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# Detection of climate warming signals in Zagros forests using cold temperature indices

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## Abstract

One of the new challenges of the last two decades is the decline of the Zagros oak forests. Numerous natural and human factors have influenced the occurrence of this phenomenon. The natural factors of climate change are decisive, which have led directly and through the superimposition of other factors to the drying out of the Zagros trees, especially the oaks. The driving forces of climate change are rising temperatures. One of the manifestations of rising temperatures is the decline in cold temperature indices. In this study, daily statistics of climate parameters in synoptic stations of the Zagros vegetation area during a complete climatic period were used to detect climate change in the Zagros oak forest ecosystem. There are 58 synoptic stations in this ecosystem. Since 30 years (1990-2019) is a climatic period, 34 stations had the appropriate statistical period length. The Expert Team on Climate Risks and Sectoral Climate Indices (ET CRSCI) method was used to identify the occurrence of climate change in the Zagros ecosystem as one of the causes of oak decline. Cold temperature indices: FD0, ID0, CSDI2, CSDI6, TN10p, and TX10p were selected from the baseline indices. The trend of changes in these indicators was extracted and zoned for the entire Zagros habitat. The results showed that the spatial distribution of cold temperature indices follows three factors: the latitude, the topographic height of the region, and the path of atmospheric currents to Zagros. All cold temperature indices showed a decreasing trend, indicating an increase in temperature and climate change in the entire ecosystem of the Zagros. Due to the temperature rise, the two indicators FD0 and CSDI6 have disappeared in the Zagros ecosystem in the last decade. This can lead to disruption of the hibernation cycle of plants and trees, changes in erosion and moisture storage, damage to soil microorganisms, and provide more suitable living conditions for pests and pathogenic fungi.

**Keywords:** Climate change; Indicators cold, Forest ecosystem, Decline of oak; FD0; CSDI6.
**Article Type:** Research Article

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## 1. Introduction

Zagros forests with an area of six hectares constitute 40% of Iran's forests. Since deforestation due to climate change is a global phenomenon that affects many species of trees (Colangelo et al., 2018), Zagros oak forests are no exception, and in the last two decades, for various reasons, including climate change, they have declined and dried up. In some studies, the area of Zagros oak forests has been reduced (Rostam Zadeh et al., 2017; Fallah & Haydari, 2018; Naseri et al., 2020; Shiravand et al., 2020). Effects of Some Environmental Factors on Drying Severity of Trees in Middle Zagros forests of Iran showed that about 50% of the total trees were dry (Golmohammadi et al., 2017).

Coronal drought is the first phenomenon that appears as a result of the tree's response to environmental stresses and is the most important indicator for assessing the health of trees and awareness of their drought status (Darabi et al., 2017). A study of the decline effect on the structure of central Zagros forests showed that the canopy area size index was calculated at 0.71 and 0.50, respectively, before and after the decline (Modaberi & Mirzaei, 2017). Determining the extent and severity of oak decay in the forests of Malekshahi city (part of Zagros) using Landsat images showed that 16% of forest areas are in a healthy condition, 58% suffer from moderate drought, and 26% suffer from severe drought (Imanyfar et al., 2017). Numerous biological and non-biological factors have contributed to the decline of Zagros oak forests, the most important of which is the effect of climate change (Kooh Soltani et al., 2018). Studies have emphasized the important feature of the phenomenon of decline, multidimensionality, and complexity (Pourhashemi & Sadeghi, 2020). So far, many studies have been conducted on the factors affecting the decline of oak forests in the Zagros. Investigate the relationship between Climate change and oak growth decline in Central Italy, showing that at both annual and decadal timescales, oak growth decline was associated with a delayed response to climate (Di Filippo et al., 2010). Preliminary study of drying of Persian oak trees (Q. brantii Lindl.) in Boram plain of Kazerun, Fars province showed that the decrease in rainfall had the greatest effect (Hamzehpour etal., 2011) Preparation of zoning map of oak decay risk in Ilam province showed that average rainfall, temperature, evaporation, humidity and annual dust play a major role in reducing Iranian oak in the region (Ahmadi et al., 2014). The effect of climatic variables of temperature and rainfall on the width of vegetative rings of Iranian oak trees in the Middle Zagros region showed that, due to the hot and dry region, rainfall and temperature had a positive and negative effect on the radial growth of trees, respectively (Sousani et al., 2014). The study of the cause of the decline of oak trees in the Mediterranean region showed that the main cause was various biological and abiotic factors, including climate change (Kim et al., 2017). Examination of the time trend of greenery of trees in the region showed that during 2008 and 2005, the amount of greenery of trees has significantly decreased. These conditions indicate a direct relationship between climatic parameters of rainfall and greenery of trees in the region (Nassaji-Zavareh et al, 2017). Rapid loss of soil moisture and intensification of the effect of water stress have been a factor in the decline of Iranian oak (Hosseinzade and Pourhashemi, 2017; Mozafari et al, 2019). The study of drought status of Iranian oak trees in Kohmareh area of Fars province showed that the moisture factor in the root rizosphere has an important and key role in the prevalence of oak tree drought (Zarafshar etal, 2020). The trend of changes in climatic parameters and reference evapotranspiration with the decline of forest ecosystems has been confirmed (Attarod et al., 2016; Dolatshahi et al., 2017). Drought and climate change have been the most important factors in the drought of Zagros oak forests (Karamian & Mirzaei, 2020; Sabernasab et al, 2020; Asgari et al., 2021; Bedrood et al., 2021). Determining effective parameters for modeling oak decay showed that the use of temperature and precipitation parameters better models drought stress (Alesheikh & Mehri, S, 2019).

