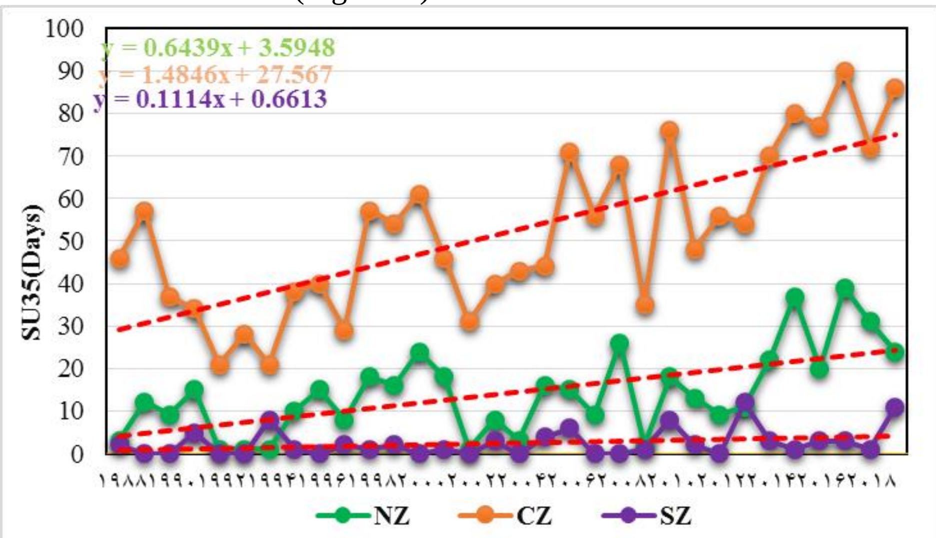

Figure (8): Liner trend slop, SU35 in Representative station in NZ, CZ and SZ

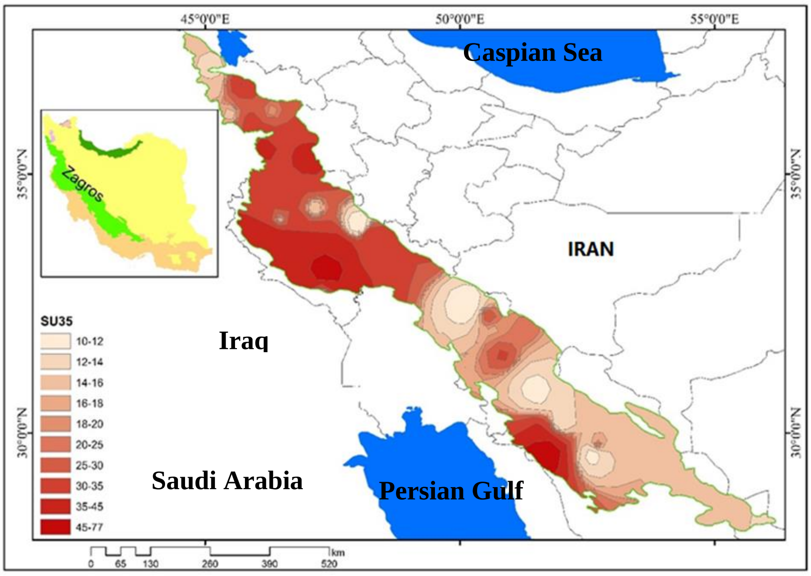

Figure (9): Trend of change, SU35, very hot day's index in Zagros forest ecosystem in Iran

TN90p, Warm Nights: This index measures the percentage of days where the daily minimum temperature (TN) exceeds the 90th percentile. Analysis of the trend in the warm night's index at three representative stations revealed distinct regional patterns. In both the northern and southern Zagros, the trend was increasing and significant. In contrast, the central Zagros exhibited a decreasing (negative) trend. This decline in the central region is potentially attributable to an increase in the frequency and intensity of dust events. Prior to approximately 2000, the index showed a positive, increasing trend. Following this period, as dust events became more prevalent and severe in this part of the Zagros, the index values decreased (Figure 10). The spatial zoning map for the warm nights index indicates that its hotspots generally coincide with those identified by other temperature indices. However, the hotspot in western Ilam province appears somewhat less pronounced in this index compared to others, likely moderated by the high frequency, intensity, and persistence of dust events. Despite this moderation, it remains a discernible hotspot (Figure 11).

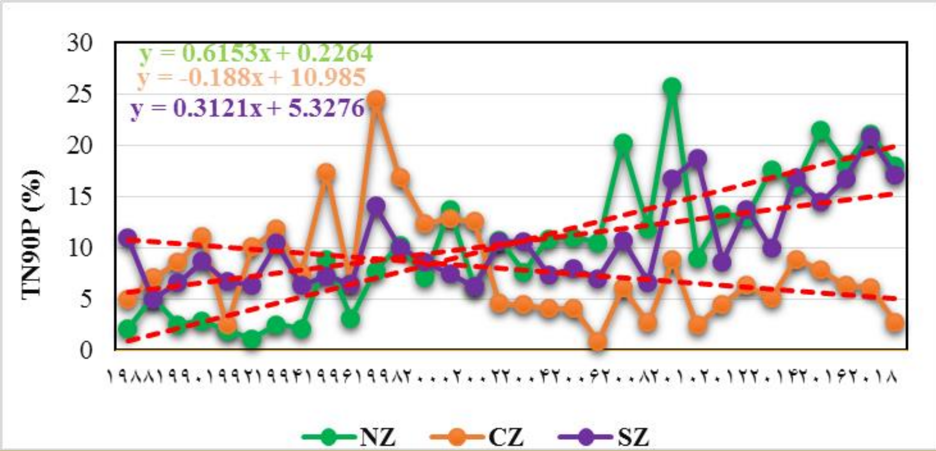

Figure (10): Liner trend slop, TN90p, warm nights in Representative station in NZ, CZ and SZ

