Journal of Agriculture, Food, Environment and Animal Sciences
Tarım, Gıda, Çevre ve Hayvancılık Bilimleri Dergisi
http://www.jafeas.com, ISSN: 2757-5659

J. Agric. Food, Environ. Anim. Sci.
6(1): 84-100, 2025

# The Effect of Climate Change and Variability on The Risk of Forest Fires in AL-Ghab Syrian Region During the Period 2007-2021

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**Research Article**

***Article History:***
Received:01 July 2024
Accepted:07 January 2025
Published online: 01 June 2025

***Keywords*:**
Climate change
Drought
Heat waves
Fire weather
Flammability

**ABSTRACT**

Forest fires are one of the main threats to forest ecosystems in the Mediterranean region due to the effects of rising temperatures and the increasing severity, duration and recurrence of droughts. Daily meteorological data on precipitation and maximum temperatures at the El-Kreem station were used to estimate the change in forest fire risk in the Al-Ghab region of Syria over the period 2007-2021 using the Keetch & Byram Drought Index. Box plots and descriptive statistical analysis were used to examine the climatic characteristics of the study area. Trend lines were also used to determine the direction of change and estimate its value. The significance of the change was tested using the Mann-Kendall test. The results showed that the fire risk in this region is high to very high in all years, but varies significantly from year to year depending on the amount and distribution of precipitation and the level of maximum temperatures. The study also showed a clear and significant trend of increasing fire risk over the study period, which requires the development of appropriate strategies to manage this risk and ensure the sustainable development of important forest areas in the region.

**To Cite :** Skaf M, Al Koubaily, R, Zaher E., 2025. The Effect of Climate Change and Variability on the Risk of Forest Fires in AL-Ghab Syrian Region During the Period 2007-2021. Agriculture, Food, Environment and Animal Sciences, 6(1): 84-100.

## INTRODUCTION

Forest fires are one of the most important disturbance factors affecting forest ecosystems especially in warm and hot climates (San-Miguel-Ayanz et al., 2013), as they play a very important role in the composition, structure and dynamics of vegetation cover and its productivity (Bond and Keeley 2005). and in carbon sequestration, water harvesting, and element cycling (Little et al., 2016; Bowman et al., 2020), in addition to their significant health (Cromar et al., 2024) and economic and social impacts (Gill et al., 2013; Kalogiannidis et al., 2023).

Climate affects the size of disturbances, the time of their occurrence, and their frequency. Therefore, as climate change continues due to global warming, disturbances are expected to increase related to the increasing intensity, duration, and recurrence of extreme weather events such as drought and heat waves, which can produce suitable conditions for the occurrence and spread of forest fires in various regions of the world (Andela et al., 2019; Dowdy et al., 2019; Abram et al., 2021), including the regions surrounding the Mediterranean basin (Lozano et al., 2017; Dupuy et al., 2020).

Forest fires have a wide range of environmental impacts, including air pollution (Huang & Skidmore. 2024; Xue et al., 2024), water pollution (Raoelison et al., 2023), soil erosion (Depountis et al., 2020; Stefanidis et al., 2022), and biodiversity loss (Halofsky et al., 2020; Kelly et al., 2020), in addition to the change in reflectivity of burned sites, which has feedback effects on the climate especially for mega-fires (Quintano et al., 2019). Furthermore, fires lead to the conversion of burned sites from carbon sinks into carbon sources (Bawman et al., 2020). On the other hand, forest fires lead to economic and social impacts, resulting from decline and reduction of many benefits and services that forest areas provide to human communities (Breshears et al., 2011; Pereira et al., 2021).

Meteorological data and fire records confirm the critical role of climate conditions in the occurrence and spread of forest fires in various regions of the world (Meyn et al., 2007; Slocum et al., 2010; Little et al., 2016), as climate affects the amount and the type of fuel over long periods of time by determining the composition, structure, and productivity of vegetation cover, which plays a very important role in the severity and spread of fire (Marlon et al., 2008; Pausas and Ribeiro. 2013), and it also controls the frequency of weather conditions that suitable for occurrence and spread of forest fires (Bowman et al., 2009; Ruffualt et al., 2020). As meteorological conditions the pre-fire season can determine the biomass of plants in the forest understory, which is subsequently converted into highly flammable fuel (Chuvieco et al., 2009; Banerjee et al., 2020). During the fire season, variation in weather conditions over months and sometimes days can control the moisture content of fuel (Dennison and Mortiz, 2009; Resco de Dios et al., 2022). After that, changes in weather conditions through days and sometimes hours, especially in terms of air humidity, temperature and wind speed, can be a reason for the occurrence and spread of large fires (Abatzoglou and Kolden, 2013; Trigo et al., 2016).

