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ORIGINAL PAPER

Statistically scrutinizing impact of climate variability on forest fire incidents in Turkey

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Abstract
This study aimed to shed light on the extent to which the changing climate would affect the fire risk in forests in Turkey. For this purpose, statistical approaches and indices were applied to some climate parameters in 39 provinces with forest presence. A statistically significant increasing trend according to Şen approaches, named ITA and IPTA, was detected in the temperature datasets of almost all provinces between May and October, which was referred to as the "forest fire period" in Turkey. The annual Lang index showed that there was a tendency towards desertification and aridification in the provinces. The monthly Lang index also pointed out semi-arid and arid climates from May to September in almost all provinces. The Ångström index classifying fire risk showed the probability of fire increasing between June and September for many provinces. These findings draw attention to the impact of climate change on possible forest fires in Turkey.

Keywords Forest fire · ITA · IPTA · Lang index · Ångström index

1 Introduction

Forests play an important role in the ecosystem, both in terms of regulating the climate and providing shelter for living things. This inherent characteristic feature of the forests contributes to the continuity of the natural balance (Fuhrer 2000; Isbell et al. 2011). They also have the ability to manage the processes of carbon storage, soil conservation, air purification, oxygen production, and regulation and quality improvement of water resources

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(Baskent and Keleş, 2009; Demeke and Afework 2014; Pourtaghi et al. 2015; Sivrikaya and Küçük, 2022).

Forest areas in the world correspond to 31% of the terrestrial area. It has been reported that between 1990 and 2020, 178 million hectares of forest area were destroyed worldwide, with forest fires accounting for about 55% of this destruction (FAO 2020). In forest areas corresponding to 29.4% of Turkey's surface area, an average of 2000 forest fires occurred annually in the last 20 years, 48% of which were human-induced (Elvan et al. 2021; Anonymous 2024a). To be more precise, most parts of the world are still at risk of forest fires, whether they occur naturally or as a result of human activity (Mohajane et al. 2021).

Biodiversity and human health are directly affected by forest fires disrupting the normal functioning of the ecosystem. Forest fires are one of the primary obstacles to environmental sustainability because of this unfavorable effect (Langmann et al. 2009; Bar et al. 2020). Fidanboy et al. (2022) stated that urbanization and climate change triggered the forest fire risk the most. It was expressed that fire had a very close interaction with climate, human activities, changes in land use, tree community, and terrain structure, but climate played a key role among these (Vélez 1993; Ying et al. 2018; Gómez-Nieto et al. 2020; Stocks et al. 1998; Fill et al. 2019). On the other hand, Elvan et al. (2021) underlined that the leading climatological factors that played a role in the occurrence of fire were temperature and wind speed. In addition, the increase in temperatures due to the variability in the climate has brought about the faster drying of the crop canopy. Further, the lack of precipitation due to global warming, long-term drought, decrease in relative humidity, dry winds, and unfavorable land conditions have been identified as factors that increase the risk of forest fire (Anonymous 2024a; Elvan et al. 2021). Živanović et al. (2020) highlighted that at the beginning of the autumn season when the plants started to dry, the relative humidity was quite low, and this characteristic process increased the probability of fire in forest areas. Researchers concentrated on looking for potential relationships between climate variability and forest fires as a result of global climate change (Boucher et al. 2020; Gu et al. 2020). According to Mokhov and Chernokulsky (2010), there would be a longer fire hazard duration in subtropical and mid-latitude regions in addition to an increased risk of fire danger.

Global climate change has a tangible impact on the probability and frequency of heat waves. Heat waves, depending on their duration and frequency, play an active role in increasing evaporation, drying out vegetation, and the initiation and spread of wildfires. Thus, the worst drought conditions can be experienced as a result of heat waves (Fischer and Knutti 2015; Xiao et al. 2022; Nolan et al. 2016; Rossa 2017). Some parts of our globe, including Spain, Italy, Portugal, France, Greece, Russia, Algeria, Bosnia, Croatia, Serbia, and North Macedonia, have experienced considerably the coupling of heat waves, wildfires, and droughts (Leone et al. 2023; Westerling 2016; Trenberth and Fasullo 2012; Balafoutis 2007; Fink et al. 2004). The interaction between heat waves and wildfires has prompted many researchers to investigate. Rodrigues et al. (2020) and, Nojarov and Nikolova (2022) highlighted a strong link between wildfires and heat waves. AghaKouchak et al. (2014) pointed out that extreme temperatures were leading to severe droughts and wildfires. AghaKouchak et al. (2020) reported that increasing extreme temperatures due to climate change have a knock-on effect in the context of increasing the severity of extreme hazards such as droughts and forest fires, that is, heat waves intensify drought conditions, while extreme droughts increase the possibility of more intense heat waves. Tedim et al. (2018) underlined that the complex interaction of topography, fuel, and climate elements has an impact on both the damaging effects of wildfires and the extent and speed of their regional spread. Laz et al. (2023) investigated spatially and temporally the interaction between heat wave and drought as a compound event. They drew attention to the fact that

heat waves and drought events were influenced, either directly or indirectly, by temperature and precipitation parameters. Berg et al. (2015) pointed out to take place heat waves and droughts concurrently.

The Intergovernmental Panel on Climate Change (IPCC 2007, 2013) pointed out that the increasing trend of greenhouse gas concentration in the atmosphere would cause fluctuations in the amount of temperature and precipitation in most regions of the world, within and between years. Houghton (2012) and Sellers and McGuffie (2012) stressed that many regions of the world have experienced drought and flood events as a result of global warming. Senatore et al. (2011) reported that summer temperatures were expected to increase in southern and central Europe and that it was likely that summer temperatures would increase significantly in the Mediterranean region. Unkašević and Tošić (2014) reported that Europe has been dealing with an overestimated rise in temperature since the turn of the twentieth century. As demonstrated by the extraordinary summer heat wave of 2003, extreme events associated with intense heating had a significant impact on natural hazards, socioeconomic activities, and health activities in Europe (Schär et al. 2004; Trigo et al. 2005). Giorgi (2006) stated that the Mediterranean basin was very sensitive in the context of possible future extreme precipitation events. It is obvious that Turkey, which is geographically located in the Mediterranean basin, would be affected environmentally by global climate change (Onol and Semazzi 2009; Vardar et al. 2011). Aktaş (2014) underlined that Turkey, where different climatic characteristics prevailed, would be affected regionally by global climate change, especially there would be problems in the direction of desertification in the central and southeastern Anatolia regions and a decrease in water resources in the Marmara and Mediterranean regions. Ozkul (2009) reported that in the Mediterranean region, which was one of the seven geographical regions of Turkey, a downward trend was expected in the annual precipitation and the number of annual rainy days. Furthermore, the study highlighted that summer temperatures increased most in Turkey's western and southwest regions. Turkes (1996) pointed out that there would be a remarkable decrease in precipitation with a tendency to increase in annual average temperatures in Turkey's Mediterranean, Aegean, and Central Anatolia regions. Mengu et al. (2008) in their research, anticipated that summer and winter temperatures in Turkey would increase by 3 °C and 1–2 °C, respectively.

For many regions on the globe, the effect of global warming has been predominantly investigated depending on meteorological (such as temperature, precipitation, and evaporation), and hydrological (such as stream flow, groundwater, and lake level) variables. As seen from a literature review, this research process was often carried out with statistical analysis approaches. To identify variability in hydro-meteorological variables, these methods—Mann-Kendal, Spearman Rho, Linear Regression, and Innovative Trend Analysis (ITA)—have been used extensively (Yürekli 2022; Banda et al. 2021; Das et al. 2020; Islam et al. 2020; Wang et al. 2020; Yagbasan et al. 2020; Şen et al. 2019; Hadi and Tombul 2018; Zhou et al. 2018; Ay et al. 2018; Güçlü 2018; Wu and Qian 2016; Yurekli 2015). In the literature, the Mann–Kendall (Mann, 1945; Kendall 1962), Spearman rho and linear regression tests have been widely preferred for the variation in hydro-meteorological variables, while the slope of the variation in the data has mostly been revealed by the Theil-Sen approach (Theil 1950; Sen 1968). However, the application of these methods is only possible if some assumptions of the data to be studied are met, namely the absence of serial correlation, normality, and length of the data. Hamed and Rao (1998) emphasized that the null hypothesis or alternative of the Mann-Kendal approach would only be realistically accepted under conditions where the data subjected to analysis could not have statistically serial correlation. The existence

of serial correlation between observations causes misinterpretation of analysis results. In this context, an important trend is indicated, especially in data with positive serial dependence (Cox and Stuart 1955; Yue and Wang 2002). Von Storch (1995) reported that the pre-whitening technique would eliminate the effect of serial dependence in the data if serial correlation was present. However, this approach has some significant advantages over Spearman Rho and linear regression, such as its high sensitivity to abrupt breaks and the fact that the theoretical probability distribution structure followed by the data has no effect on the analysis (Jaagus 2006). The notable advantages of the Speraman Rho test are: It is not affected by the theoretical distribution fitted to the data, it is relatively robust to extremes, and it is useful even with small sample sizes (Gauthier 2001). The most important constraint in analyzing the existence of a trend based on the linear regression test is the theoretical distribution characteristic that the data follows. This approach is applied under the condition that the data exhibits normal distribution characteristics (Jaiswall et al. 2015). Şen (2012) introduced a methodology (Innovative Trend Analysis) to the literature that does not require any assumptions and visually reveals the change in the data by classifying the data categorically. This technique has significant advantages over other methods. In fact, the weaknesses of the others are of no importance in this approach. This approach does not have prerequisites such as the data in the analysis having to follow any theoretical distribution, the length of the sample size, and the absence of serial dependence in the data. Another superiority feature of this method is that every time series value is positioned in an upward or downward order along the 1:1 line. Consequently, a judgment regarding all of the data's values is feasible. Information regarding the trend of the data clustered by various values (low, medium, and high) is provided by this feature. The statistical analysis of the ITA graphical template was also carried out by Şen (2017). Kundzewicz and Robson (2000) highlighted the need for a robust graphical technique to avoid errors when identifying hidden (short-term) sub-trends (Caloiero 2018). For these reasons, the Innovative Trend Analysis (ITA) technique has been widely applied in many areas. The ITA test is used in analyzing natural disasters such as forest fires, hail, and frost hazards (Li et al. 2019), monitoring climate change (Ceyhunlu et al. 2021), managing water resources (Zakwan 2021), and analyzing drought conditions (Caloiero 2018; Tuğrul and Hinis 2024). Yurekli (2021) compared the performances of these four methodologies, which were often considered to reveal variability in a time series. In 87% of the precipitation data examined, the Innovative Trend Analysis approach found a statistically significant change; in the other three approaches, this rate ranged from 7 to 13%. There were also some studies (Kisi 2015; Zhou et al. 2018; Güçlü 2018; Wang et al. 2020) that coincided with the findings of Yurekli (2021). To explain the correlation between wildfires and climatologic conditions, some efforts are possible to find in the literature (e.g., Papadopoulos et al. 2013; Mueller et al. 2020; Westerling et al. 2003; Guo et al. 2023; Koutsias et al. 2012). Compared to previous studies in the literature, the innovative aspect of the current study is the use of indices that shed light on fire risk, as well as ITA and ITA-based IPTA (Innovative Polygon Trend Approach) approaches, which are very effective in determining the variability in climate elements to establish the relationship between climate elements and wildfires.