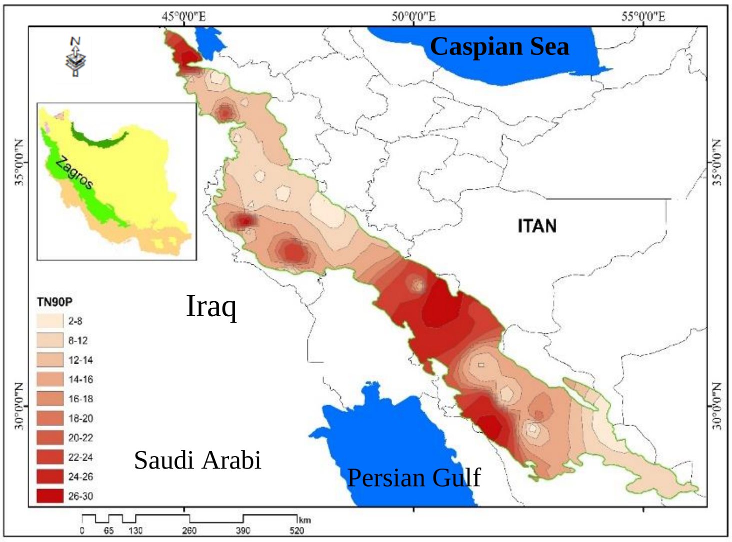

Figure (11): Trend of change, TN90p, warm night's index in Zagros forest ecosystem in Iran

TX90p, Warm Days: This index measures the percentage of days where the daily maximum temperature (TX) exceeds the 90th percentile. Analysis of this index across the Zagros ecosystem revealed a significant increasing trend (Figure 12). A notable finding is that the greatest increase in the percentage of warm days in the northern, central, and southern Zagros occurred in 2010. The spatial zoning map for this index, while identifying several other warm areas, confirms that the four principal hotspots established by previous indices are also distinctly evident here (Figure 13).

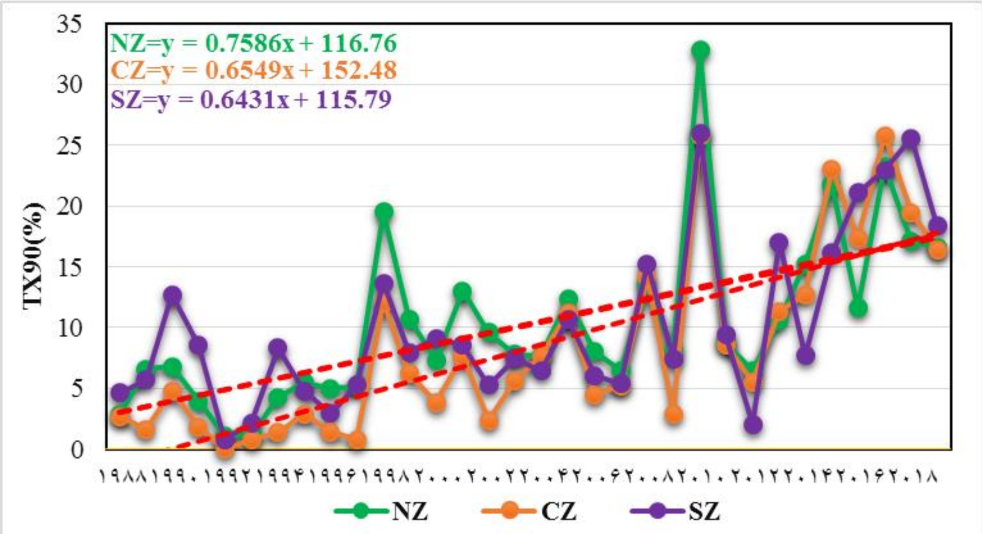

Figure 12. Liner trend slop, TN90p, warm nights in Representative station in NZ, CZ and SZ

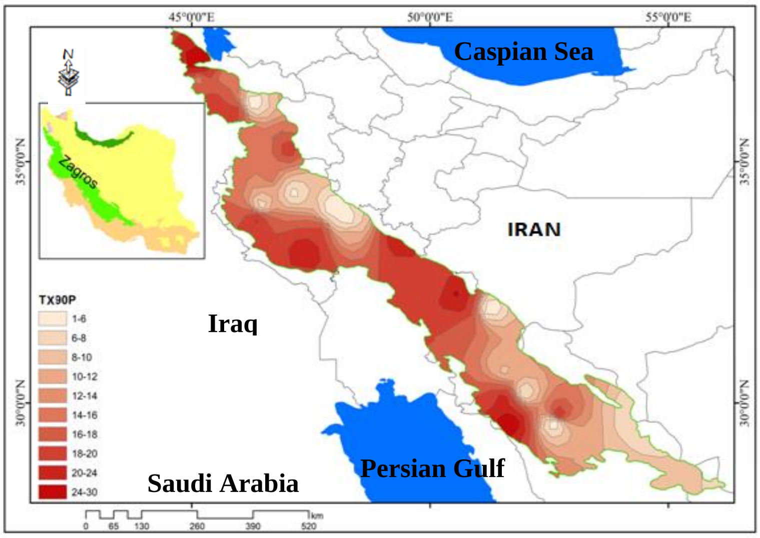

Figure (13): Trend of change, TX90p, warm days in Zagros forest ecosystem in Iran