The regions surrounding the Mediterranean basin are characterized by long, hot, dry summers and flammable vegetation. Complex topographic factors and human activities in areas adjacent to forest ecosystems contribute to the occurrence and spread of fires (Ruffault et al., 2017). Therefore, under resent climate change, the risk of the outbreak and spread of forest fires, the length of the fire season and the expansion of burned areas are expected to increase (Amatuli et al., 2013; Kotroni et al., 2020) due to

the impact of rising temperatures and increasing drought intensity and frequency (Zittis et al., 2019; Cos et al., 2022).

The drying of dead fuel on the forest floor is the most important indicator for the onset of fire danger. A group of meteorological indicators is used to determine the level of danger one of the most important of which is the Keetch and Byram drought index, which is widely used in various regions of the world, including regions subject to the Mediterranean climate (Kum and Sönmez, 2016; Abatzoglou and Williams, 2016; Sirca et al., 2018).

Al-Ghab region is one of the most important agricultural areas in Syria, which adjacent to the eastern slopes of the coastal mountains, where the vegetation cover is highly dense and rich in tree, shrub and herbaceous species, which can turn into highly flammable fuel during the dry summer season. Therefore, estimating the risk of forest fires and their variability and change in this region is extremely important to take the necessary preventive measures to limit the outbreak and spread of fires in a way that ensures the sustainable development of these important forest systems.

The research objective was to determine the temporal characteristics of fire danger and to detect changes in these characteristics during the study period extending from 2007 to 2021.

## MATERIAL and METHOD

Daily meteorological data of maximum temperature and precipitation for Al-Kreem station were used to evaluate the risk of forest fires during the period 2007-2021. These data were obtained from the Syrian General Directorate of Meteorology.

Al-Kreem station is located in Al-Ghab Plain, in the sub-humid region (Figure 1) at latitude 35° 26′ and longitude 36° 20′, and is 350 meters above sea level. Average annual precipitation 674 mm with a standard deviation of 203.4 mm.

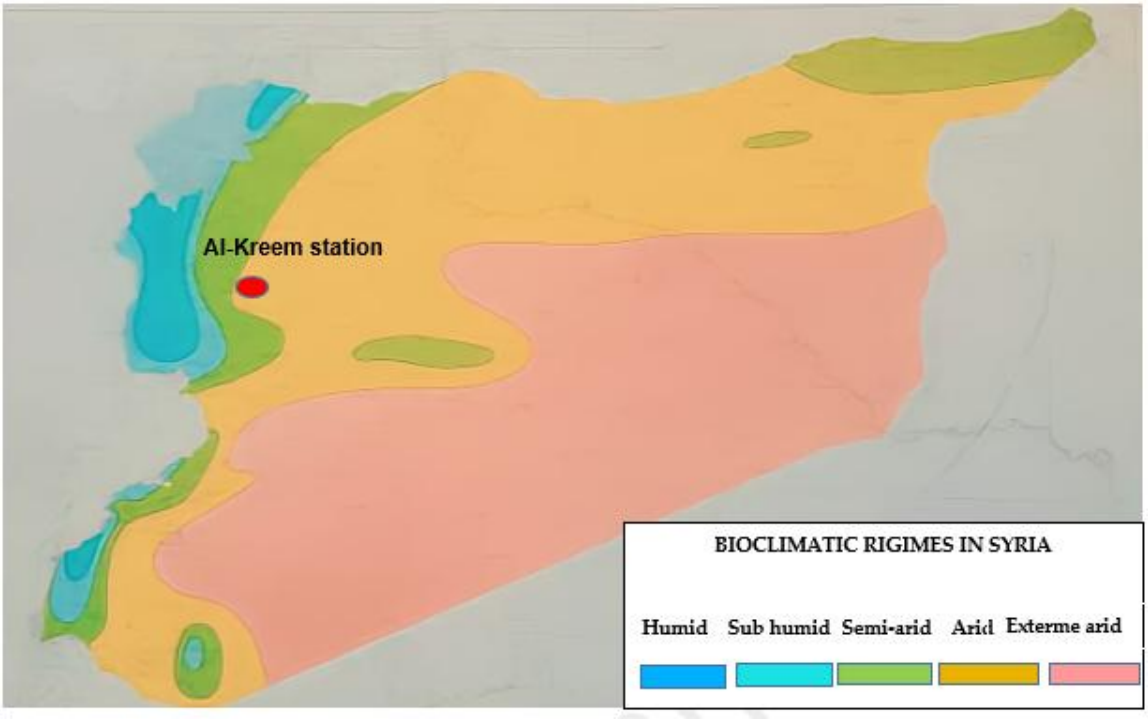


Figure 1. Location of Al-Kreem station, representing Al-Ghab Plain in Syria

The slopes adjacent to Al-Ghab Plain are covered with many trees and shrubs, the most important of which are Pinus brutia, Quercus calliprinos, Quercus pseudocerris, Quercus infectoria Laurus nobiles, Arbutus unedo, Rhus coriaria, Rhus cotinus, Pistacia palaestina, and many other species which together form a dense vegetation cover.