The main purpose of this study was to establish how the variability in the climate triggered forest fires in the conditions of Turkey. Accordingly, the efforts to achieve this goal are a- to realize the confirmatory analysis (such as completing the missing data) of the climate parameters to be considered in detecting variability in the climate of the studied area, b- to statistically analyze the variability (inhomogeneity) in the time series

associated with climate elements with parametric or non-parametric approaches, c- to reveal the trend of change in climate elements with the innovative trend analysis method (ITA), d- to determine the climate class and fire risk of the studying area based on indices, e- to draw links between fires that have occurred and findings from the analysis of climate elements.

2 Study area and data

Turkey is located in the middle belt of the Northern Hemisphere, between 36° and 42° north parallels and 26°—45° east meridians. The average height of the country, which is surrounded by the sea on three sides, is 1132 m, and its surface area is 783,577 square kilometers (Mızrak 1983; Atalay 2011; Celik 2020). Turkey has regions where different climate types prevail, as well as microclimate areas, due to its geographical location and topographic structure. Climate elements, especially precipitation, show temporal and spatial changes that are noteworthy throughout the country (Kapluhan 2013). While the country's average annual precipitation is 574 mm, the region of Rize receives the highest precipitation (2254 mm). In contrast, there are seasons where precipitation falls below 300 mm around Tuz Lake. Air masses, frontal systems, and orographic features are effective in the distribution of precipitation by months. While the highest monthly precipitation usually falls in December and January, seasonally, it is in autumn (Anonymous 2024b; Akin 2019; Polat and Sunkar 2017). Most parts of the country, which is geographically divided into seven regions, have a semi-arid climate, although there is a humid climate towards the Eastern Black Sea Region. The Black Sea climate, which is rainy in all seasons, is observed in the north, and the Mediterranean climate, which is dry and very hot in summers and warm and rainy in winters, is in the south. The continental climate is experienced in the inner regions (Central Anatolia, Eastern Anatolia, and most of Southeastern Anatolia) (Cicek and Ataol 2009; Haktanir and Cıtakoglu 2014).

In Turkey, which has a rich ecological diversity, forests have an important place in terms of species and composition. The forested areas cover approximately 29.4% of the country's surface area (Anonymous 2024a) Turkey's forest density is mainly close to the coastal areas, and this density is more pronounced in the Western Black Sea, Southern Aegean, and Mediterranean regions. According to the report of the General Directorate of Forestry, 3.399 forest fires occurred in Turkey in 2020, and 20.971 hectares of forest area were damaged in these fires. In Fig. 1, the amount of forest area burned and the number of forest fires between 2015 and 2020 years were given.

In the study, the climate parameters measured at the meteorological stations in the provincial centers operated by the Turkish State Meteorological Service were used to reveal the existence of climatic variability. However, for this purpose, instead of all stations in Turkey, based on the fact that approximately 30% of Turkey's territories are covered by forests, provinces where 30% or more of the surface area is covered with forest were included in the study area to detect the interaction between fire risk and climate variability (Fig. 2). For the analysis, the daily average temperature, daily relative humidity and daily total precipitation data measured from 1965 to 2020 of 39 stations were used. To achieve the goal of the study setup, the variability of the climatic elements within the observation period was tried to be analyzed with statistical approaches. In addition, bioclimatic areas and the possibility of fire in the study area were tried to be revealed with indices.

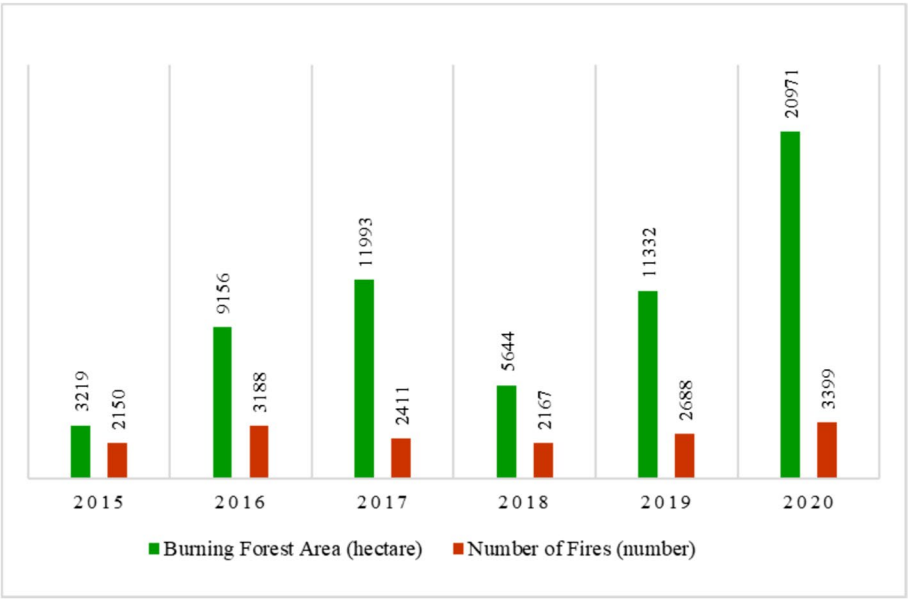


Fig. 1 Forest fire areas and the number of forest fires for the period from 2015 to 2020 (Anonymous 2024a)

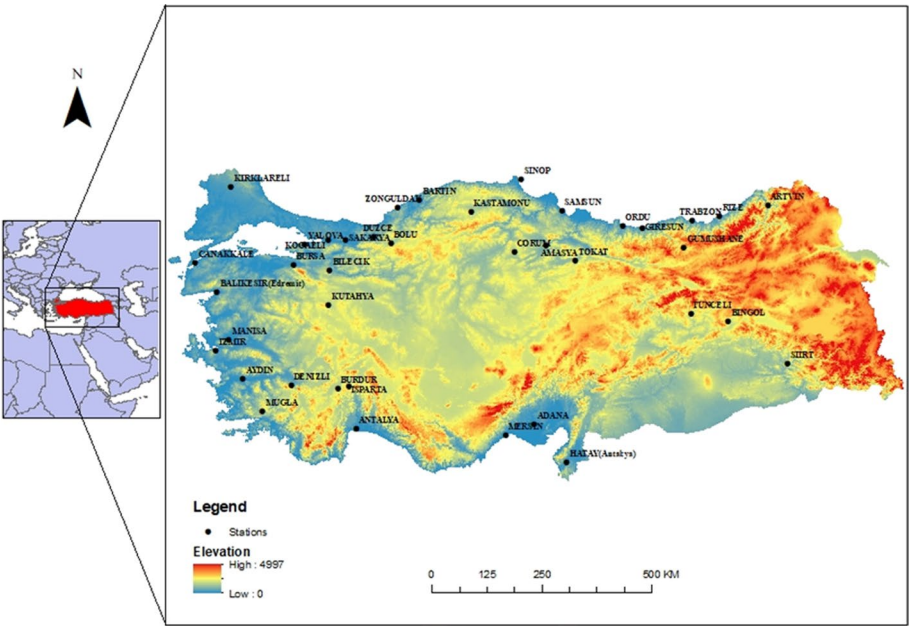


Fig. 2 Geographic location of the provinces where forest fire occurred in Turkey

2.1 The lang precipitation factor

Recognizing that temperature is the driving force in the evaporation process, Lang (1920) defined the bioclimate structure of a place by the ratio of precipitation to temperature. According to the rate value ($L_{pf} = \mathrm{P/T}$) calculated on a monthly or annual basis, the climatic characteristic of the place to be subjected to analysis is categorized. The Lang precipitation factor (L_{pf}) value obtained from the monthly total temperature and rainfall data highlights a humid and arid climate class if it is greater than 6.6 or less than 3.3, respectively. On the other hand, the L_{pf} value calculated between 3.3 and 5.0 or 5.0 and 6.0 characterizes the semi-arid and semi-humid climate class. But, if the L_{pf} results provided from the annual rainfall and temperature data are less than 40 and greater than 160, it shows arid and perhumid climates, respectively. The L_{pf} of being between 40 and 160 corresponds to the humid climate class. Additionally, bioclimatic areas were classified into six classes according to the L_{pf} range: desert (0–20), semi-desert (20–40), steppes and savannas (40–60), low forests (60–100), high forests (100–160), and barrens and tundra (> 160).

2.2 The Ångström index (AI)

The index was developed based on temperature and relative humidity parameters for the reconnaissance of fire risk and potential (Ångström 1936; Langholz and Schmidtmayer 1993; Živanović et al. 2020; Shetinsky 1994; Tošić et al. 2019; Willis et al. 2001; Holsten et al. 2013). Its mathematical relationship of the index is as follows:

$$\mathrm{AI} = \frac{\mathrm{R}}{20} + \frac{(27 - \mathrm{T})}{10} \tag{1}$$

where R is relative humidity (%) and T is temperature (°C). The index has four risk classifications, and they are given in Table 1.