Climate warming increases the severity and duration of drought and heat waves. Thus, climate change can increase deforestation in many ecosystems of the world, especially in semi-arid forests (Ogaya et al., 2020). Thus, climate change is affecting forests and may impair their ability to provide essential ecosystem services in the coming decades (Sousa-Silva et al., 2018). Climate change is believed to cause the extinction of many species in the near future (Valavi et al., 2019). Mapping areas prone to oak decay in the Ilam province, the results showed that more than 77% of oak forests in the province are very prone to decay (Motlagh et al., 2021). Assessment and forecasting of drought in Zagros oak forests with a climate change approach showed that in the coming period, most drought indices in the region will experience an increasing trend (Shiravand et al., 2019). Predicting the effect of climate change on the geographical distribution of different species in the Zagros habitat showed that their extent will decrease in the future (Haidarian Aghakhani et al., 2017; Naghipour et al., 2019; Teimoori Asl et al., 2020; Safaei et al., 2022).

The occurrence of climate change has not been the same in different parts. In this study, the aim is to detect the occurrence of climate change throughout the Zagros ecosystem using cold temperature indicators to detect climate change. Identifying areas of the Zagros forest ecosystem where climate change has occurred more severely helps managers and decision makers of the Zagros forest ecosystem in climate change adaptation planning.

Among climatic factors, temperature changes have the greatest impact on the decline of oak forests. So that the increase in temperature in the Zagros ecosystem has led to an increase in the height of the snow line (Ghadimi et al., 2019), and a decrease in snow cover in the Zagros (Mohammadi et al., 2019) has led to drying of karst springs (Masoompour Samakoush et al., 2017). Awareness and knowledge of forest ecosystem managers and planners about climate change help them to adapt to climate change and preserve and rehabilitate forests. This study employed cold temperature indicators to assess and detect the occurrence of climate change throughout the Zagros forest ecosystem.

## 2. Materials and Methods

### *2*.1. Study Area:

The Zagros forests in western Iran are about 1265 km long and about 200 km wide in the widest places. The oak forests of the Zagros region start from the northwestern tip of Iran (West Azerbaijan province) and then run west (Ilam and Lorestan provinces) and southwestern Iran (Kohgiluyeh, Boyer-Ahmad provinces of Khuzestan and Fars). The area of these forests is about 6 million hectares, which are scattered in an area of nearly 30 million hectares. The Zagros forests, which are spread in 11 provinces in Iran. The average rainfall in this forest ecosystem is between 300 and 800 mm (Dargahian et al., 2025) (Figure 1). The trees of this forest ecosystem, especially the oak, have been decayed for various reasons and most importantly, the occurrence of climate change, but the phenomenon of decay throughout this ecosystem has different intensities and weaknesses due to the factor affecting this phenomenon (Figure 2).