KBDIS software version 1.0 was used to calculate daily cumulative drought index values of the Keetch and Byram (Keetch and Byram, 1968), from the end of the rainy season to the end of the dry summer for each year to estimate of the risk of forest fires during the period 2007–2021.

Since the software use mm and C for rainfall and temperature, respectively, the equation takes the following form:

$$dQ = \frac{(203.2-Q)(0.968\exp(0.0875T+1.5552-8.30)dT}{1+10.88exo(-0.001736R)} * 10^{-3}$$

Here, dQ stands for drought factor (mm), and Q for moisture deficiency (KBDI value for the previous day or value as reduced by the daily net precipitation values); T is expressed as daily maximum temperature (°C); R as mean annual rainfall (mm); and dT is described as time increment (1 day).

Fire risk is determined according to the cumulative values of the index as follows in Table 1.

Table 1. Flammability and associated risk of forest fires depending on different cumulative values of Keetch and Byram drought index

| KBDI | Risk Levels |
|---|---|
| < 99+ | Very Low |
| 100-199 | Low |
| 200-299 | Moderate |
| 300-399 | High |
| 400-599 | Very high |
| More than 600 | Extreme |

Box-plots and descriptive statistical analysis were used, with the Coefficient of Variation (CV%) to study the statistical characteristics of the values of the meteorological elements. Also, to study the statistical characteristics of the fire danger index values during the various months of the study period 2007-2021.

Trends with Mann-Kendall test (Kendall, 1975) were used to detect significant changes in the onset of fire danger, the length of fire season, and the maximum values of KBDI during the period 2007-2021.

## RESULTS and DISCUSSION

### The Characteristics of Maximum Temperatures and Precipitation on the Study Area

Figure 2 shows the most important statistical characteristics of the monthly maximum temperatures during the study period 2007-2021 at Al-Kreem Station which illustrates a clear difference between winter and summer maximum temperatures during the year, with the lowest average in January (11.6°C) and the highest one in August (37C°).

On the other hand, the interannual variability in maximum temperature is very limited, as the value of the coefficient of variation CV% was less than 5% during the summer months, while it exceeds 10% during the cool season months, with the highest value in January (13.8%).

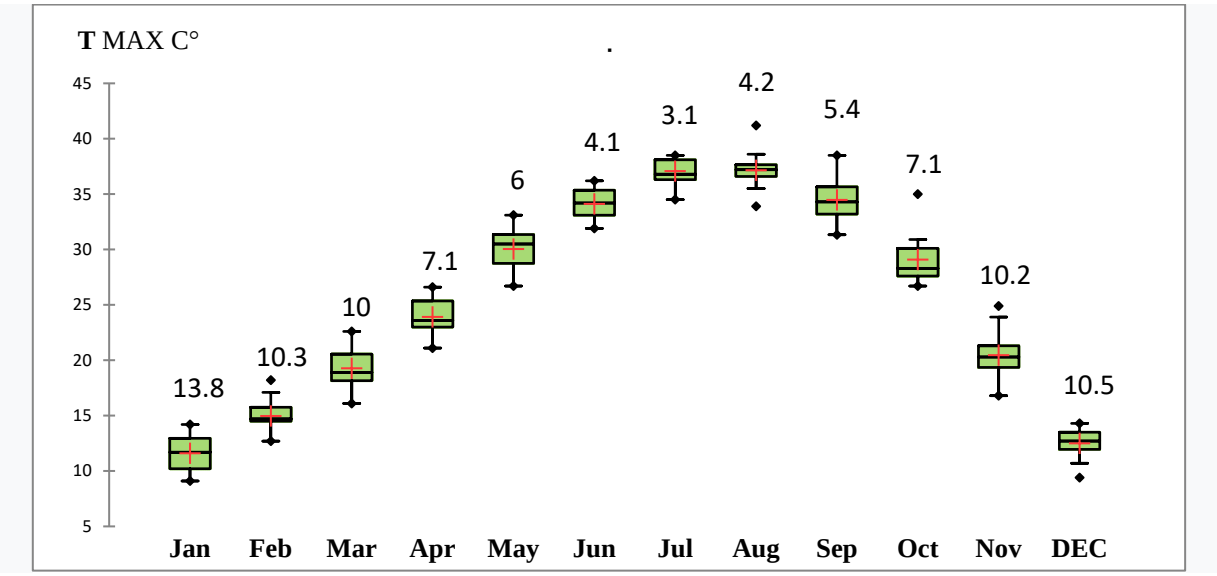


Figure 2. Statistical characteristics of monthly mean maximum temperature at Al-Kreem station 2007-2021

As shown in Figure 3, the precipitation regime in the study regions is Mediterranean with the highest amounts in winter, while the summer is dry. On the other hand, there is high inter-annual variability of perception in all months during the rainy season especially in spring and autumn.