2.3 Data homogeneity check

Whether there is a difference in the mean and variance of the observations of a studied time series is examined with statistical approaches, which are either parametric or non-parametric. Parametric ones allow being used when the normality condition is fulfilled. However, it is not also possible to conclude that every non-parametric approach does not have a demand for the normality condition. Considering these preliminary explanations made in the context of statistical approaches, the normal distribution behavior of the climatic elements (temperature and rainfall) to be analyzed in the study was checked with the Kolmogorov–Smirnov method. And then, to check the homogeneity of the data, the complete data

Table 1 Class ranges of the Ångström index

AI	Probability of fire
I > 4.0	Unlikely
4.0 < I < 3.0	Unfavourable
3.0 < I < 2.5	Favourable
2.5 < I < 2	More favourable
I < 2	Very likely

was divided into two parts (1965–1992 and 1993–2020). The student's t-test was applied to prove the difference in the means of two subseries split from normally distributed data (Wilcox 2017). Another assumption required for this approach is to investigate the equality of variances of the two data sets. For this reason, the Levene approach (Odoi et al. 2019) is a popular statistical test that does not require the assumption that data sequences have a normal distribution. The general form of the student's t-test statistic is calculated using Eq. 2.

$$t_{cal} = \frac{\overline{X}_1 - \overline{X}_2}{S_{\overline{X}_1 - \overline{X}_2}} \tag{2}$$

The denominator of Eq. 2 corresponds to the standard error of the difference in the means and is calculated according to the homogeneity and non-homogeneity of the variances of the data sets. In the homogeneous variance condition, the denominator in question is calculated with $S_p^2\left(\frac{1}{N_1}+\frac{1}{N_2}\right)^{1/2}$, and in non-homogeneous conditions, it is calculated with $\left(\frac{S_1^2}{N_1}+\frac{S_2^2}{N_2}\right)^{1/2}$. Where $\overline{X}_1$, $\overline{X}_2$, S_1^2 and S_2^2 are means and variances of the split series. N_1 and N_2 are the number of observations in each split series. S_p^2 is the pooled variance. The t_{cal} value is compared to the t_{crit} value from the student's t Distribution Table. This table value is picked for the 5% significance level and the degree of freedom which is obtained based on the condition that the variance of two data sets is homogeneous or inhomogeneous.

The homogeneity of a time series that is put forward to not be statistically normally distributed is mostly checked by the non-parametric Mann–Whitney U method (MWU) whose details are available in Yurekli (2015). The null hypothesis (H_o) associated with this method is that the statistical difference between the medians of the two data sets is not significant. To confirm that the two data sets belong to the same population, the Z_U test value calculated based on its "U" parameter is compared with the Z_T value obtained from the standard normal distribution table. The fact that the Z_U is greater than the Z_T requires rejecting the null hypothesis, that is, an indication that the two medians are statistically significantly different from each other.

2.4 Innovative trend analysis (ITA)

The most prominent approaches in the literature to control for the presence of statistically significant variability in time series are Mann-Kendal, Spearman Rho, Linear regression, and Innovative Trend Analysis. Among them, the ITA has a dominant advantage over the others in terms of its power to disclose the trend in the data without any prerequisite requirements during the application of the test. In addition to these superiorities, another distinguishing advantage of this approach is that it allows making a judgment about the internal variability of the data in terms of its methodological construct (Yurekli 2023, 2021; Wickramagamage 2016; Longobardi and Villani 2010). The graphical structure and statistical analysis methodology of this approach was introduced to the literature by Şen (2012) and Şen (2017). For both the graphical structure and statistical significance analysis of any hydro-meteorological data based on ITA, first, the full data is divided into two equal sub-data and then the ascending sequences of the two-half series are made. To visually detect the presence of the trend, the two sub-series in ascending order are positioned against each other in the cartesian coordinate, and the scattering of these positions (points)

around the 45-degree inclined line is scrutinized. The points positioned above, below, and on the line indicate an increase, a decrease, and no trend in the considered data, respectively. The null hypothesis of this approach regarding the absence of statistically significant change in the dataset is not rejected when the slope (S_{cal}) value calculated with Eq. 3 remains within the confidence interval (CI) obtained from Eq. 4, otherwise, the alternative hypothesis is accepted.

$$S_{cal} = \frac{2\left(\bar{y}_2 - \bar{y}_1\right)}{n} \tag{3}$$

$$CI_{(1-\alpha)} = 0 \pm S_{crit}\sigma_S \tag{4}$$

In equations, $\bar{y}_1$ and $\bar{y}_2$ are the averages of the first and second sub-data sequences formed from a complete dataset with "n" observations. The parameter "σ_s" in Eq. 4 is calculated as follows:

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1-\rho_{\bar{y}_1\bar{y}_2}} \tag{5}$$

where The terms "$\rho_{\bar{y}_1\bar{y}_2}$" and "σ" are the cross-correlation coefficient and standard deviation of the full data, respectively. The S_{crit} value is taken from the Standard Normal Distribution Table for the 5% confidence level.

2.5 Innovative polygon trend approach (IPTA)

In this study, Innovative Polygonal Trend Analysis (IPTA) based on the ITA template proposed by Şen et al. (2019) was taken into consideration to find out what kind of internal change of climate elements had on a monthly basis. In the IPTA methodology to be applied to different time-scale hydro-meteorological data sequences, analysis is performed by dividing the data into two parts as in the original ITA template. In this context, first half matrix (FHM) and second half matrix (SHM) for IPTA analysis based on a matrix of dimension m x n are formed as shown in the equation below. Where "m" and "n" correspond to the observation period and the months of the year, respectively.

$$FHM = \begin{bmatrix} x_{1,1} & \cdots & x_{1,12} \\ \vdots & \ddots & \vdots \\ x_{\frac{m}{2},1} & \cdots & x_{\frac{m}{2},12} \end{bmatrix} \quad SHM = \begin{bmatrix} x_{\frac{m}{2}+1,1} & \cdots & x_{\frac{m}{2}+1,12} \\ \vdots & \ddots & \vdots \\ x_{m,1} & \cdots & x_{m,12} \end{bmatrix} \tag{6}$$

To apply the IPTA to a time series with "m" observation years on a monthly time scale, the statistical parameters, such as mean and standard deviation, etc., regarding each half-matrix column are first calculated. Then, the statistical parameter values provided for the first and second parts of each month are positioned against each other in the Cartesian coordinate system. The positioned point for any month is combined with that of the subsequent month with a straight line. Figure 3 shows the IPTA template (Ceribasi et al. 2021). The slope and length of the straight-line connecting consecutive months are determined according to the coordinates of the points referencing this line. The regular form of IPTA is such that approximately half of the points and the lines connecting them are above the trendless region, or the 1:1 (45) line and the rest are below (Şen et al. 2019). In Fig. 3, the regular IPTA form seems to be distorted by the difference in parameter values belonging to

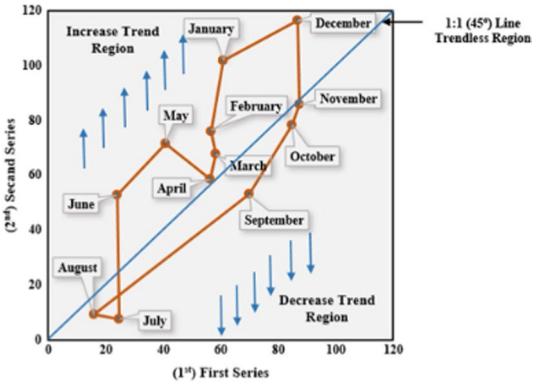


Fig. 3 IPTA template based on monthly time scale

March, April, August, and July. As can be seen from the figure in question, the limps above and below the trendless region contribute to our understanding of the internal change of the hydro-meteorological variable being studied. In other words, a rise in limp indicates an increase in the relevant data, and a fall indicates a decrease. While a regular IPTA form has a single-loop polygon, the IPTA template of hydro-meteorological variables occurring under unusual physical conditions may be in the form of polygons with multiple loops. The IPTA template of a data set under consideration provides the opportunity to make qualitative and quantitative judgments about the system in which that data set was produced. How to make inferences about a constructed polygon was detailed in Şen et al. (2019).

3 Results and discussions

In the study, first of all, it was checked whether the temperature and rainfall data of the meteorological stations were usable for analysis in line with the purpose of the study. In this context, the presence of missing data in the data sequences in question was investigated. No missing records were found for both temperature and rainfall data. Another effort for data conformity was homogeneity checking, based on parametric and non-parametric approaches. In the study, checking whether all data series for parametric analysis satisfied the requirement of being normally distributed was done with the Kolmogorov–Smirnov method (Tables 2 and 3). Non-parametric Mann–Whitney U test was applied to data sets that were confirmed to be not statistically normally distributed. The complete data set was split into two sections, 1965–1992 and 1993–2020, in order to conduct a homogeneity analysis using both parametric and non-parametric techniques. The results regarding temperature and rainfall variables are presented in Tables 4 and 5. In Table 5, a dark green character was used for temperature data where homogeneity was statistically accepted, and a lighter green character was preferred for temperature data where homogeneity was statistically rejected. When Table 4 is examined, it is observed that there is inhomogeneity in the temperature series measured at most meteorological stations in the period from May to September. The null hypothesis of homogeneity was rejected in all temperature data series in Mersin province. On the other hand, homogeneity was not achieved statistically in ten months of the monthly temperature values of Aydın and Denizli stations. On the contrary, Bingöl and Gümüşhane stations had inhomogeneity in temperature values for only one month. As for the rainfall data, in Table 5, the dark melon color indicates the presence of