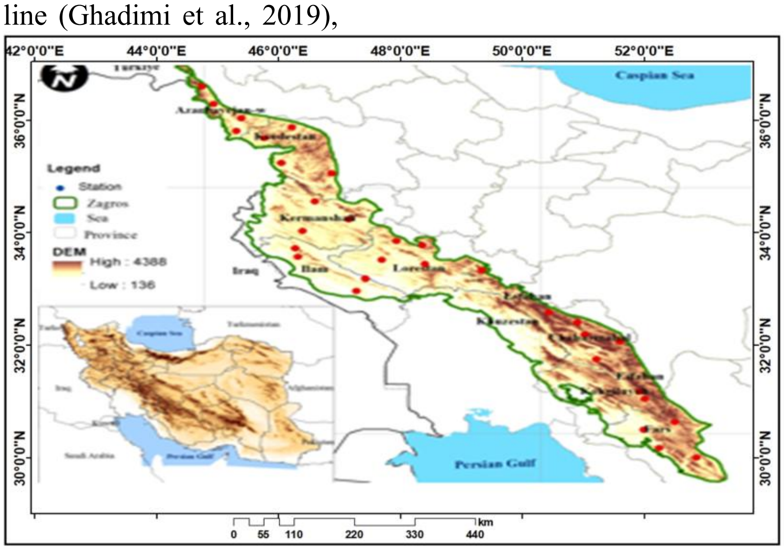


**Figure 1. Location of Zagros forest ecosystem in Iran**

**Figure 2. Decline of oak trees in the Zagros forest ecosystem, 2022**

## 2.2. Methodology

Iran has an area of 164 million hectares, 14 million and 300 thousand hectares of forest land. The Zagros forests, with 6 million hectares, have the highest forest area. 40% of the water produced in the country is due to the forests of the Zagros. During the last two decades, the trees of this forest ecosystem have declined for various reasons, including climate change. The Expert Team on Climate Risk and Sector-Specific Climate Indices (ET CRSCI) method was used to detect the occurrence of climate change in the Zagros ecosystem as one of the causes of oak tree decline.

First, the location of the Zagros forest ecosystem was determined, and synoptic stations were identified in its area. Despite high-resolution network data, observational data were used due to high accuracy. There are 58 synoptic stations within this ecosystem. Since 30 years is a climatic period, 34 stations had the appropriate statistical period length. Data was extracted for the period 1990 to 2019. The climatic parameters required to implement the climate change detection model were selected. Data included daily precipitation, daily maximum temperature, and daily minimum temperature (Lisa Alexander, 2015). Before calculating the indices, the daily input data were checked for quality and homogeneity because homogeneity means the compatibility of a series over time and is an obvious need for strong analysis of climate time series.

In order to calculate the indicators of climate change detection, the ClimPACT software written in the R environment was used. The ***ClimPACT*** software is based on the RClimDEX software developed by the World Meteorological Organization (WMO) Commission for Climatology (CCl) Open Panel of CCl Experts on Climate Information for Adaptation and Risk Management (Expert Team on Climate Change Detection and Indices (ETCCDI). Data were entered into the software, and the indices were calculated and extracted. Cold temperature indices were selected from the output indices **(Table 1).**

## 2.3. Cold Temperature indices:

**2.3.1. FD0, frost days 0:** count of days where TN (daily minimum temperature) < 0°C

Let $TN_{ij}$ be the daily minimum temperature on day *i* in period *j*. Count the number of days where $TN_{ij}$ <0°C.

**2.3.2. ID0, ice days:** count of days where TX < 0°C

Let $TX_{ij}$ be the daily maximum temperature on day *i* in period *j*. Count the number of days where $TX_{ij}$ <0°C.

**2.3.3. CSDIn*, user-defined cold spell duration index:** count of days in a span of at least *n* days where TN < $10^{th}$ percentile.

Let $TN_{ij}$ be the daily minimum temperature on day *i* in period *j,* and let $TN_{ib}10$ be the calendar day $10^{th}$ percentile of daily minimum temperature calculated for a five-day window centered 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, $TN_{ij}$ < $TN_{ib}10$ where $n$<= 10.

**2.3.4. CSDI*, cold spell duration index:** count of days in a span of at least six days where TN < 10th percentile.
Let TN*ij* be the daily minimum temperature on day *i* in period *j,* and let TN*ib*10 be the calendar day 10th percentile of daily minimum temperature calculated for a five-day window centered 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, TN*ij* < TN*ib*10.

**2.3.5. TN10p, cold nights:** count of days where TN < 10th percentile
Let TN*ij* be the daily minimum temperature on day *i* in period *j,* and let TN*in*10 be the calendar day 10th percentile of daily minimum temperature calculated for a five-day window centered on each calendar day in the base period *n* (e.g., 1971-2000). Count the number of days where TN*ij* < TN*in*10.

**2.3.6. TX10p, cold days:** count of days where TX < 10th percentile
Let TX*ij* be the daily maximum temperature on day *i* in period *j,* and let TX*in*10 be the calendar day 10th percentile of daily maximum temperature calculated for a five-day window centered on each calendar day in the base period *n*. Count the number of days where TX*ij* < TX*in*10.
These steps were performed for all synoptic stations in the whole area, and finally, the selected indicators were zoned for the whole Zagros habitat. In this way, the areas in which the occurrence of climate change was more severe were identified and introduced to the decision makers of the programs to decrease and adapt to climate change.