TX50p, Above Average Days: This index counts the number of days where the daily maximum temperature (TX) exceeds the 50th percentile. Analysis of the above-average days' index showed a significant increasing trend across the entire Zagros ecosystem (Figure 14). The zoning map for this index revealed that the spatial distribution of hotspots aligns precisely with the patterns observed in other warm-temperature indices. The four primary hotspots identified are located in: The northern Zagros plateau, Western Ilam province, The central Zagros highlands within Chaharmahal and Bakhtiari and Kohgiluyeh and Boyer-Ahmad provinces, and Northwestern Fars province. These hotspots correspond directly to the four core areas consistently identified by the preceding temperature indices (Figure 15).

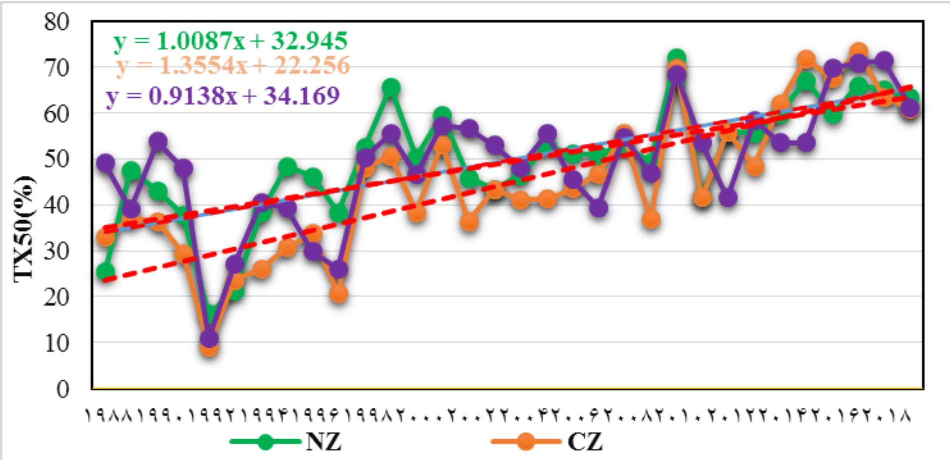

Figure (14): Liner trend slop, TN90p, warm nights in Representative station in NZ, CZ and SZ

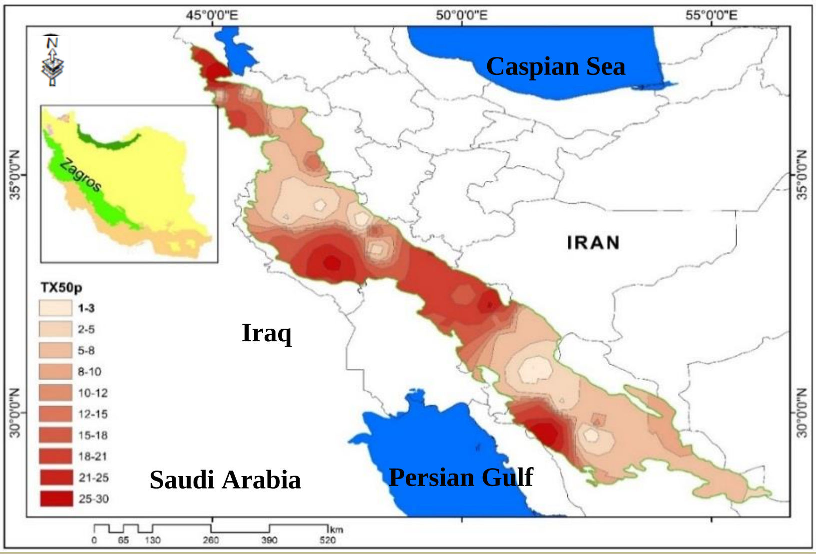

Figure (15): Trend of change, TX50p, above average days in Zagros forest ecosystem in Iran

Warm Spell Duration Index (WSDI): This index counts the annual number of days contributing to warm spells—periods of at least two consecutive days where the daily maximum temperature (TX) exceeds the 90th percentile. The study of the 2-day warm spell duration index (WSDI2) revealed a significant increasing trend across the entire Zagros ecosystem. The rate of change, indicated by the slope of this index, was greatest at the representative station for the Central Zagros, exceeding the rates observed in the Northern and Southern sectors. The highest frequency of these 2-day warm spells occurred in 2010 across the northern, central, and southern Zagros (Figure 16). The spatial distribution zoning map for this index confirms that, like the other indices, the four primary temperature hotspots align with those previously identified. The strongest increasing trend is observed at high latitudes in the North Zagros and in the highlands of the South Zagros within Chaharmahal and Bakhtiari and Kohgiluyeh and Boyer-Ahmad provinces. Other major hotspots are located in Ilam, Kurdistan, and Fars provinces (Figure 17).