Table 2 Normality analysis of monthly average temperature data of the provinces

Province	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adana	√	√	√	√	√		√	√	√	√		√
Amasya		√	√		√	√	√			√	√	√
Antalya			√	√	√		√	√	√	√	√	
Artvin	√	√	√	√	√		√	√	√	√	√	√
Aydın	√	√	√	√	√	√	√	√	√	√	√	√
Edremit	√	√	√	√	√		√	√	√	√	√	√
Bartın	√	√	√	√	√	√	√	√	√	√	√	√
Bilecik	√	√	√	√	√		√	√	√	√	√	√
Bingol			√	√	√			√		√		
Bolu	√	√	√	√	√	√	√	√		√	√	√
Burdur		√	√	√	√	√	√	√	√		√	√
Bursa	√	√	√	√	√	√	√	√	√	√	√	√
Canakkale	√	√	√	√	√	√	√	√	√	√	√	√
Corum		√	√	√	√	√	√	√		√	√	√
Denizli	√	√	√	√	√	√	√	√	√	√	√	√
Duzce	√	√	√	√	√	√	√	√	√	√	√	√
Giresun	√	√	√	√	√		√	√	√			√
Gumushane	√	√	√	√	√		√	√		√	√	√
Hatay	√	√	√	√	√	√	√			√	√	
Isparta	√	√	√	√	√	√	√	√		√	√	√
Izmir	√	√	√	√	√		√	√	√	√	√	√
Kastamonu	√	√	√	√	√	√	√	√		√	√	√
Kirklareli	√	√	√	√	√	√	√	√	√	√	√	√
Kocaeli	√	√	√	√	√	√	√		√		√	√
Kutahya		√	√	√	√		√	√	√	√	√	√
Manisa	√	√		√	√	√	√	√	√	√	√	√
Mersin		√		√	√	√			√		√	√
Mugla	√	√	√	√		√	√	√	√		√	√
Ordu	√	√	√	√	√	√	√	√	√	√	√	√
Rize	√	√	√	√			√	√	√	√	√	√
Sakarya	√	√	√	√	√	√	√		√	√	√	√
Samsun	√	√	√	√	√		√	√	√		√	√
Siirt	√	√	√	√	√		√	√		√	√	√
Sinop	√	√	√	√	√	√			√	√	√	√
Tokat	√	√	√	√	√	√	√	√		√	√	√
Trabzon	√	√							√		√	√
Tunceli	√											√
Yalova	√	√	√	√	√	√	√	√	√	√	√	√
Zonguldak	√	√	√	√	√		√	√	√	√	√	√

Table 3 Normality analysis of the monthly average rainfall amounts of the provinces

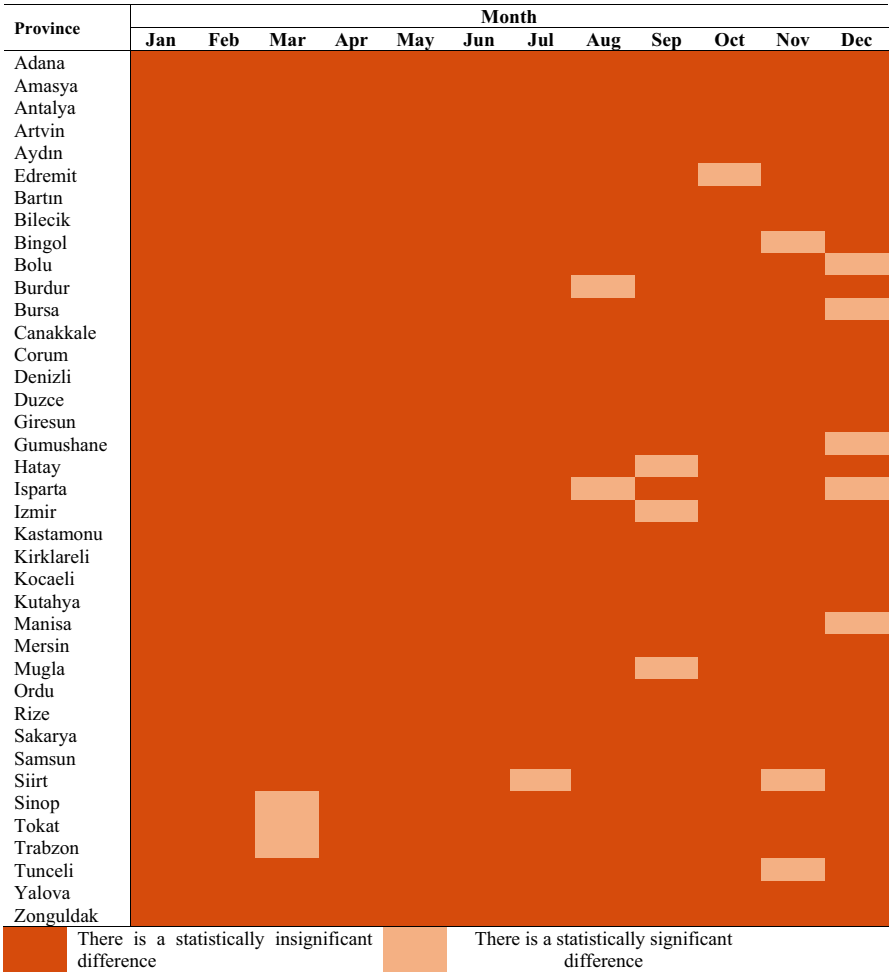
Province	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adana		√										√
Amasya	√		√	√	√							
Antalya												
Artvin				√	√	√						√
Aydın	√		√	√							√	√
Edremit			√	√						√	√	√
Bartın			√	√	√					√		√
Bilecik	√		√	√	√						√	√
Bingol	√			√								√
Bolu	√		√	√	√				√	√	√	√
Burdur		√								√	√	
Bursa	√	√	√							√	√	√
Canakkale	√	√		√								√
Corum			√	√								√
Denizli		√	√	√	√					√	√	√
Duzce		√	√	√		√			√	√		√
Giresun	√			√	√	√		√	√	√	√	√
Gumushane	√	√		√	√	√			√		√	√
Hatay		√								√	√	√
Isparta					√	√						
Izmir			√								√	
Kastamonu	√		√	√	√			√			√	√
Kirklareli	√			√						√	√	
Kocaeli	√	√	√	√		√					√	√
Kutahya										√		√
Manisa		√	√	√	√						√	
Mersin		√									√	
Mugla	√	√	√								√	√
Ordu	√		√	√	√	√		√	√	√		√
Rize	√	√	√	√	√	√			√	√	√	√
Sakarya	√	√	√	√					√	√	√	√
Samsun	√		√			√			√			
Siirt	√	√	√	√								√
Sinop	√	√			√				√	√	√	√
Tokat	√	√				√						
Trabzon			√		√					√	√	√
Tunceli		√	√	√	√						√	√
Yalova	√	√	√								√	√
Zonguldak	√	√	√						√	√	√	√

Table 4 Homogeneity analysis results of temperature data



statistical homogeneity, and the light melon color indicates the absence of statistical homogeneity. The overwhelming majority of the monthly rainfall series belonging to the stations taken into consideration in the research had statistically significant homogeneity. In other words, statistically significant inhomogeneity was revealed in approximately 4% of all series. The rainfall data sequences of Sinop, Tokat, and Trabzon provinces for March were inhomogeneous, the remaining inhomogeneous data series were detected in one month at different stations in the months after July and in two months at Isparta and Siirt stations. The following figures provide the reader with a more geographically interpretable view of the normality and homogeneity results of the temperature and rainfall data from the meteorological stations considered in the study. The normality results for temperature and rainfall are shown in Figs. 4 and 5, respectively, while that of homogeneity is in Figs. 6 and 7.

Table 5 Homogeneity analysis results of rainfall amounts



Using innovative trend analysis (ITA), it was determined whether climate elements like temperature and rainfall, which are thought to have a significant influence on the occurrence of forest fires, tend to increase or decrease over time. In the context of the ITA analysis results of rainfall time series, a statistically significant upward trend was detected at some stations in March, May, August, September, and October, whereas, the opposite result was revealed at some stations in February, November, and December. Rainfall amounts in July, which is one of the months where forest fires occur frequently, showed a statistically insignificant decreasing trend in 24 of 39 provinces. As for temperature changes, a statistically significant increasing trend was detected in the temperature time series of almost all provinces for the months from May to October (Table 6). The interval, with the rise in temperature from late spring to late autumn, coincides with the period when forest fires are most experienced in Turkey. In addition to these findings, a statistically significant

increasing trend was found for some stations in the remaining months. Dramatically, temperature data for all months in Mersin province had an increasing trend. Interestingly, an upward trend was detected even in monthly temperature data that showed a statistically insignificant change. The visual of the ITA test results for temperature is as in Fig. 8. Flannigan and Harrington (1988) investigated the correlation of the monthly burned area with meteorological variables for the months from May to August. They found that months with bad fires were not influenced by the amount of rainfall, but they were strongly influenced by temperature, relative humidity, and the frequency of rainfall. Gillett et al. (2004) stated that over the past forty years, as summer temperatures have risen, so too has the area burned by forest fires in Canada. They demonstrated how human-induced climate change has had a discernible impact on the area burned by forest fires in Canada in recent decades. Founda and Giannakopoulos (2009), and Unkašević and Tošić 2011) reported that the heat waves that occurred in the Balkans in the summer of 2007 were mainly responsible for the formation of the area that suffered the most fire damage. Lukić et al. (2017) announced that the 2012 Tara Mountain case study disclosed that the frequency of forest fires was

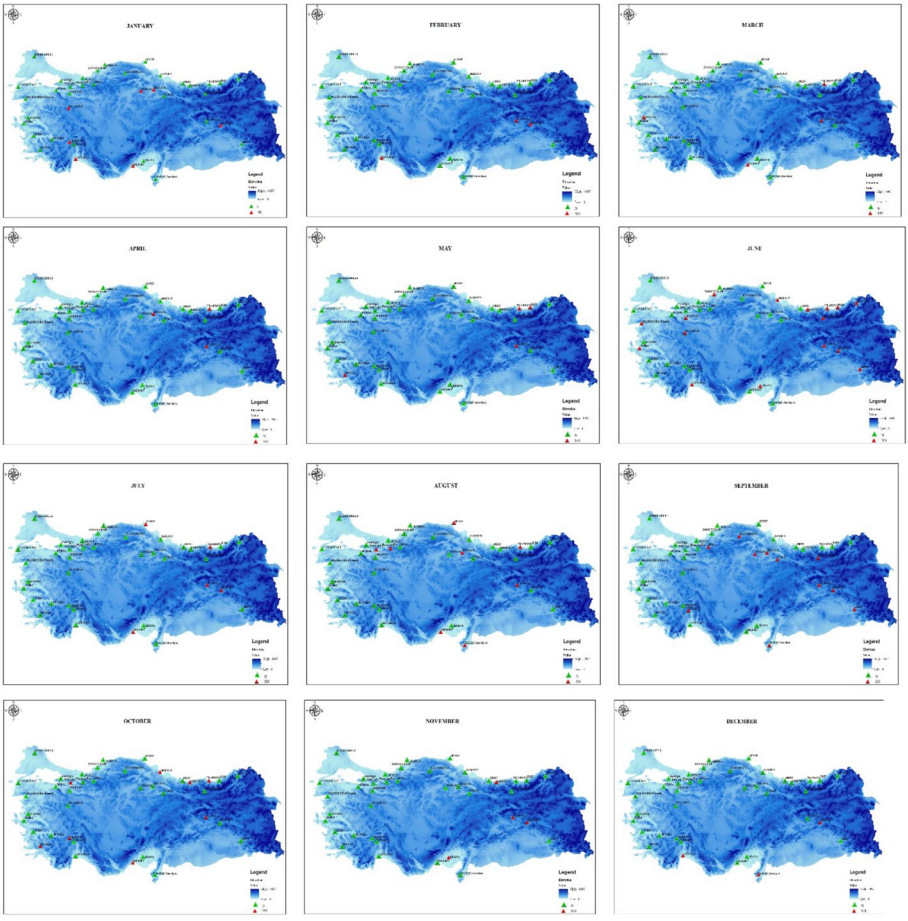


Fig. 4 Geographical representation of the normality results of the monthly average temperature data of the considered stations (N: Normal, NN; Non-Normal)