These conditions exert intense stress during the summer and the beginning of autumn, as high temperatures are accompanied by the dry season, which increases the possibility of forest fires, especially during Years in which rain subsides early.

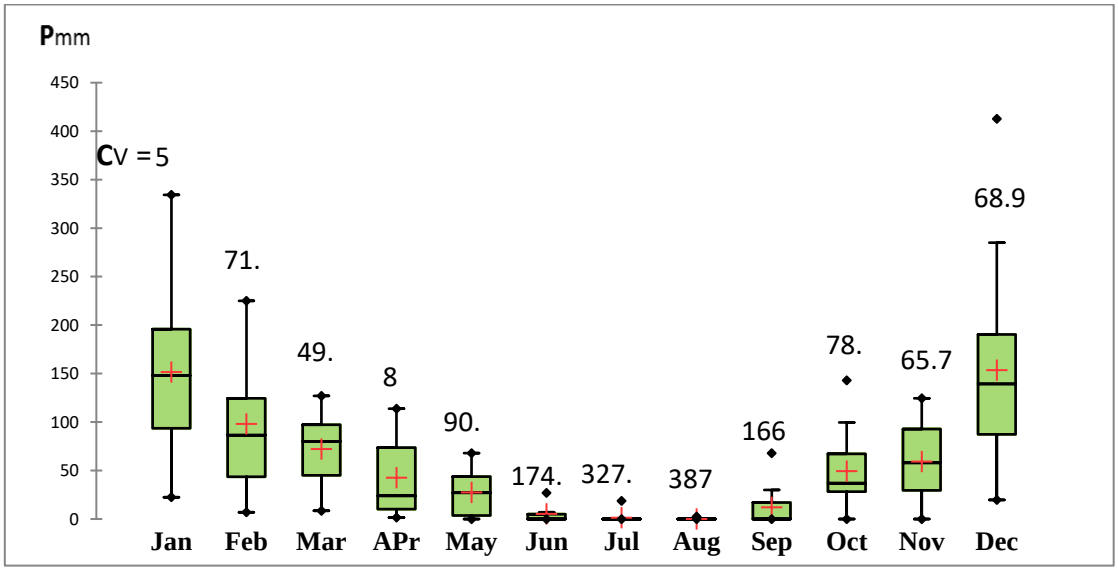


Figure 3. Statistical characteristics of the monthly precipitation amounts at the AL-Kreem station for the years 2007-2021

**Changes in Forest Fire Risk in The Al-Ghab Region**

Figure 4 shows the inter-annual variability in conditions conducive to forest fires during the period 2007-2021. As seen from these charts in figure 4, the risk largely differs from year to year depending on the change in the quantities and distributions of precipitation , as well as the path of maximum temperatures, which play a very important role in determining the outcomes of the vapor pressure deficit (VPD) and thus the accumulation of danger after the last rain event with more than 5.1 mm, in addition to the possibility of rain events during the dry season, which limits the outbreaks of forest fire until accumulation of drought index again that exceeds the danger limits.

The charts in Figure 4 show the changing risk of forest fires in the different years of the study period, which often coincides with the month of July, as happened in the years 2007, 2009, 2010, 2013, 2015, 2018, 2019, 2020 and 2021, but in some years the risk may be delayed until August, as happened in the years 2008, 2011, 2012, 2014, 2016 and 2017. As for the very high risk, it often coincides with August, as happened in the years 2007, 2009, 2011, 2012, 2013, 2015, 2016, 2017, 2018, 2020 and 2021. In a few years, it may begin July, as happened in the years 2010 and 2019. But it is sometimes delayed until September, as happened in the year 2014. Although some years may not witness a very high risk, such as the year 2008, the risk of extreme intensity was the defining characteristic of some years, at September at 2010 and at October in both years. 2020 and 2021. On the other hand, the severe danger may continue for many years until November, as is the case in the years 2020 and 2021, and to a lesser extent in the year 2017.