**Table 1: Cold temperature indices (Lisa Alexander, 2015).**

| | **ID** | **Indicator name** | **Definitions** | **UNITS** |
|---|---|---|---|---|
| 1 | FD0 | Frost days 0 | Annual count when TN < 0ºC | days |
| 2 | ID0 | Ice days | Annual count when TX < 0ºC | days |
| 3 | CSDI2 | Cold spell duration indicator | Annual count of days with at least *n* consecutive days when TN<10th percentile, where n>= 2 (and max 10) | days |
| 4 | CSDI6 | Cold spell duration indicator | Annual count of days with at least 6 consecutive days when TN<10th percentile | days |
| 5 | TN10p | Cool nights | Percentage of time when the daily min temperature < 10th percentile | % |
| 6 | TX10p | Cool days | Percentage of time when the daily max temperature < 10th percentile | % |

## 3. Results and Discussion

### 3.1. Frost Days Index

The spatial distribution of the number of frost days in the Zagros habitat is shown in Figure 3. A frosty day is a day when the minimum temperature of the day is zero or less. This index is considered one of the most important cold climate indices for monitoring climate change. The number of frost days in the entire Zagros habitat has had a significant decreasing trend. The decrease in this indicator has accelerated in recent decades. Since frost is part of the physiological cycle of deciduous trees, it can lead to disruption of the winter dormancy phase of plants and trees. On the other hand, many forest pests are controlled by extreme cold, so the decrease in frost increases the survival of pests such as the bud-eating moth (Tortrix viridana). On the other hand, night frost plays an important role in storing soil moisture. The study of the spatial distribution of the number of days with frost in the Zagros habitat showed that two factors, altitude and latitude, play a decisive role. So that the highest number of glacial days with a frequency of 100 to 120 days per year corresponds to the North Zagros in West Azerbaijan in terms of having a higher latitude, and the heights of the Middle

Zagros, such as Oshtorankouh, and South Zagros, such as Dena and Zardkouh Bakhtiari. The trend of changes in the glacial number index for all synoptic stations was calculated, and its spatial distribution was zoned for the whole ecosystem. The results showed that throughout the Zagros, there was a decrease in the number of frosty days, but the most decreasing changes occurred in the coldest regions, and between 35 and 80 days of frost occurred. At high latitudes and altitudes, the number of frosty days reached 50%. The decrease in frosty days is accompanied by a decrease in snow storage in these areas, which can affect the water resources of the Zagros.

### 3.2. Ice Days Index

The spatial distribution of the number of icy days in the Zagros habitat is shown in Figure 4. An icy day is a day when the maximum daily temperature is zero or less than zero. Reduced frost days result in incomplete or early dormancy of trees, which makes them vulnerable to late spring frosts. Increased acceleration in the process of species transformation can also be an effect of reduced frost days. Climate change and reduced frost days may cause changes in floristic composition and weaken native species. Reduced frost days lead to changes in soil freeze-thaw patterns. Surface freezing of soil during frost days controls erosion and stores moisture. Reducing this phenomenon leads to increased erosion, reduced permeability, and damage to soil microorganisms. The number of icy day events in the whole Zagros is not high. Examination of the spatial distribution of trend changes in this index showed that it has a decreasing and significant trend throughout the Zagros. The greatest decrease in icy days occurred in the North Zagros with 20 to 30 days. Reducing the number of icy days, such as reducing the number of icy days, leads to rapid melting of snow and lack of water penetration due to snow and strengthening of groundwater. The number of icy days in the South Zagros and the Middle Zagros has sharply decreased and almost disappeared in the last decade, and may be unrepeatable in the future due to climate change and rising temperatures.