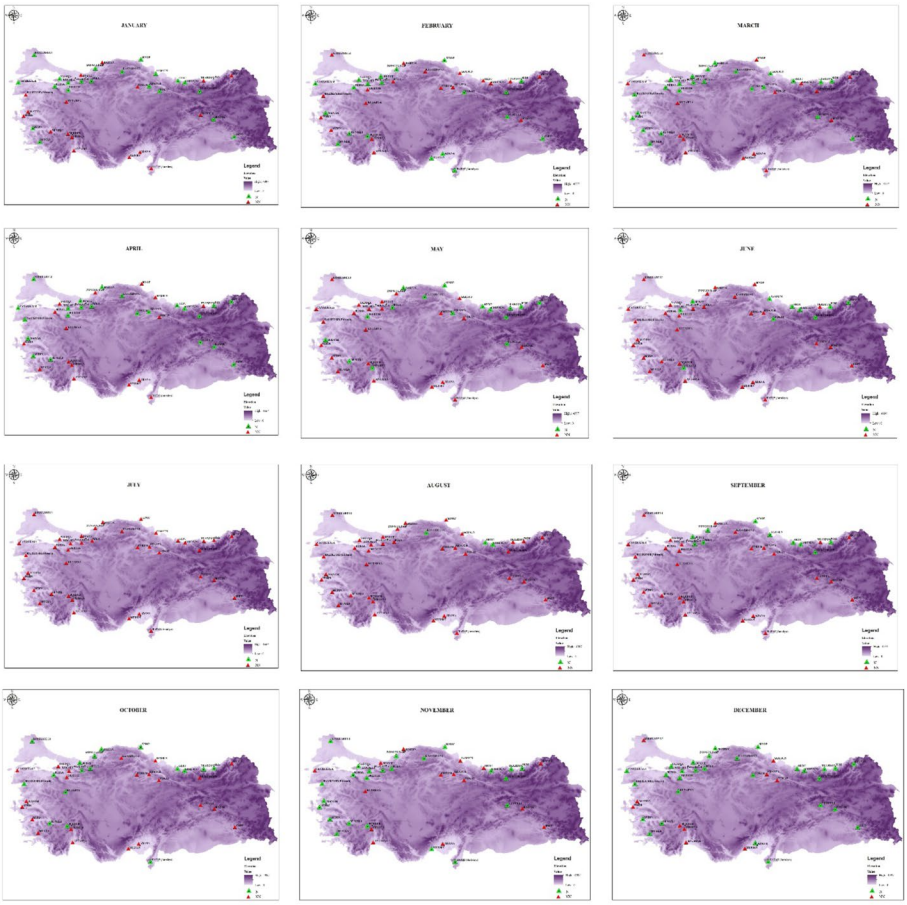


Fig. 5 Geographical representation of the normality results of the monthly average rainfall data of the considered stations (N: Normal, NN; Non-Normal)

strongly influenced by climatic conditions. Chen et al. (2014) stressed that the occurrence and severity of wildfires are significantly influenced by some characteristics of precipitation, such as depths, duration, and frequency. They found that precipitation regimes were significantly related to fire activity, with drought being more strongly related to fire activity than precipitation, particularly in drier regions. In other words, they highlighted that wildfires in drier areas were significantly influenced by the frequency and duration of precipitation. Littell et al. (2009) reported that wildfire variability is associated with short-term changes in precipitation regimes that modulate fuel moisture content. Pausas (2004) examined the relationship between forest fire occurrence and climatic factors for the studied area and came to the conclusion that summer rainfall plays a significant role in determining the area burned. It was expressed that in the majority of North American forests, fires happen simultaneously during periods of low precipitation and following a lengthy period of days with less than 1.5 mm of precipitation (Carcaillet and Richard 2000).

In Fig. 9, the number of forest fires that took place in the provinces under investigation between 2013 and 2020 is shown. During the period mentioned above, the highest number

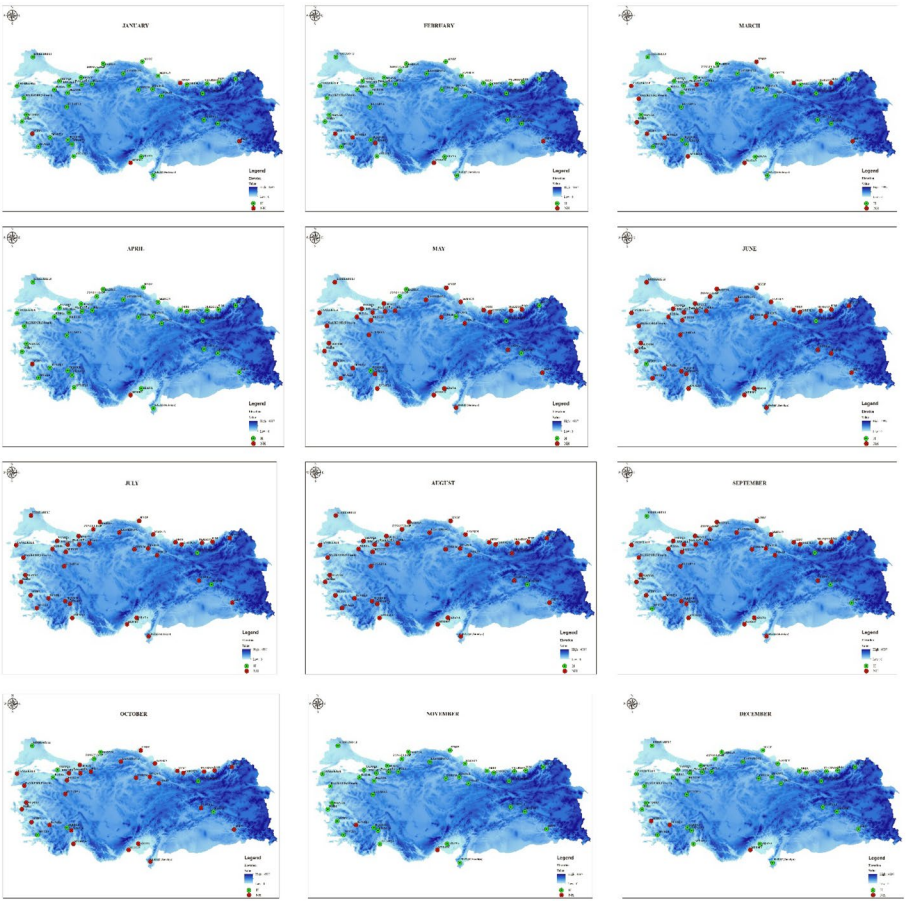


Fig. 6 Geographical representation of the homogeneity results of the monthly average temperature data of the considered stations (H: Homogeneity, NH: Non-Homogeneity)

of fire incidents in total occurred in the provinces of Mugla (2100), Antalya (1947), and İzmir (1340). Following these provinces, Adana (877), Hatay (797), Mersin (744), and Manisa (739) had the highest number of fire incidents. During the specified period, the number of fires experienced in the remaining provinces ranged between 22 and 592 (Anonymous 2024a).

The Innovative Polygon Trend Analysis (IPTA) templates, based on the monthly temperature average values of the provinces, formed similar polygon shapes. The IPTA polygons belonging to the provinces supported their ITA results. In other words, the positions of the average-based polygons for almost all provinces were higher than the 1:1 line. Since the IPTA templates for all provinces would increase the volume of the article, only the IPTA templates for the provinces where forest fires occurred more frequently than other provinces (mentioned above) were given in the study (Fig. 10). In comparison to other consecutive months, the trend amount and length of these seven stations between July and August were quite low. This result highlights how similar the temperatures recorded during the aforementioned consecutive months are to one another. However, the trend length

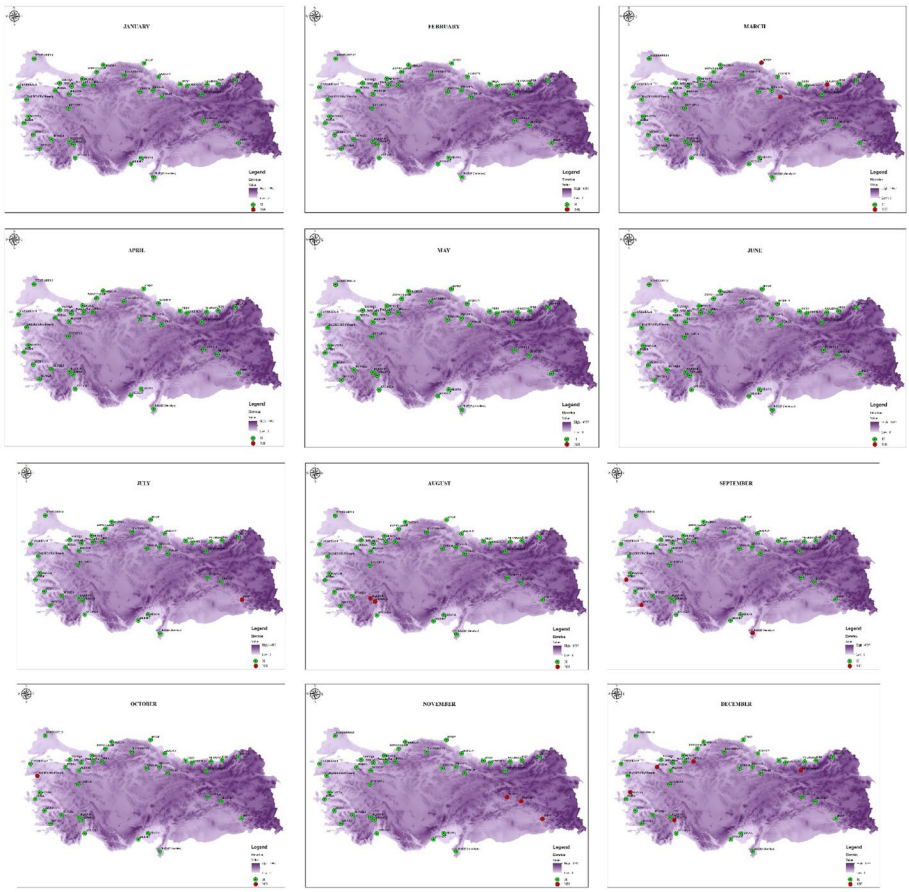


Fig. 7 Geographical representation of the homogeneity results of the monthly average rainfall data of the considered stations (H: Homogeneity, NH: Non-Homogeneity)

values between April–May, May–June, September–October, and October–November were found to be quite high. This points out that the variability between the successive months in question is significantly different. The trend length value between June and July shows that there is a significant change in temperature when compared to that of July and August. The IPTA results point out the probable effect of changes in temperature that lead to the occurrence of forest fires.