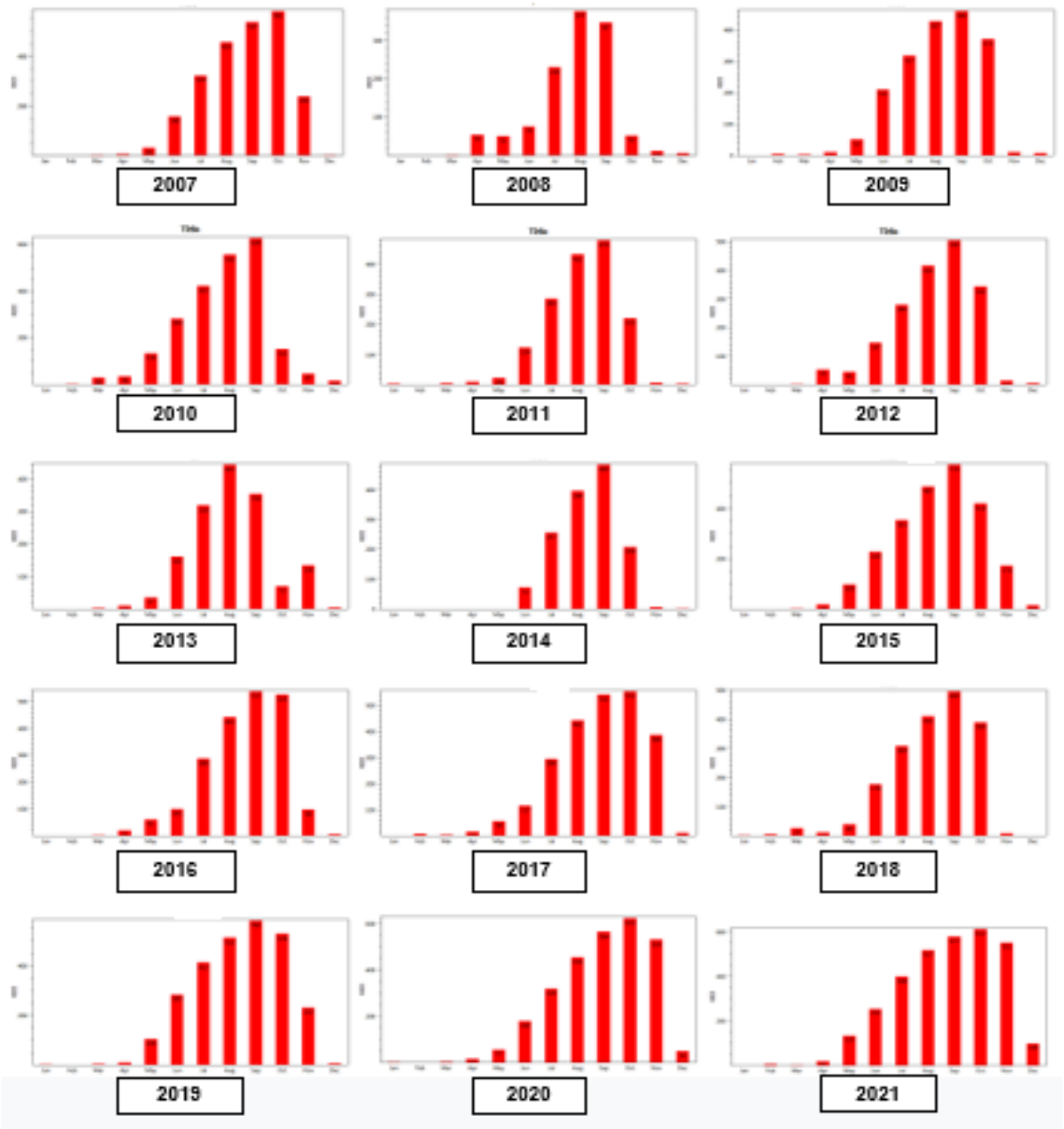


Figure 4. Variability of the risk of forest fires between years in AL-Ghab region for the years 2007-2021

Figure 5 shows the statistical characteristics of the monthly KBDI index values during the study period 2007-2021 at Al-Kreem station, which illustrate that the highest rate of risk of forest fires occurs in September, followed by August and October. Noting that the greatest risk of fire may correspond to October, at a level like September in some years. This result is consistent with the study of Kum and Sönmez (2016) in Türkiye on periods of greatest risk for forest fires.

This large variation in danger during the month of October results from the large differences between years at the beginning of the rainy season, as early rainfall in September or November reduces the risk of fire outbreaks, while the continuation of

the dry season has a clear role in increasing the fire risk during the years in which there is a delay in the start of the rainy season.