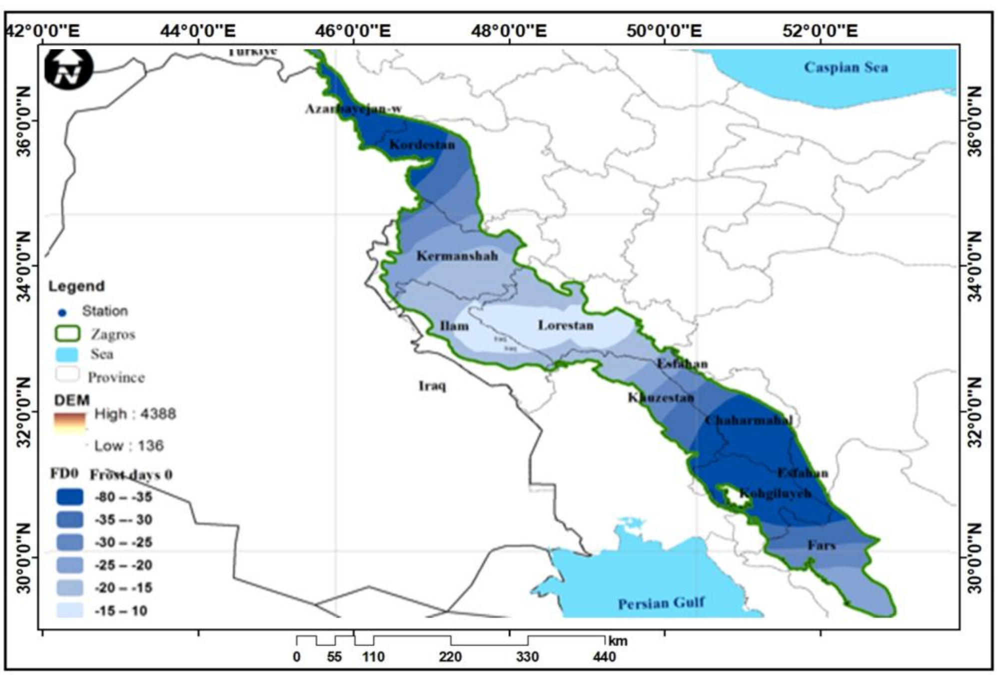


**Figure 3. The trend of changes in the Frost Days Index in the Zagros forest ecosystem**

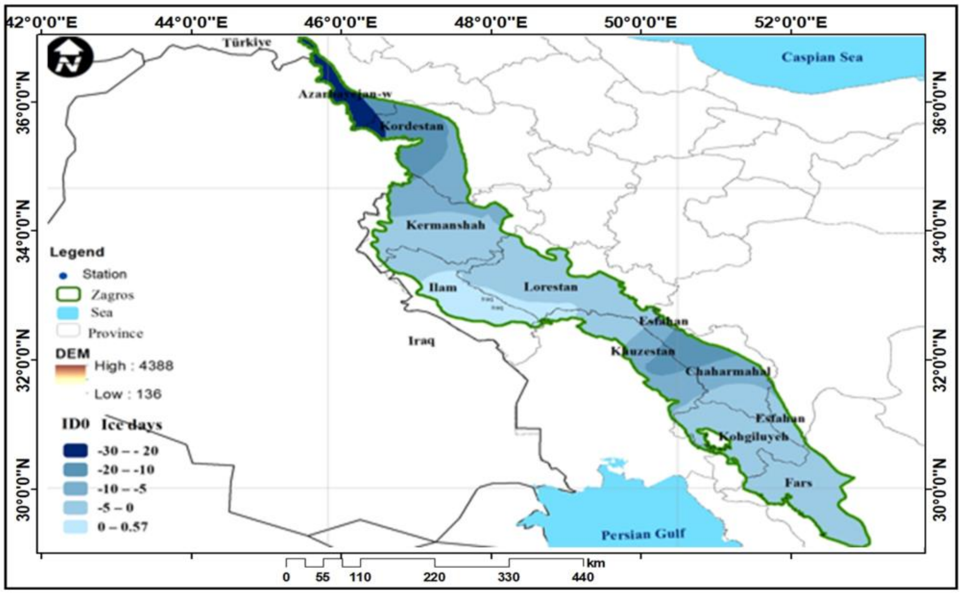


**Figure 4. The trend of changes in the Ice Days Index in the Zagros forest ecosystem**

### 3.3. Cool days Index

The spatial distribution of the number of cool days in the Zagros habitat is shown in Figure 5. One of the cool temperature indicators revealing the occurrence of climate change is the frequency of occurrence of the percentage of cool days. If this index decreases, it indicates that the number of relatively cold days is decreasing. And this is while the percentage of this index has a significant decreasing trend throughout the Zagros habitat. Examination of the spatial distribution of changes in this index showed that throughout the Zagros ecosystem, the frequency of cool days is decreasing significantly. The highest decreasing trend occurred in North Zagros in West Azerbaijan province, in Middle Zagros in Ilam province, and in South Zagros in the west of Fars province, with a 30 to 40% decrease.