An attempt was made to ascertain how the bioclimatic areas and climate classes of the provinces representing the forest area of Turkey in the study were evolving under the influence of climate variability using the Lang precipitation factor (L_{pf}) relationship, which was computed based on annual and monthly temperature and rainfall. For this purpose, the analysis was carried out by dividing the 1965–2020 observation period, which was taken into account in the study in the context of temperature and rainfall data, into two parts (1965–1992 and 1993–2020). Over these two periods for annual data sets, the L_{pf} value increased by 1.3% and 4.7% in only two of the 39 provinces (Izmir and Trabzon), respectively. However, in all remaining provinces, the L_{pf} value showed a decreasing trend

Table 6 ITA results for temperature time series

Province	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adana	0,02	0,05	0,05	0,05	**0,06↑**	**0,05↑**	**0,07↑**	**0,09↑**	**0,05↑**	**0,08↑**	**0,07↑**	0,04
Amasya	0,10	0,12	**0,08↑**	0,00	**0,07↑**	**0,07↑**	**0,12↑**	**0,12↑**	**0,10↑**	**0,12↑**	0,05	0,08
Antalya	0.001	0,05	0,04	0,03	**0,08↑**	**0,08↑**	**0,09↑**	**0,11↑**	**0,07↑**	**0,07↑**	0,04	0,04
Artvin	0,08	0,07	0,03	-0,01	0,05	**0,07↑**	**0,09↑**	**0,12↑**	**0,09↑**	**0,08↑**	0,01	0,05
Aydın	0,06	0,06	0,05	0,04	**0,07↑**	**0,09↑**	**0,10↑**	**0,13↑**	**0,07↑**	**0,07↑**	**0,05↑**	0,05
Balikesir	0,05	0,06	**0,07↑**	0,05	**0,09↑**	**0,11↑**	**0,13↑**	**0,14↑**	**0,07↑**	**0,07↑**	**0,06↑**	0,05
Bartın	0,02	0,04	0,04	0,00	0,04	**0,06↑**	**0,09↑**	**0,11↑**	**0,08↑**	**0,06↑**	-0,01	0,01
Bilecik	0,06	0,08	0,07	0,02	**0,08↑**	**0,08↑**	**0,12↑**	**0,14↑**	**0,09↑**	**0,07↑**	0,03	0,05
Bingol	0,08	0,10	**0,10↑**	0,03	0,02	**0,05↑**	0,02	**0,04↑**	0,01	0,05	0,02	0,05
Bolu	0,08	0,09	0,06	0,02	**0,08↑**	**0,08↑**	**0,11↑**	**0,13↑**	**0,08↑**	**0,08↑**	0,05	0,07
Burdur	0,03	0,06	0,04	0,03	**0,07↑**	**0,08↑**	**0,11↑**	**0,11↑**	**0,06↑**	0,04	0,02	0,04
Bursa	0,03	0,05	0,07	0,02	**0,09↑**	**0,08↑**	**0,12↑**	**0,13↑**	**0,08↑**	**0,06↑**	0,01	0,02
Canakkale	0,03	0,04	**0,08↑**	0,03	**0,07↑**	**0,09↑**	**0,12↑**	**0,14↑**	**0,08↑**	**0,07↑**	0,05	0,03
Corum	0,06	0,08	0,05	0,01	**0,07↑**	**0,08↑**	**0,11↑**	**0,13↑**	**0,09↑**	**0,08↑**	-0,01	0,03
Denizli	0,07	**0,09↑**	**0,08↑**	0,07	**0,11↑**	**0,12↑**	**0,17↑**	**0,19↑**	**0,13↑**	**0,11↑**	**0,08↑**	**0,08↑**
Duzceü	0,06	0,08	0,06	0,01	**0,07↑**	**0,07↑**	**0,10↑**	**0,13↑**	**0,09↑**	**0,07↑**	0,03	0,04
Giresun	0,05	0,03	0,06	0,01	**0,06↑**	**0,07↑**	**0,09↑**	**0,12↑**	**0,09↑**	**0,08↑**	0,02	0,04
Gumushane	0,08	0,08	0,05	-0,02	0,02	0,04	0,05	**0,07↑**	0,04	0,05	0,00	0,06
Hatay	0.05	0.05	**0.06↑**	0.04	**0.07↑**	**0.07↑**	**0.07↑**	**0.08↑**	**0.05↑**	**0.08↑**	0.04	0.03
Isparta	0.04	0.08	0.04	0.03	**0.06↑**	**0.08↑**	**0.11↑**	**0.12↑**	**0.08↑**	**0.07↑**	0.05	0.07
Izmir	0.04	0.06	**0.07↑**	0.04	**0.07↑**	**0.08↑**	**0.10↑**	**0.12↑**	**0.07↑**	**0.07↑**	0.04	0.05
Kastamonu	0.07	0.07	0.03	0.01	**0.06↑**	**0.07↑**	**0.10↑**	**0.11↑**	**0.07↑**	**0.06↑**	0.01	0.01
Kirklareli	0.05	0.06	0.07	0.04	**0.08↑**	**0.08↑**	**0.10↑**	**0.14↑**	**0.05↑**	**0.06↑**	0.04	0.03
Kocaeli	0.04	0.06	0.07	0.02	**0.07↑**	**0.06↑**	**0.10↑**	**0.13↑**	**0.08↑**	**0.07↑**	0.04	0.05
Kutahya	0.06	0.09	0.07	0.02	**0.08↑**	**0.07↑**	**0.12↑**	**0.12↑**	**0.08↑**	**0.07↑**	0.04	0.06
Manisa	0.01	0.03	0.05	0.02	**0.07↑**	**0.07↑**	**0.10↑**	**0.13↑**	**0.06↑**	**0.05↑**	0.01	0.02
Mersin	**0.10↑**	**0.12↑**	**0.12↑**	**0.09↑**	**0.13↑**	**0.12↑**	**0.13↑**	**0.14↑**	**0.14↑**	**0.16↑**	**0.13↑**	**0.11↑**
Mugla	0.03	0.04	0.03	0.03	**0.06↑**	**0.08↑**	**0.10↑**	**0.11↑**	0.03	0.04	0.03	0.03
Ordu	0.06	0.05	**0.08↑**	0.03	**0.08↑**	**0.10↑**	**0.12↑**	**0.15↑**	**0.11↑**	**0.09↑**	0.04	0.05
Rize	0.05	0.04	0.06	0.02	**0.08↑**	**0.10↑**	**0.12↑**	**0.15↑**	**0.12↑**	**0.10↑**	0.04	0.05
Sakarya	0.06	0.07	**0.09↑**	0.04	**0.09↑**	**0.09↑**	**0.14↑**	**0.15↑**	**0.11↑**	**0.10↑**	**0.07↑**	0.07
Samsun	0.05	0.03	0.06	0.00	**0.06↑**	**0.09↑**	**0.10↑**	**0.13↑**	**0.10↑**	**0.07↑**	0.01	0.05
Siirt	**0.10↑**	**0.09↑**	0.08	0.05	**0.08↑**	**0.10↑**	**0.07↑**	**0.08↑**	0.04	**0.09↑**	0.05	0.07
Sinop	0.04	0.03	**0.06↑**	0.03	**0.06↑**	**0.09↑**	**0.10↑**	**0.14↑**	**0.10↑**	**0.08↑**	0.03	0.03
Tokat	0.06	0.07	0.06	0.03	**0.07↑**	**0.08↑**	**0.12↑**	**0.14↑**	**0.10↑**	**0.09↑**	-0.02	0.04
Trabzon	0.04	0.03	0.06	0.01	**0.07↑**	**0.10↑**	**0.12↑**	**0.15↑**	**0.11↑**	**0.07↑**	0.01	0.03
Tunceli	0.10	**0.16↑**	**0.12↑**	0.03	0.03	**0.06↑**	**0.04↑**	**0.06↑**	0.01	0.05	0.02	0.06
Yalova	0.04	0.06	**0.08↑**	0.04	**0.09↑**	**0.09↑**	**0.12↑**	**0.14↑**	**0.09↑**	0.05	0.02	0.02
Zonguldak	0.02	0.03	0.06	0.00	0.04	0.04	**0.08↑**	**0.10↑**	**0.08↑**	0.05	0.00	0.03