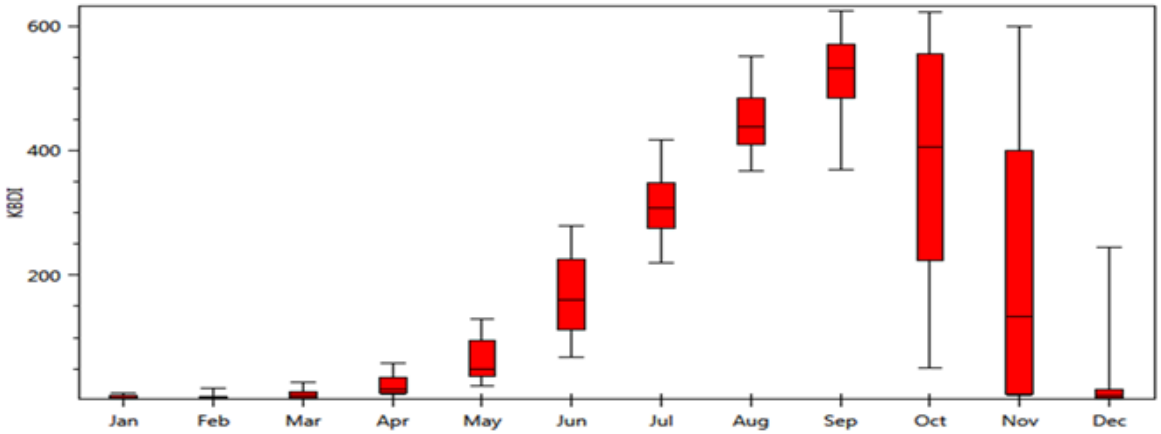


Figure 5. Statistical characteristics of the Keetch & Byram index values calculated for for the years 2007-2021 which express the variation in the risk of forest fires outbreak at Al- Kreem station

Figure 6 shows the change in the onset of wildfire risk during the study years according to the exceedance of the sums of the KBDI values for the thresholds of moderate risk (greater than 200), high risk (greater than 300), and very high risk (greater than 400), since the end of April. It is noted that the number of days until the start of moderate risk varies between 62 days and 104 days during different years, while the number of days until the start of high risk varies between 80 days and 123 days, while the number of days until the start of very high risk varies between 109 days and 145 days.

Analyzing the time series of the number of days until the beginning of the risk of forest fires during the years of study period, it is noted that there is a clear trend towards a decrease in the number of days until the start of the risk. The number of days until the beginning of the moderate risk decreased by 13 days, and of high risk decreased by 13.5 days, while of very high risk decreased by 12.5 days. Subsequently, there is a clear trend towards an increasing early risk of the outbreak and spread of forest fires in the region.