### 3.4. Cool Nights Index

The spatial distribution of the number of cool days in the Zagros habitat is shown in Figure 6. One of the cool temperature indicators revealing the occurrence of climate change is the frequency of occurrence of the percentage of cool nights. Examination of the spatial distribution of changes in this index showed that throughout the Zagros ecosystem, the frequency of cool nights has a decreasing and significant trend. The highest decreasing trend occurred in the North Zagros in Kurdistan Province and in the southern half of the Zagros with 30 to 50%. The percentage decrease of this index is more than the index of cool days, which indicates a further decrease in temperature minima than the maximum temperature throughout the Zagros ecosystem (Figure 6).

### 3.5. Cold spell duration indicator 2-day Index

The spatial distribution of the number of cool days in the Zagros habitat is shown in Figure 7. One of the cold temperature indicators revealing the occurrence of climate change is the frequency of occurrence of two-day cold periods. Examination of the spatial distribution of changes in this index showed that throughout the Zagros ecosystem, the frequency of cold two-day periods is decreasing significantly. The highest decreasing trend occurred in the North Zagros in Kurdistan province and in the southern half of the Zagros on the border between Fars, Chaharmahal, and Kohgiluyeh Zagros provinces, with 100 to 130 days.

### 3.6. Cold spell duration indicator 6-day Index

The spatial distribution of the number of cool days in the Zagros habitat is shown in Figure 8. One of the cold temperature indicators revealing the occurrence of climate change is the frequency of occurrence of the cold six-day period. Examination of the spatial distribution of the changes in this index showed that throughout the

Zagros ecosystem, the frequency of six-day cold periods is decreasing significantly. The highest decreasing trend occurred in North Zagros in Kurdistan province and in the southern half of Zagros in the border between Fars provinces of Chaharmahal and Kohgiluyeh with 60 to 70 days.