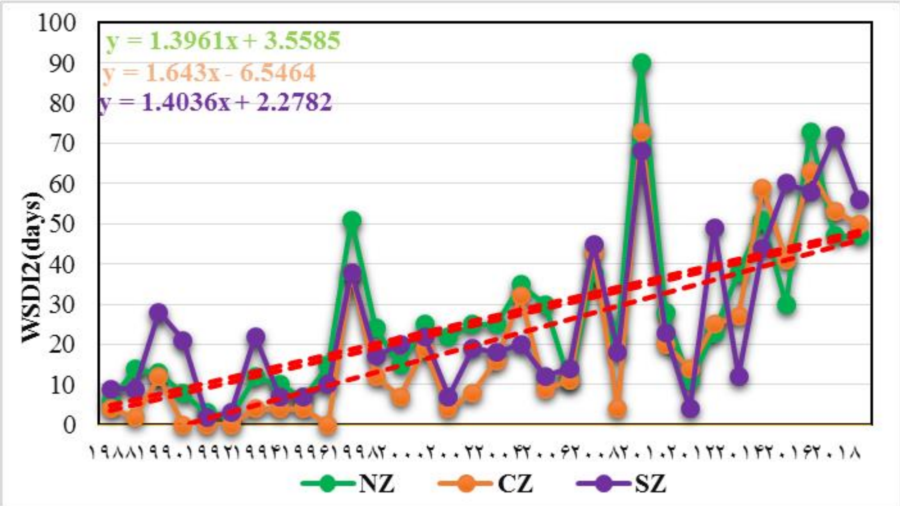

Figure (16): Liner trend slop, WSDI2, warm nights in Representative station in NZ, CZ and SZ

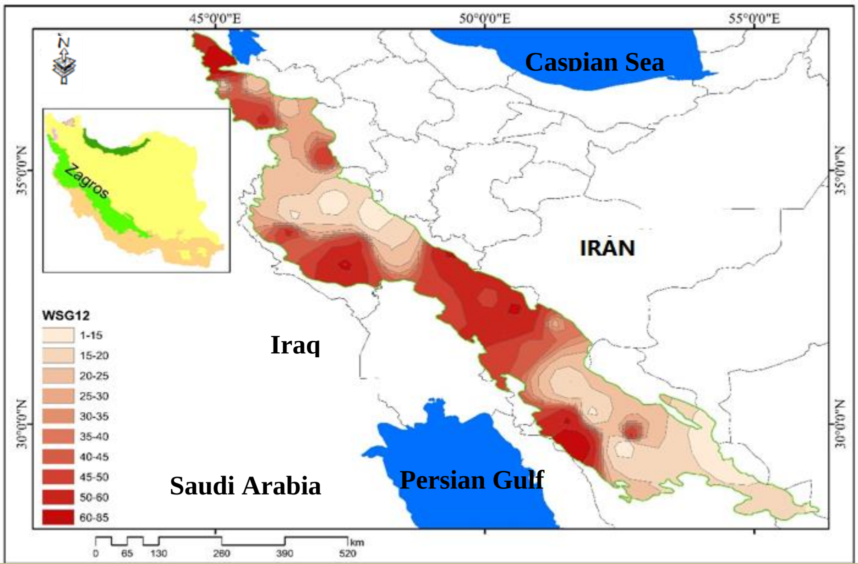

Figure (17): Trend of change, WSDI2, warm spell duration index in Zagros forest ecosystem in Iran

WSDI6, Warm Spell Duration Index (6-Day): This index counts the annual number of days contributing to extended warm spells—periods of at least six consecutive days where the daily maximum temperature (TX) exceeds the 90th percentile. Analysis of the 6-day warm spell duration index revealed a significant increasing trend across the entire Zagros ecosystem. The value of this index is highly variable, with the count of 6-day warm spell events being zero in some years, particularly in the earlier part of the record. The trend in the Southern Zagros is steeper than in the Central and Northern sectors. The year 2010 recorded the highest frequency of these events across the Northern, Central, and Southern Zagros. In the Southern Zagros, 2018 also registered a notably high frequency following 2010 (Figure 18). The zoning map for this index confirms that the identified hotspots correspond to those established by the other temperature indices (Figure 19).

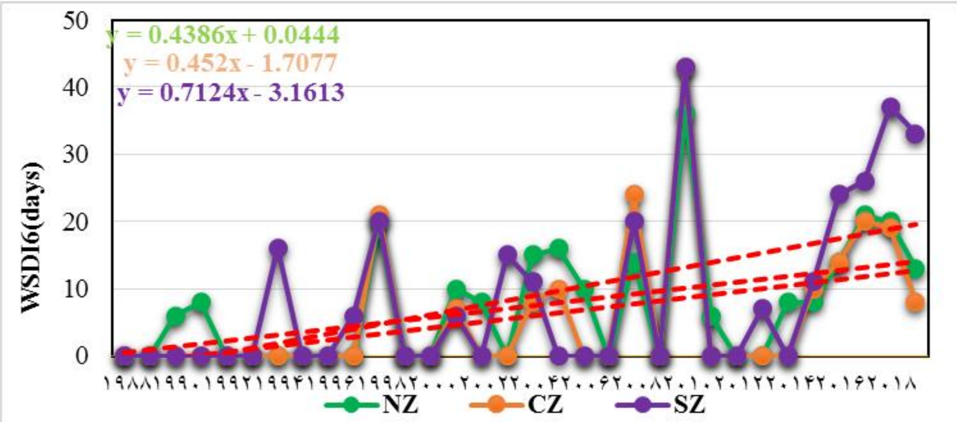

Figure (18): Liner trend slop, WSDI6, warm nights in Representative station in NZ, CZ and SZ