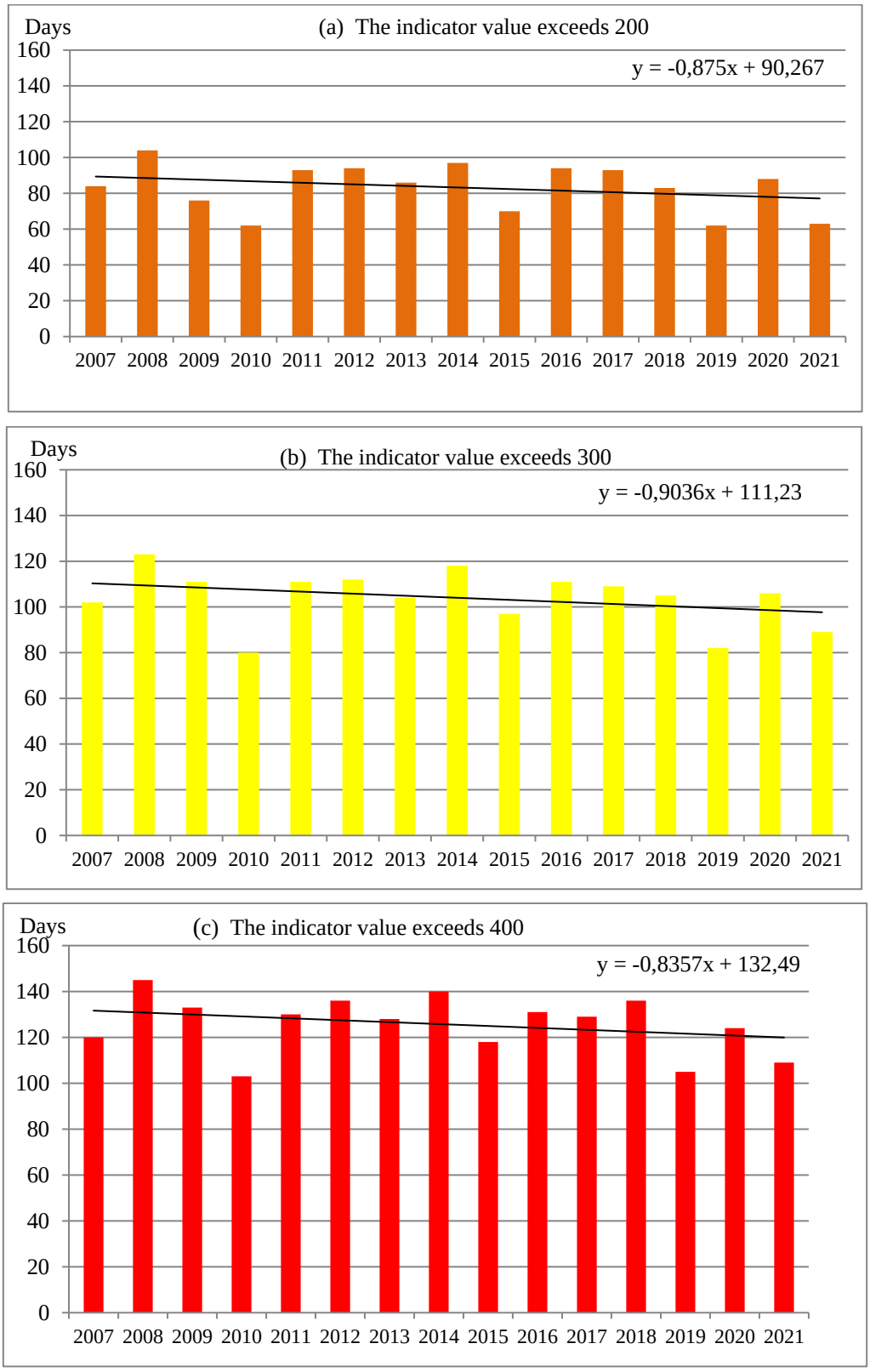


Figure 6. Number of days from the end of April until the beginning of the risk of forest fires: (a) moderate risk, (b) severe risk, (c) very severe risk.

Figure 7 shows the difference in the highest value of the forest fire danger index between the years of the study period in AL-Ghab region, where it is noted that the fire danger is very high during all years except 2008, when the index value did not exceed the high danger level. while during the years 2010, 2020 and 2021, the level of danger was extremely severe. By analyzing the time series of the highest value of the index, there is a sharp increase in the maximum value of fire danger, where the highest value of the KBDI index increased by 117.4 during the study period, and the change was significant at the level of 0.05.

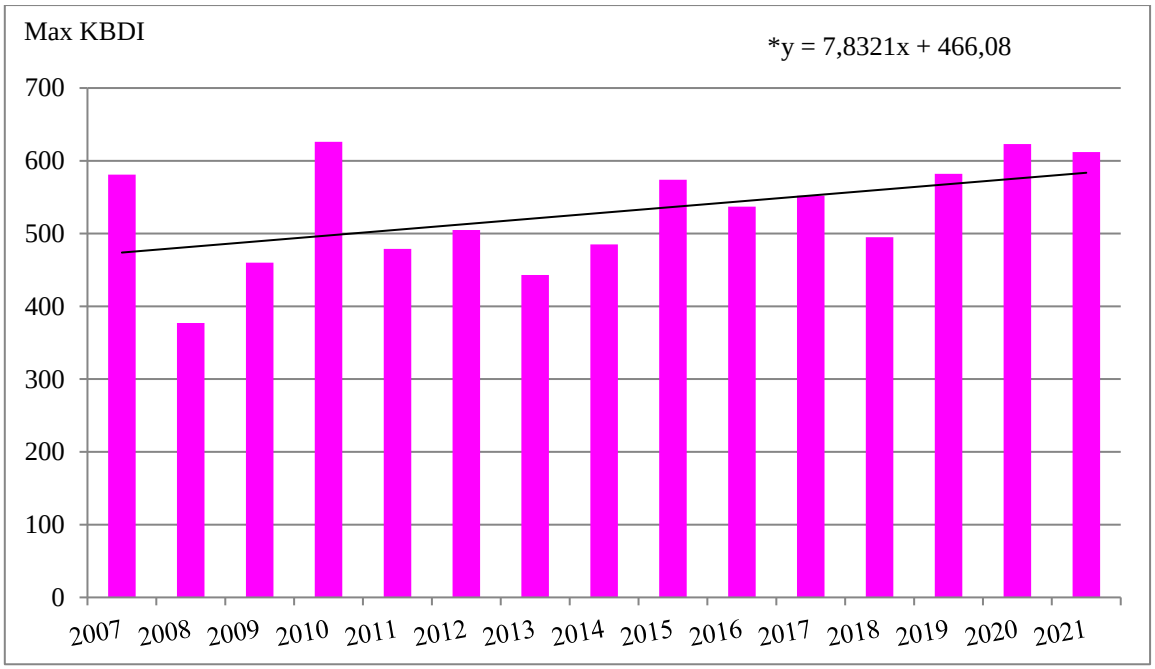


Figure 7. Variation in the highest value of the Keetch & Byram index between years at Al-Kreem station with the general trend of change during the period 2007-2021. * The change is significant at the 0.05 level

Figure 8 the length of the fire season varies greatly from year to year, whereas the length of the fire season in 2008 was limited to 72 days, the fire season extended to 189 days in 2021. On the other hand, there is a clear and significant trend towards an increase in the length of the fire season during the study period by about 72 days as shown in Figure 8.