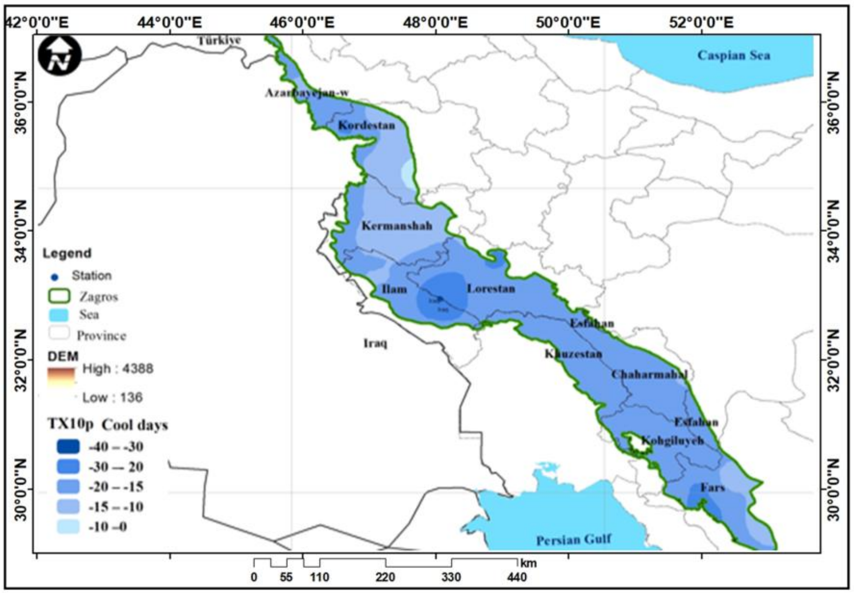


**Figure 5. The trend of changes in Cool Day's index in the Zagros forest ecosystem**

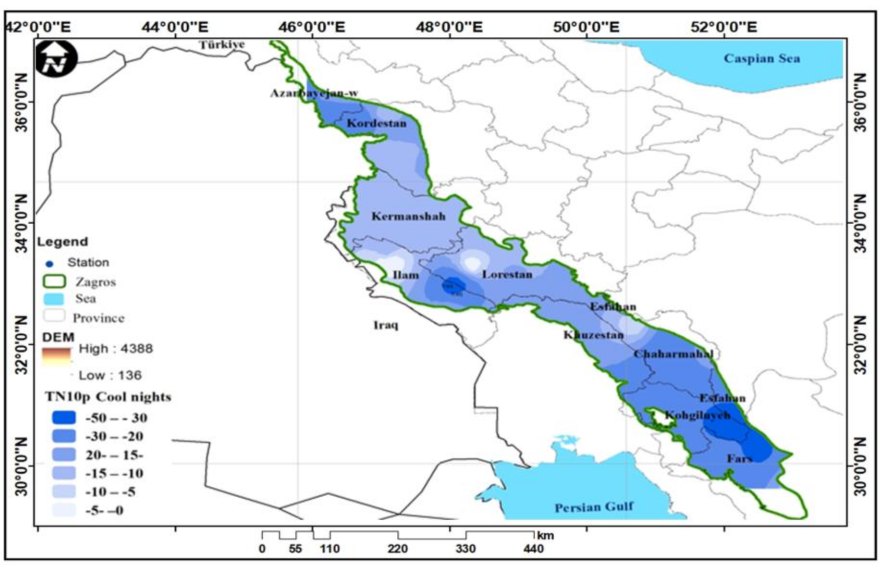


**Figure 6. The trend of changes in the Cool Nights Index in the Zagros forest ecosystem**

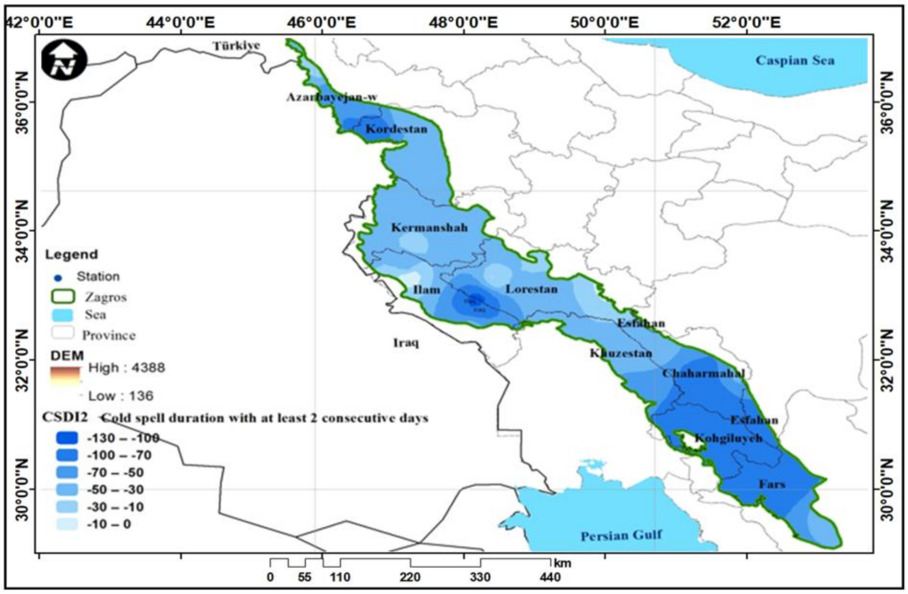


**Figure 7. The trend of changes in the CSDI2 Index in the Zagros forest ecosystem**

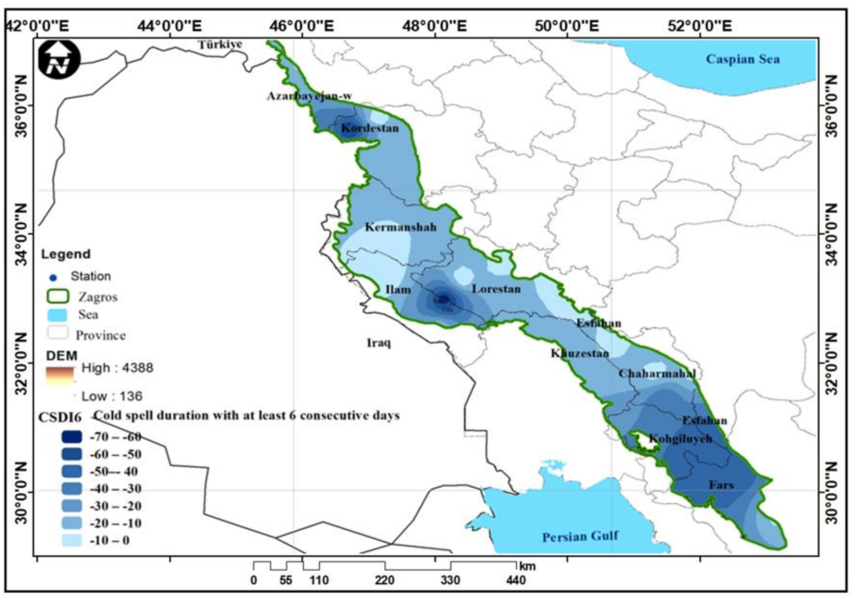


**Figure 8. The trend of changes in the CSDI2 Index in the Zagros forest ecosystem**

## 4. Conclusions

The Zagros forests, which are spread in 11 provinces of the country with an area of 6 million hectares, comprise 40% of Iran's forests, of which about 70% of the Zagros forest species are oaks, and play such an important role in oxygen production that some call Iran's lungs they have put on it. Zagros forests play an effective role in groundwater recharge, sustainable agriculture, soil conservation, flood control, and air purification. Deforestation due to climate change is a global phenomenon that affects many tree species (Colangelo et al., 2018). The forests of the Oak are no exception, and it is declining all over the world (Brasier et al., 1993). The first report on the occurrence of oak decay in the Zagros forests in Iran was in 2001. In 2014, more than one million hectares of forest fell into decline (Pourhashemi et al., 2017). The phenomenon of decline is expanding every day (Pourhashemi & Sadeghi, 2020), and with the continuation of climate change in the future will increase its range.

Standard detection indices were used to detect the occurrence of climate change in the Zagros forest ecosystem. In this study, cold temperature indices were selected from 61 output indices. The results showed that the two factors of altitude and latitude play a decisive role in the spatial distribution of cold temperature indices, and the greatest decreasing trend in cold temperature indices has occurred in the coldest regions. All cold indicators of climate change showed a significant decreasing trend with a 95% confidence level. The percentage of decrease in cold night temperature indices is more than daily cold temperature indices. Indices that were more intense in showing cold temperature events had a greater downward trend than other cold temperature indicators. The occurrence of some indicators, such as the icy day index and six-day cold periods throughout the Zagros ecosystem, especially in the last decade, have been severely reduced and somewhat erased, and will probably be unrepeatable in the future due to continued temperature rise.

Many factors play a role in the deterioration of oak forests. Natural factors include biotic and abiotic factors. Biological agents include insects, fungi, viruses, and bacteria, which are abundant due to the ease of assessment and research in this field. Non-biological natural agents that operate on a large scale and provide a suitable environment for the operation of biological agents. Climate change, especially the increase the temperature and as a result, the increase in evaporation and removal of sufficient moisture, is not available to oak trees. On the other hand, there is a decrease in rainfall