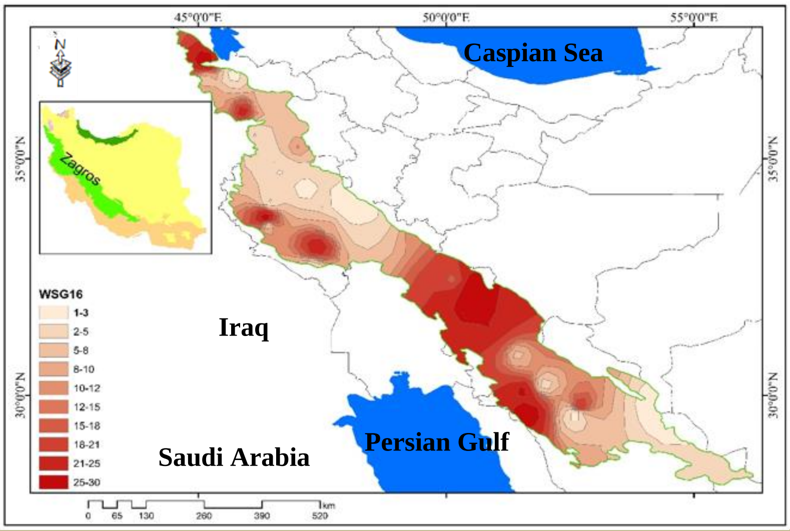

Figure (19): Trend of change, WSDI6, warm spell duration index in Zagros forest ecosystem in Iran

4. Discussion

Climate change stands as one of the most complex challenges confronting humanity. Successful adaptation is highly dependent on a system's adaptive capacity, and effective adaptation strategies can reduce vulnerability while contributing to sustainable development. The first step in this process is to detect the occurrence of climate change using standardized indicators. Rising temperatures, as a primary driver of climate change, lead to cascading consequences such as increased snowmelt, a shift in precipitation from snow to rain, temporal changes in precipitation patterns, greater rainfall intensity, heightened evapotranspiration, and reduced soil moisture. In the Zagros ecosystem, this results in drought and humidity stress, creates conditions favorable for pest and pathogen outbreaks, and has directly contributed to tree decline, particularly among oak species. Analysis of the trend slopes for temperature indices revealed significant increases across the ecosystem: The SU25 index showed a significant increase in summer days, with hotspot areas experiencing a rise of 40 to 85 days. The SU30 index (hot days) also increased significantly, rising by 26 to 30 days in hotspots. The SU35 index (very hot days) increased by 45 to 77 days in hotspots. The percentile-based indices (TN90p, TX90p, TX50p) all exhibited significant increasing trends, with their frequency of occurrence rising by 26–30%, 24–30%, and 25–30%, respectively, in hotspot areas. While rising temperatures alone can damage forest ecosystems, the compounding effect of persistent heat is particularly critical. The increasing frequency of warm spells, as measured by the WSDI2 and WSDI6 indices—which rose by 60–85 days and 25–30 days in hotspots, respectively—intensifies drought stress and accelerates forest decay. Examination of all warm-temperature indices confirmed a significant increasing trend throughout the Zagros. The results consistently identified four primary temperature hotspots: Chaharmahal and Bakhtiari, Kohgiluyeh and Boyer-Ahmad, and northwestern/western Fars province in the southern Zagros, Southwestern Ilam province in the central Zagros, Sardasht and Piranshahr regions in the northern Zagros. These hotspots, which cover a considerable area especially in the southern Zagros, align with zones previously identified as having high to very high fire potential (Jafari & Mafi Gholami, 2017). Climate change is thus a pivotal factor in forest degradation; increased temperatures and decreased humidity facilitate pest and disease proliferation. Conversely, forest destruction can exacerbate climate change, amplifying its impacts on global systems and human livelihoods, including water resources and food security. These findings, which demonstrate climate change across the forest ecosystem using globally standardized detection indices, align with numerous studies attributing Zagros degradation to climate change, particularly warming trends (Sallé et al., 2014; Tulik & Bijak, 2016; Rodríguez-Calcerrada et al., 2017; Reed et al., 2018; Ahmadi et al., 2019; Gea-Izquierdo et al., 2021; Dargahian & Pourhashemi, 2021; Dargahian & Razavizadeh, 2022). The formation of these hotspots is a direct consequence of climate change and correlates with elevated fire risk. Research on the northern Zagros has shown a significant positive correlation at the 95% confidence level between annual mean temperature and both the number of fires and area burned in Sardasht forests (Beygi Heidarlou & Karamat Mirshekarlou, 2024). Furthermore, studies on post-fire germination dynamics of Iranian oak suggest that to support oak regeneration and ecosystem resilience, managers should implement selective thinning to reduce competition and prevent short-interval repeat fires (Kyani Asl et al., 2025).