It is clear from the results reached in this research that there is a close relationship between the risk of forest fires and the changing meteorological conditions from year to year. The amount and distribution of precipitation and maximum temperature levels play a very important role in determining the onset and severity of the danger, depending on the time of precipitation retention at the end of spring and the extension of the dry season accompanied by high temperatures, which determine the continuity of fire danger with the delayed start of the rainy season in the fall.

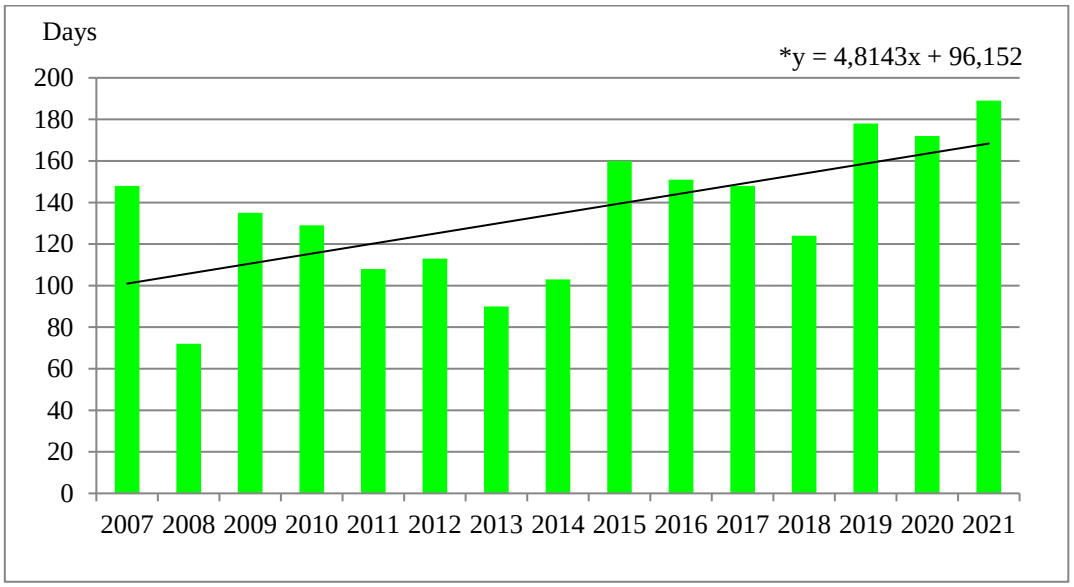


Figure 8. Variability and change in the length of the fire season at AL-Ghab region during the period 2007-2021

The results of this study are consistent with many studies on the role of current climate change in increasing the risk of forest fires in various regions of the world (Gannon and Steinberg, 2021; Jones et al., 2022), especially those subject to the Mediterranean climate (Varela et al., 2019; Bacciu et al., 2021; Serbouti et al., 2022).

## CONCLUSION and RECOMMENDATIONS

It is clear from studying the general climatic characteristics of the Al-Ghab region that the climatic conditions are conducive to the outbreak of forest fires, due to the long dry and hot summer and the large inter-annual variability of precipitation.

The results of the study showed a clear difference between years in the timing of the onset of forest fire risk, depending on the quantity and distribution of precipitation and the level of maximum temperatures.

The results indicated that the greatest risk of the outbreak and spread of forest fires often occurs in September or August, but the risk may be very high in October when rainfall is delayed.

The study confirmed an increase in the risk of forest fire outbreaks due to the rising tendency of maximum KBDI values, a longer fire season, and earlier onset of fuel dryness in the Al-Ghab region during the study period of 2007-2021. This poses a threat to the forest ecosystems and requires appropriate preparation to confront the danger of fires.

We suggest that there is a need to expand the study of forest fire risk in different forest areas in Syria using various indices over extended periods of time. Additionally, there is a need for the integration of meteorological and remote sensing indicators to accurately predict the dryness of live and dead fuels, as well as to identify the onset of forest fire risk and take the necessary measures to address it.

**Conflict of Interest**

The authors have declared that there are no competing interests.

**Authors Contribution**

MS conceptualized the paper, EZ statistical analysis: MS, RA, and EZ performed literature search; MS, RA and EZ wrote the manuscript. All authors read and approved this manuscript.

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