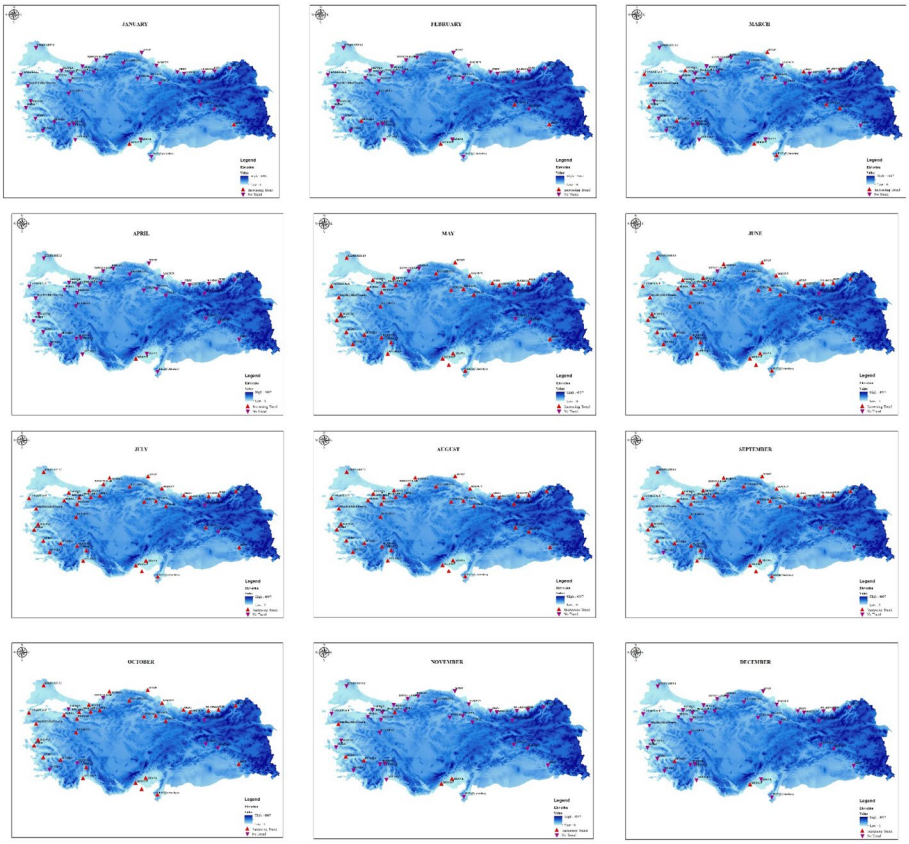


Fig. 8 Geographical representation of the ITA results for temperature data of the considered stations

between 0.6% and 16.7%. Lang precipitation factor decreased by more than 10% in 13 provinces and more than 5% in 19 provinces. This finding emphasizes that there is a tendency towards desertification and aridification classes in terms of the bioclimatic area and climate class of the provinces. Despite the decrease in the L_{pf} values of the provinces in the second period, a change in terms of bioclimatic area was detected only in the provinces of Balıkesir, Çanakkale, Çorum, Hatay and Manisa. Except for Hatay, in these provinces, there was a transition from the steppes and savannas class to the semi-desert class, and in Hatay, it was found that there was a transition from the low forests class to the steppes and savannas class. On the other hand, the climate class of all provinces remained the same except Hatay and Tunceli. There was a transition from the humid class to the arid class in these two provinces.

The Lang precipitation factor results based on monthly data revealed that January, February, March, November, and December were in the semi-humid and humid climate classes at almost all stations (except Adana, Aydın, Bilecik, Burdur, and Denizli). Among the 39 provinces, only Rize province showed a climate characteristic of being humid in nine months and semi-humid in three months. Rize region is the part with the highest average annual rainfall in Turkey. All provinces indicated semi-arid and arid climates in June, July, August, and September. However, in September, Zonguldak province switched to a

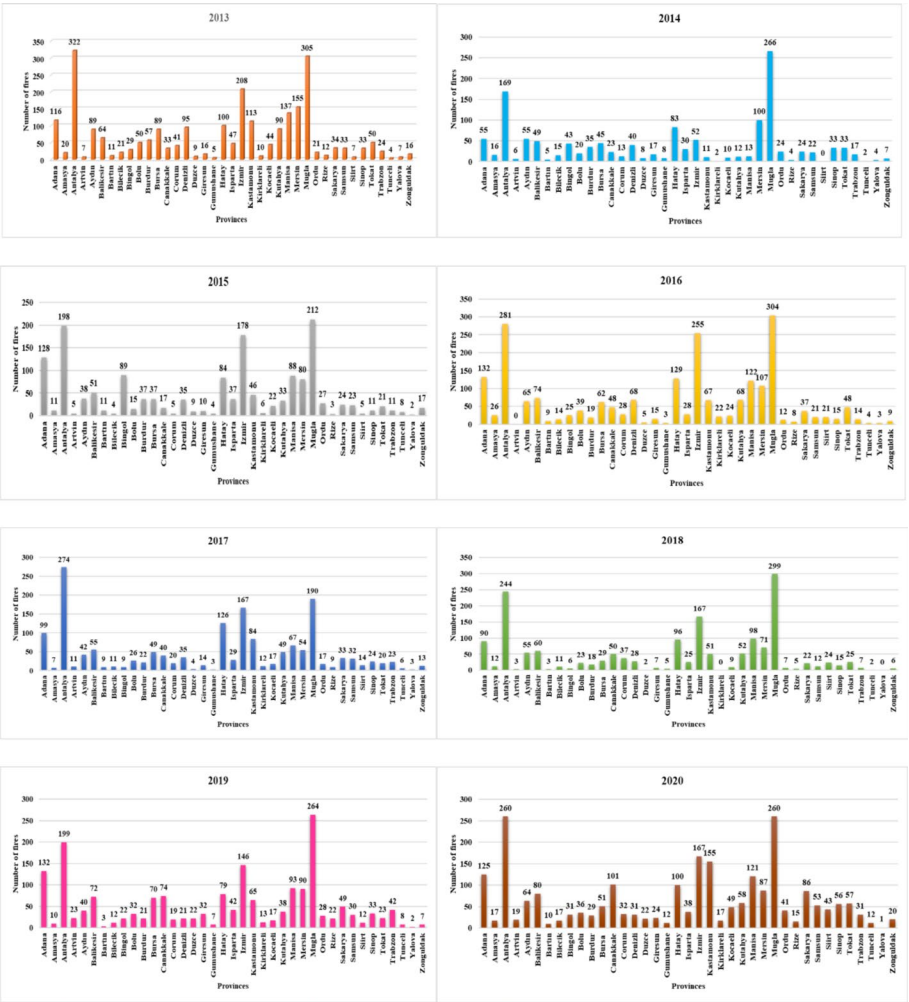


Fig. 9 Number of Forest Fires for provinces in the study

semi-arid climate class in the first period and a semi-humid climate class in the second period. A similar finding was obtained in May. In this month, only Kastamonu province was in the semi-humid climate class in both periods. As for April, semi-arid and arid climate classes dominated in 11 provinces. Regarding the monthly L_{pf} results of the seven provinces with the highest number of forest fire incidents among the thirty-nine provinces in the study area, in Adana and Mersin provinces, it was semi-arid and arid from March to November in both periods (1965–1992 and 1993–2020), and even the arid period (from April to October) was more dominant. In Antalya, Izmir, and Manisa provinces, all months from April to October remained semi-arid and arid classes. Hatay and Mugla provinces also prevailed the semi-arid and arid periods from May to October. Mihai et al. (2022) noted that by the end of the twenty-first century, Southern and Eastern Europe would experience severe drought events and considerable temperature increases, which would have a major effect on forest management, growth, and adaptation. They used a variety of indices,