Conclusion

In recent years, the decline of Zagros oak forests has emerged as one of Iran's most pressing environmental challenges. While multiple factors contribute to this decline, climate change is widely regarded as the primary driver due to its role in amplifying and facilitating other stressors (Dargahian et al., 2024). Research indicates that rising temperatures and increased aridity in the central Zagros have significantly reduced biomass and soil carbon sequestration (Matinfar et al., 2025). Moreover, decreased precipitation and higher temperatures are depleting soil organic carbon across all elevational zones—particularly at higher altitudes—transforming soils from carbon sinks into carbon sources (Misaghi et al., 2024). Climate change also threatens forest biodiversity by altering species distribution and undermining ecological stability (Khajei et al., 2025). Regional studies further underscore this trend. In Ilam Province, reduced rainfall and prolonged dry spells are key accelerators of oak forest decline (Mirzaei et al., 2025). Simultaneously, Zagros forests face compounded pressures from both climate change and intensified dust storms, resulting in progressive canopy drying, weakened regeneration, and overall forest degradation (Pato et al., 2025). Similarly, in northeastern Khuzestan, a significant reduction in forest cover between 2007 and 2020 correlates strongly with rising air and surface temperatures and recurrent droughts (Molayee et al., 2025). The degradation of Zagros forests, in turn, exacerbates climate change impacts across Iran, leading to: Quantitative and qualitative declines in freshwater resources, The spread of desertification and wind erosion, Increased dust storms, Shifts in plant communities and loss of valuable climax species, Adverse economic and social consequences, including rural migration, Threats to food and health security, Biodiversity loss, Weakening of the Zagros forests' role as a protective natural barrier in western Iran. Spanning 11 provinces and covering approximately six million hectares—accounting for 40% of Iran's forests—the Zagros ecosystem is inherently challenging to manage due to its vast extent and the complexity of interacting stressors. Identifying areas most vulnerable to climate change is therefore crucial. It enables forest managers to prioritize interventions, reduce ecological damage, and enhance adaptability to current and future climatic shifts. Nevertheless, further research remains essential to fully understand and effectively mitigate oak forest decline.

Reference

1. Ahmadi, E., Kowsari, M., Azadfar, D., & Salehi Jouzani, G. (2019). Bacillus pumilus and Stenotrophomonas maltophilia as two potentially causative agents involved in Persian oak decline in Zagros forests (Iran). *Forest Pathology*, *49*(5), e12541
2. Attarod, P, Sadeghi, S. M. Taheri Sartshanizi, F., Saroei, S, Abbasian, P., Masihpoor, M., Kordrostami, F., Dirikvandi, A. (2016). The effect of climatic factors and evapotranspiration on the decline of Central Zagros forests in Lorestan province. Research on protection and conservation of forests and rangelands of Iran, 13 (2), 97-112.
3. Azizi, G., Miri, M., Mohammadi, H., Pourhashemi, M. 2015. Analysis of relationship between forest decline and precipitation changes in Ilam Province. Journal of Forest and Poplar Research, 23(3): 502-515.
4. Beygi Heidarlou, H., & Karamat Mirshekarlou, A. (2024). Understanding the effects of climate change on wildfires in the Iranian Northern Zagros Forests. *Forest Research and Development*, *10*(3), 379-393. doi: 10.30466/jfrd.2024.55283.1720.
5. Bedrood, F., Gh., H., Valipour, A. (2021). Application of the Logical Framework Analysis for planning and evaluation of oak decline’s forest management plan. Iranian Journal of Forest and Poplar Research, 29(1), 53-64.
6. Clatterbuck, W.K. and Kauffman, B.W., 2006. Managing oak decline. Professional hardwood notes,
7. University of Kentucky’s Cooperative Extension Publication FOR-099, University of Tennessee,
8. Knoxville, Tennessee, 6p.
9. Colangelo, M., Camarero, J. J., Borghetti, M., Gentilesca, T., Oliva, J., Redondo, M. A., & Ripullone, F. (2018). Drought and Phytophthora are associated with the decline of oak species in southern Italy. Frontiers in plant science, 9, 1595.
10. Dargahian, F., & Razavizadeh, S. (2022). Detection of heat waves in Zagros decay monitoring sites Chaharmahal and Bakhtiari province. *Iranian Journal of Forest and Range Protection Research*, *20*(1), 1-14.
11. Dargahian F, Pourhashemi M. Detection of Climate Change Based on Warm Temperature Indices in Zagros Forest Ecosystem; Chaharmahal and Bakhtiari Province. ijae 2021; 10 (3) :81-99.
12. Dargahian, F., Pourhashemi, M. and Lotfinasabasl, S. (2025). Investigating the occurrence of drought in the forest ecosystem of Zagros due to its coincidence with the decline of oak forests. *Iranian Journal of Forest and Range Protection Research*, *22*(2), 285-308. doi: 10.22092/ijfrpr.2024.366110.1631
13. Dargahian, F., Ghasemi Aryan, Y. and Heydarnejad, S. (2024). Revealing the change of the frost indices as a consequence of climate change, a case study of Northern Zagros forests (Azerbaijan). *Iranian Journal of Forest and Range Protection Research*, *22*(1), 30-46. doi: 10.22092/ijfrpr.2024.363591.1601
14. Di Filippo, A., Alessandrini, A., Biondi, F., Blasi, S., Portoghesi, L., & Piovesan, G. (2010). Climate change and oak growth decline: Dendroecology and stand productivity of a Turkey oak (Quercus cerris L.) old stored coppice in Central Italy. Annals of Forest Science, 67(7), 706-706.
15. Gea-Izquierdo, G., Natalini, F., & Cardillo, E. (2021). Holm oak death is accelerated but not sudden and expresses drought legacies. Science of the Total Environment, 754, 141793.
16. Ghadirian, O., Hemami, M., Soffianian, A., Pourmanaphi, S., Malekian, M., Tarkesh, M. (2018). Probabilistic prediction of forest decline in Lorestan province using a

combined modeling approach. Iranian Journal of Forest and Range Protection Research, 15(2), 131-146.