and the incidence of drought, as well as the entry of dust particles from Iran's neighboring countries into the forest ecosystem of Zagros, which acts as a natural factor in the path of dust entry. In addition to natural factors, many human activities, such as excessive livestock grazing, over-harvesting of underground water, etc., can be considered as effective in the decline of these trees. Many studies have shown the role of climatic factors in the decline of these ecosystems. Among the climatic factors, temperature changes have shown the most relationship with oak decline (Poursartip et al., 2017; Ghadirian et al., 2018; Alesheikh & Mehri, 2019; Sabernasab et al., 2020; Moradi et al., 2021; Dargahian & Razavizadeh, 2022 ). Decreasing trend of cold temperature indicators revealing climate change and continuation of this decreasing trend in the future will lead to rapid melting of snow and lack of water infiltration due to snow on the ground, and strengthening of groundwater. The result of a sharp decline in cold temperature indices throughout the Zagros ecosystem should be a reduction in groundwater abstraction in sustainable forest management plans. Because many factors are effective in the decline of Zagros forests, it cannot be said explicitly that the share of climate change in this natural challenge is a few percent. Some factors, such as human activities that are indirectly affected by climate change, must be identified and added to the share of climate change, in which case the share of climate change in the decline and drying of forest ecosystems seems to increase. Forest ecosystems help slow down the process of climate change by storing carbon, so intensifying deforestation can accelerate the process of climate change (Misaghi et al., 2024; Matinfar et al., 2025). Today, one of the most important challenges for Iran's natural environments is the decline of Zagros oak forests. Several factors have been and are effective in the decline of these natural ecosystems, but climatic factors are considered the most important because they facilitate other factors and conditions for decline. The decreasing trend of cold indices has led to the limitation of wintering for many pests and has prepared the ground for the growth of pests and diseases. Given the trend of increasing temperatures in the coming years, this decreasing trend will continue, and the ground will be prepared for temperature and humidity stresses and the growth and outbreak of more pests and diseases (Dargahian et al., 2024).

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**Author Contributions**:

**Fatemeh Dargahian:** Modeling, performing software analysis, and writing the initial version of the article.

**Sakineh lotfinasabasl:** Cooperation in the preparation and Manuscript editing.

**Azadeh Gohardoust:** Preparation of data and information and controlling the results

**Conflicts of interest**

The authors of this article declared no conflict of interest regarding the authorship or publication of this article.

**Data availability statement:**

The datasets are available upon a reasonable request to the corresponding author.

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