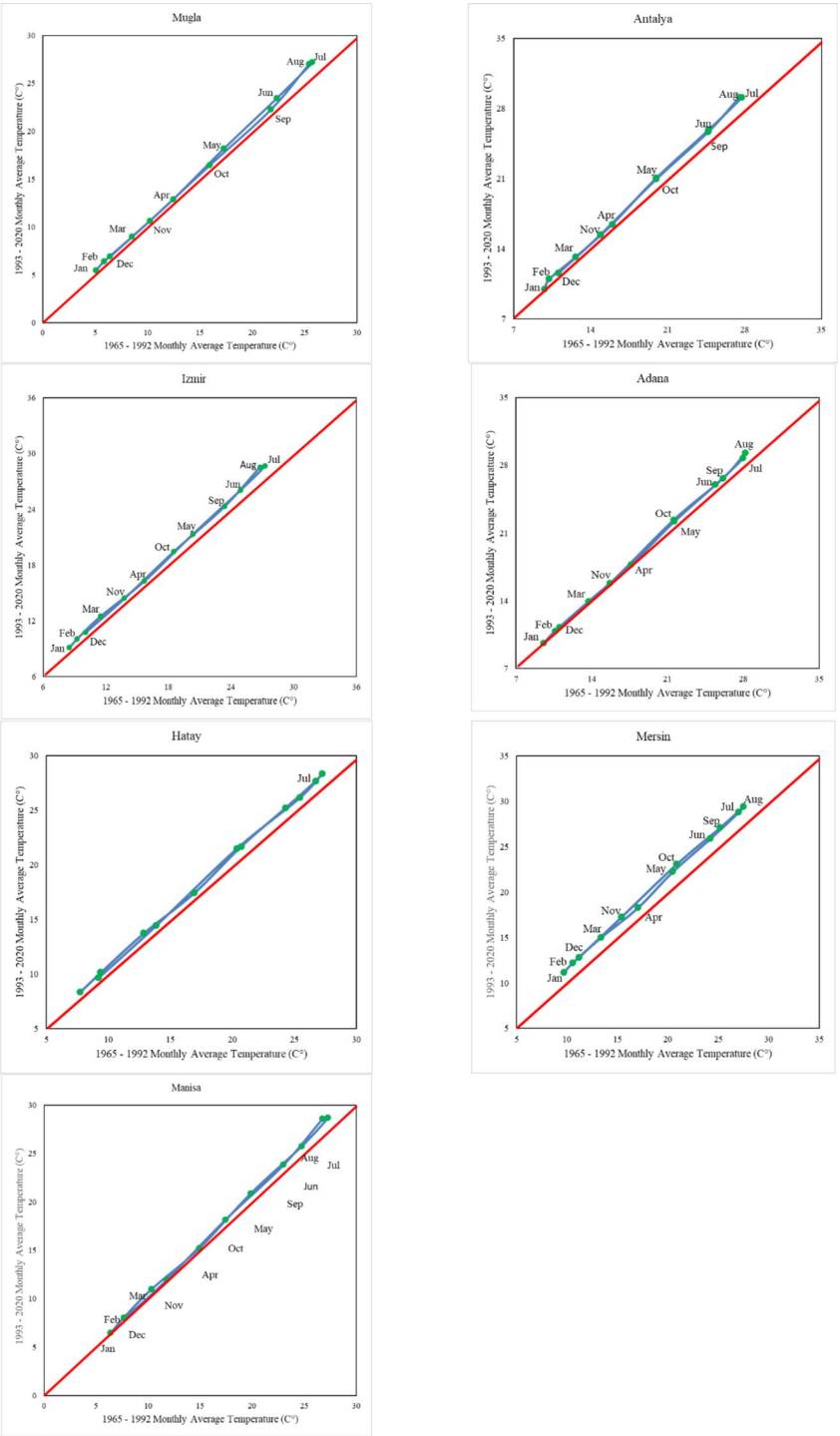


Fig. 10 IPTA template based on monthly time scale for provinces

including the Ellenberg coefficient, the Lang rainfall index, and the De Martonne aridity index, to quantify climate change and its unfavorable effects on forest assets in Romania's Provenance Regions. According to the De Martonne aridity index belonging to the vegetation season, 86% of the ecological sectors were classified as arid or semiarid, indicating a very high level of vulnerability for forest species. Some forest species experienced a shift to forest steppe climate conditions, according to the Lang precipitation index. The Ellenberg coefficient emphasized that the warming process is more noticeable at higher elevations, and the degree of vulnerability rises at lower elevations or at the edge of species distribution. Živanović et al. (2020) expressed that Serbia was seeing an increase in the number of forest fires and fire-affected areas. They analyzed the risk of fires using the Lang precipitation factor and Ångström index. Summertime and springtime were when the precipitation factor's low values were found. The study's conclusion was that the probability of a fire occurring was significantly impacted by the rise in air temperature and the fall in precipitation during the studied period. This result emphasized that there was a higher fire risk in forest areas of Serbia during the summer months.

In this study, the Ångström index, which was used to classify fire risk, was estimated for each province over a 12-month period at two distinct times (1965–1992 and 1993–220). Index values of many provinces show that the probability of fire increases in all or part of June, July, August, and September. According to this index, it was determined that the risk of forest fire was not significant in the remaining months. In the four months mentioned above, there was a decrease in the index values of most provinces compared to the first period in the 1993–2020 period. That is, this finding points out the risk of fire increasing. Among the seven provinces mentioned above, where forest fires occurred more in number, the Ångström index values of Manisa province were less than three in the period from June to September. Moreover, the index values obtained for the 1993–2020 period were lower than the results of the first period. This finding obtained for Manisa province was calculated in June, July, and August for İzmir and Mugla provinces. In Antalya province, the index value below three was obtained in July and August. As in Manisa province, index values in Izmir, Mugla, and Antalya in the 1993–2020 period were lower than those in the 1965–1992 period. For Hatay, Mersin, and Adana provinces, the index values calculated for the period from June to September remained between three and four values. Therefore, according to the index classification, the fire probability was "Unfavourable". Lukić et al. (2017) employed the Angstrom and Nesterov indices to predict the likelihood of a fire in the study area. These indices were thought to be instruments that could help forest managers and other stakeholders implement preventative actions. According to the Angstrom index, the last week of August and the first week of September were found to be risky in terms of fire risk. The Nesterov index indicated that the mentioned period for the Angstrom index was low risk. Mavrakis and Salvati (2015) used two indices, called Nesterov and Angstrom, to assess fire risk for the period between 1 June and 31 August from 1998 to 2013. According to the results of these indices, the weather in the summer of 2007, during which Greece had experienced particularly severe and frequent forest fires, was exceptional and had a high chance of catching fire. Using the Angström index and statistical techniques, the fire risk of an area of interest located in Bulgaria's wildfire-prone Rila mountain was evaluated for the years 1985–2021 (Todorova et al. 2023). It has been demonstrated that the Angström index is a trustworthy tool for predicting the weather conditions that could lead to a fire in the area of interest. In the examined actual wildfire incidents, low relative humidity was found to be the primary factor influencing the occurrence of fires.

4 Conclusion

Due to the climate change we are facing today, it is foreseen that the forest existence that covers approximately one-third of the terrestrial area of the globe we live on is under a serious fire threat. It has been underlined that this risk is growing as a result of drought brought on by rising temperatures and falling precipitation, particularly in the forest areas of the Mediterranean Basin, which includes Turkey (FAO 2020; Bölük 2016). Mhawej et al. (2016) reported that almost 50% of large forest fires occurred due to climate change. Furthermore, it is predicted that global warming will increase the frequency and intensity of forest fires worldwide (Solomon et al. 2007). Temperature and precipitation are climate parameters that are effective in the formation and expansion of forest fires as they affect the moisture content of the biofuel and the distribution of vegetation. It has been observed that the most common period of forest fires in Turkey was from May to October. According to Doganay and Doganay (2004), Turkey's 160-km-long stretch from the Mediterranean, Aegean, and Marmara Coasts to the interior is the most vulnerable to forest fires. Therefore, 58% of the country's forest resources are located in this sensitive area. This study was carried out according to statistical approaches and indices to reveal the effect of global warming on forest fires in Turkey. For this purpose, temperature, rainfall, and relative humidity data, including the period 1965–2020, for 39 provinces where 30% or more of the surface area is covered with forests, were used in the analysis. The entire dataset was examined for conformity. The remarkable judgments based on the findings of the study are as follows:

- Upon analyzing the normality results of monthly rainfall and temperature data sequences belonging to the provinces, it was found that the temperature data series had a higher proportion of normally distributed data than the rainfall data.
- In terms of homogeneity, it was determined that the rainfall data showed more homogeneity in number. Interestingly, the months in which inhomogeneity was achieved in temperature data were mostly found in the period from May to September. About 51% of all temperature data sequences (39 provinces × 12 months) lacked inhomogeneity. On the other hand, there were provinces (Aydın and Denizli, Mersin) where inhomogeneity was achieved in 10 and 12 months. Regarding rainfall data, the results showed that homogeneity was not attained in approximately 4% of all rainfall data sequences. Compared to temperature data, rain data turned out to be more stable.
- In the study, the Innovative Trend Approach (ITA), which has the highest power to capture the change in a time series as emphasized in the literature, was applied to temperature and rainfall series, which are climate elements known to have a significant effect on forest fires. The ITA results of rainfall data revealed a statistically significant change in approximately 3.4% of all data series. Of the 16 series in which the change was detected, it was increasing in 12 and decreasing in the rest. Interestingly, in July, one of the months where forest fires are frequently experienced, rainfall amounts showed a statistically insignificant decreasing trend in 24 of 39 provinces. This trend contributes to the formation of a positive environment for fire.
- As a very remarkable result in the context of temperature, a statistically significant increasing trend was calculated in the data series of almost all provinces between May and October. This is the period when forest fires are most common in Turkey.

Considering all temperature data, most of the data sets have an increasing trend, even if it is statistically insignificant.

- Among the 39 provinces subject to the research, the provinces with the highest number of fire incidents between 2008 and 2020 were Mugla (2100), Antalya (1947), İzmir (1340), Adana (877), Hatay (797), Mersin (744), and Manisa (739). The numbers in parentheses are the number of forest fires.
- Innovative Polygon Trend Analysis (IPTA) based on the ITA mentality was used to reveal how the variability in temperature transitions between months. The polygons indicated an increase in temperature data. When the IPTA pattern of seven provinces where forest fires occur in high numbers is examined, the transition (trend length) between July and August is much shorter than the transition between other months. This means that the temperatures between these two months are very similar to each other. However the trend length value between June and July was higher when compared to that of July and August. On the other hand, the trend length values between April–May, May–June, September–October, and October–November were found to be quite high. This points out that the variability between the successive months in question is significantly different. Based on both ITA and IPTA results, it could be concluded that a suitable environment for forest fires has occurred.
- The Lang precipitation factor (L_{pf}) index was used to ascertain how the bioclimatic areas and climate classes of the provinces in the study were evolving under the influence of climate variability by dividing the 1965–2020 observation period into two parts (1965–1992 and 1993–2020). The index value of 39 provinces, calculated on an annual basis, decreased between 0.6% and 16.7%. This result explains that the provinces have a tendency towards desertification and aridification classes in terms of bioclimatic area and climate class. On the other hand, the findings of this index obtained for June, July, August, and September showed a semi-arid and arid climate for all stations. According to the monthly L_{pf} results, the seven provinces where forest fires occurred most frequently in Turkey had an arid or semi-arid climate during the months of May through October, which were referred to as the "forest fire period".
- The Ångström index, which was considered a measure of forest fire susceptibility, was calculated on a monthly basis for 39 provinces for two different distinct periods (1965–1992 and 1993–220). Index values for June, July, August, and September proved that the probability of fire increased for many provinces. However, this risk could not be detected in the remaining months. As was already mentioned, these four months fall within the designated period of forest fires related to Turkey. Moreover, the index values of most provinces compared to the first period in the 1993–2020 period tended to be downward. This finding indicated an increased fire risk. The index values were less than three in Manisa (June to September), Izmir and Mugla (June to August), and Antalya (July and August). In other words, this finding indicates an increase in the likelihood of fire.

Based on the results of the study, the statistically significant rise in temperature during the months that comprised the period designated as Turkey's forest fire season supported the association between climate and forest fires. Similarly, the results of the indices mentioned above provide evidence of the relationship between climate and forest fire. Consequently, it raises the likelihood that forest resources threatened by climate change will experience more frequent fires.

Author contributions All authors contributed to the concept and design of the study. Data collection and data curation was carried out by Muberra Erdogan Karaagaçlı. The methodology was applied by Kadri Yurekli. Review, writing, analysis and editing were carried out by, Muberra Erdoğan Karaagaçlı, Kadri Yürekli, M.Murat Comert. Muberra Erdogan Karaagacli and Kadri Yürekli carried out the inspection. Analysis was done by Muberra Erdogan Karaagacli, M.Murat Comert and Nurcan Menevse. All authors read and accepted the final version of the manuscript.

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Data availability The dataset analyzed during the current study is provided by the Turkish State Meteorological Service. It is not publicly available because the author is not authorized to share the data set received from the institution. The dataset can be obtained by applying in person from the General Directorate of State Meteorology.

Declarations

Conflict of interests The authors have no relevant financial or non-financial interests to disclose. The authors declare no competing interests.

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