17. Goodarzi, M., Pourhashemi, M., & Azizi, Z. (2019). Investigation on Zagros forests cover changes under the recent droughts using satellite imagery. Journal of Forest Science, 65(1), 9-17.
18. Haidarian Aghakhani, M., Tamartash, R., Jafarian, Z., Tarkesh Esfahani, M., & Tatian, M. (2017). Predicting the impacts of climate change on Persian oak (Quercus brantii) using Species Distribution Modelling in Central Zagros for conservation planning. Journal of Environmental Studies, 43(3), 497-511.
19. Jafari M, Hosseini, A, hoseinzadeh J. Spatial Distribution Map of Degradation in Zagros Forests of Ilam city. ifej. 2020; 8 (15):1-9.
20. Jafari, A., & Mafi Gholami, D. (2017). Wildfire hazard mapping using an ensemble method of frequency ratio with Shannon's entropy. *Iranian Journal of Forest and Poplar Research*, *25*(2), 232-243. doi: 10.22092/ijfpr.2017.111758
21. Hamzehpour, M., Kia-daliri, H., Bordbar, K. (2011). Preliminary study of manna oak (Quercus brantii Lindl.) tree decline in Dashte-Barm of Kazeroon, Fars province. Iranian Journal of Forest and Poplar Research, 19(2), 363-352. doi: 10.22092/ijfpr.2011.107578
22. Hernández-Lambraño, R. E., de la Cruz, D. R., & Sánchez-Agudo, J. Á. (2019). Spatial oak decline models to inform conservation planning in the Central-Western Iberian Peninsula. Forest Ecology and Management, 441, 115-126.
23. Hosseinzadeh, J., Pourhashemi, M. (2017). Emergence of desiccation within Zagros forests decline. Nature of Iran, 2 (4), 18-21.
24. Karamian M., mirzaei J. 2020. The Most Important Factors Affecting Persian Oak (Quercus brantii) Decline in Ilam Province. Ecology of Iranian Forest, 2020; 8 (15):93-103.
25. Keča, N., Koufakis, I., Dietershagen, J., Nowakowska, J. A., & Oszako, T. (2016). European oak decline phenomenon in relationto climatic changes.
26. Khajei, N., Etemad, V. and Bazrafshan, J. (2025). Predicting climate change impacts on distribution of Brant's oak trees (Quercus brantii Lindl.) in the Zagros forests, Fars Province. *Iranian Journal of Forest*, *15*(4), 393-409. doi: 10.22034/ijf.2023.344228.1876.
27. Kyani Asl M, Soltani A, Mafi-Gholami D. Post-Fire Sprouting Dynamics of Quercus brantii Lindl.: Assessing Stem Size Influence and Adaptive Responses to Recurrent Fires. *ECOPERSIA* 2025; 13 (3) :231-241
28. Kim, H. N., Jin, H. Y., Kwak, M. J., Khaine, I., You, H. N., Lee, T. Y., ... & Woo, S. Y. (2017). Why does Quercus suber species decline in Mediterranean areas? Journal of Asia-Pacific Biodiversity, 10(3), 337-341.
29. Kooh Soltani, S., Alesheikh, A., Ghermezcheshmeh, B., Mehri, S. (2018). An evaluation of potential Oak decline Forest of the Zagros using GIS, RS, FAHP methods. Iranian journal of Eco hydrology, 5(2), 713-725.
30. Lisa Alexander, C., 2015. WMO CCl Expert Team on Sector-specific Climate Indices (ET SCI) Workshop, Nadi, Fiji 7th – 11th.
31. Maroofzadeh, E., Attarod, P. (2021). Are changes in forest cover in the North Zagros vegetation area in line with the trend of climatic parameters? Iranian Forest Journal, 12 (4), 449-466.
32. Matinfar, H.R., Shamsipour, A. and Sadeghi, H. (2025). Investigating the consequences of climate change on the organic carbon content of soils in the forest areas of Middle Zagros. *Climate Change Research*, *6*(22), 97-114. doi: 10.30488/ccr.2024.475201.1243.
33. Misaghi, M., Golchin, A. and Askari, M. S. (2024). Simulating Changes in Organic Carbon of Forest Soils Due to Climate Change at Different Altitudes Using the Roth C Model. *Journal of Geography and Environmental Hazards*, *13*(3), 150-183. doi: 10.22067/geoeh.2024.85968.1445.
34. Mirzaei, S., Attarod, P. and Mostafanezhad Nesheli, K. (2025). The effect of long-term trends of precipitation and consecutive dry days on Zagros forests decline in Ilam Province. *Forest and Wood Products*, *78*(1), 1-10. doi: 10.22059/jfwp.2025.392721.1344.
35. Moreno-Fernández, D., Ledo, A., Martín-Benito, D., Cañellas, I., & Gea-Izquierdo, G. (2019). Negative synergistic effects of land-use legacies and climate drive widespread oak decline in evergreen Mediterranean open woodlands. Forest Ecology and Management, 432, 884-894.
36. Mozafari, F., Karamshahi, A., & Heydari, M. (2019). Mapping Dieback Intensity Distribution in Zagros Oak Forests Using

Geo-statistics and Artificial Neural Network. Iranian Journal of Applied Ecology, 8(3), 31-44.

37. Molayee, M. , Rahimi, D. and Zakerinejad, R. (2025). Reanalysis of Climate Change Impact on Zagros Oak Forest Cover (Khuzestan Province). *Journal of Geography and Regional Development, 23*(1), -. doi: 10.22067/jgrd.2025.93010.1548.
38. Naghipour, A. A., Haidarian, M., & Sangoony, H. (2019). Predicting the impact of climate change on the distribution of Pistacia atlantica in the Central Zagros. Journal of Plant Ecosystem onservation, 6(13), 197-214.
39. Naseri, M., ShataeeJooibari, S., Mohammadi, J., & Ahmadi, S. (2020). Investigation on the Amount of Mortality of Iranian Oak Trees (Quercus brantii Lindi) using Satellite Imagery (Case study: Dashtebarm forests of Fars Province). Ecology of Iranian Forest, 8(16), 72-80.
40. Pourhashemi, M., Jahanbazi Goujani, H., Hoseinzadeh, J., Bordbar, S.K., Iranmanesh, Y., Khodakarami, Y. 2017. The history of oak decline in Zagros forests. Nature of Iran, 2 (1), 37-30.
41. Ogaya, R., Liu, D., Barbeta, A., & Peñuelas, J. (2020). Stem mortality and forest dieback in a 20-years experimental drought in a Mediterranean holm oak forest. Frontiers in Forests and Global Change, 2, 89.
42. Pato, M., moradi, S. and henareh, J. (2025). Investigating the effects of climate change and dust storms on the health and sustainability of the Zagros forest ecosystem. *Journal of Drought and Climate change Research*, (), -. doi: 10.22077/jdcr.2025.9043.1126.
43. Reed, K., Denman, S., Leather, S. R., Forster, J., & Inward, D. J. (2018). The lifecycle of Agrilus biguttatus: The role of temperature in its development and distribution, and implications for Acute Oak Decline. *Agricultural and forest entomology*, *20*(3), 334-346.
44. Romagnoli, M., Moroni, S., Recanatesi, F., Salvati, R., & Mugnozza, G. S. (2018). Climate factors and oak decline based on tree-ring analysis. A case study of peri-urban forest in the Mediterranean area. Urban Forestry & Urban Greening, 34, 17-28.
45. Rostam Zadeh, H., Darabi, S., Shahabi, H. (2017). Change detection of Oak forests using object-based classification of multitemporal Landsat imageries (Case study: forests of the northern province of Ilam). Journal of RS and GIS for Natural Resources, 8(2), 92-110.
46. Rodríguez-Calcerrada, J., Sancho-Knapik, D., Martin-StPaul, N. K., Limousin, J. M., McDowell, N. G., & Gil-Pelegrín, E. (2017). Drought-induced oak decline—factors involved, physiological dysfunctions, and potential attenuation by forestry practices. In *Oaks physiological ecology. Exploring the functional diversity of genus Quercus L.* (pp. 419-451). Springer, Cham
47. Safari, A., & Sohrabi, H. (2019). Effect of climate change and local management on aboveground carbon dynamics (1987–2015) in Zagros oak forests using Landsat time-series imagery. Applied Geography, 110, 102048.
48. Saleh, I., Rafiee, H., Mirbagheri, S. (2021). Investigating the effects of climatic and economic variables on forest degradation of Iran. Iranian Journal of Forest, 12(4), 467-489.
49. Sallé, A., Nageleisen, L. M., & Lieutier, F. (2014). Bark and wood boring insects involved in oak declines in Europe: current knowledge and future prospects in a context of climate change. *Forest Ecology and Management*, *328*, 79-93.
50. Shiravand, H., Khaledi, Sh., Behzadi, S. 2019. Evaluation and Prediction of Decline of Oak Forests in Middle Zagros (Lorestan Section) with a Climate Change Approach. Journal of Forest and Range Protection Research, 33(1): 64.81.
51. Shiravand H, Khaledi S, Behzadi S, sanjabi H A. 2020. Monitoring and Assessing the Changes in the Coverage and Decline of Oak Forests in Lorestan Province using Satellite Images and BFAST Model. Researches in Geographical Sciences. 20 (57):265-280.
52. Shehabi, H., & Akbari, E. (2020). Investigation and prediction on Forests Covers Changes Using Fuzzy Object-Based Satellite Image Classification and CA-Markov (case study: City of Romeshkan). Journal of Environmental Research and Technology, 6(6), 103.
53. Soosani, J., radmeh, A., Ghalebahmani, S., balapour, S., Sepahvand, A. (2014). Effects of climate variables (temperature and precipitation) on the width of Rings-growth in Persian coppice oak in the central Zagros (Case study: Khoramabad). Journal of Wood and Forest Science and Technology, 21(2), 43-60.

54. Tulik, M., & Bijak, S. (2016). Are climatic factors responsible for the process of oak decline in Poland?. *Dendrochronologia*, *38*, 18-25.
55. Valavi, R., Shafizadeh-Moghadam, H., Matkan, A., Shakiba, A., Mirbagheri, B., & Kia, S. H. (2019). Modelling climate change effects on Zagros forests in Iran using individual and ensemble forecasting approaches. Theoretical and Applied Climatology, 137(1), 1015-1025.
56. Zarafshar, M., Neghdar S., Jahanbazi Gojani, H., Pourhashemi, M., Abbasi. (2020). Drying of pure masses of Persian oak (Quercus brantii Lindl.) In the forests of South Zagros, Koohmoreh sorkhi region of Fars province. Iranian Forest Journal, 12 (2), 291-303.