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RESEARCH ARTICLE

Using high precision climate data for wildfire risk assessment

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Abstract

The present study is focused on examining the changes of key weather parameters using detailed daily data for the period 1985-2021 in an area of interest situated in Rila mountain in Bulgaria which is a territory that is prone to wildfires. Using this long-term horizon, the research defines the main climate factor trends and relates them with real events of wildfires by using the Angström index and statistical methods with focus on outlining specific weather conditions that indicate fire risk. As a result, the Angström index was proven to be a reliable source for determining the potential weather conditions for fire occurrence in the area of interest, part of protected area BG0000496 Rilski manastir. Low relative humidity was identified as the main factor influencing fire occurrence in the reviewed real wildfire events. Specific range and behavior of the key weather parameters, influencing wildfire occurrence were detected. These findings could be a good source of information when elaborating a forest fire prevention system and may help for appropriate prioritization of factors and management of resources.

Keywords

wildfires, Angström index, climate change, climate data, Rilski Manastir protected area

Introduction

Wildfires have been a topic for research all over the world. The causes, effects, evaluations of hazards and vulnerability, prevention and risk calculations are only a small part of the aspects of this issue. Now that the climate change effects are becoming more and more tangible and nature worldwide more and more fragile, wildfires acquire new roles in ecosystem and global processes. The frequency and intensity of wildfires, and amount of burned areas depend on the current weather conditions, therefore warming of climate, generally, will increase the risk of hot and dry weather, conducive for wildfires (Semenova, 2022). Moreover, wildfires threaten forest values and ecosystem services, as well as people and human assets, which is also raising the risk issue. In the context of global warming, shifts in fire regimes and future risk need to be anticipated for the adaptation of forest and fire management policies (Dupuy, 2020). The change in the fire regimes may have significant ecological consequences because the newly emerged regimes could affect the ecosystem's ability to recover and provide services. There is an opportunity for land management to mitigate these impacts, either by limiting changes in the fire regime or by maintaining and enhancing landscape resilience (Aponte, 2016). Although landscape pattern and fuel limitations were key factors that historically limited fire size and severity, these limitations have been largely removed from many contemporary landscapes, thus increasing the potential for large high-severity fires, particularly in a warming climate (Halofsky, 2020).

The relationships between various aspects of fire activity and the key factors such as weather – climate, fuels, and people have already been established. These factors regulating wildfire are dynamic and will continue to change as the climate, fuels, and people respond to global change and other influences. Fire activity is expected to continue to increase owing to climate change (Flannigan, 2009). Research to date suggests that fire weather will be more severe, fire ignitions (people-caused and lightning-caused) and area burned will increase, and the fire season will lengthen (Flannigan, 2006). Climate and weather are decisive drivers of fire activity, e.g. through high temperatures, low precipitation, wind occurrence and lightning (Zumbrunnen, 2010). Variability in rainfall, temperature, wind and humidity as a result of climate change – under the scenarios considered – will mean that the fuel moisture of deep layers of wood, leaves, soil and other organic matter on the ground will be affected (de Rigo, 2017).

Considering the crucial role of climate factors for the occurrence and spread of wildfires, the present research is focused on examining the changes of temperature and humidity for the temporal horizon of 36 years in the period 1985-2021, based on detailed daily data for an area of interest situated in Rila Mountain, Bulgaria, that is prone to forest fires. Using this long-term horizon, the article aims to define the main climate factor trends and relate them with real events of forest fires by using the Angström index with focus on outlining specific weather conditions that indicate fire risk.

Methods

To trace the trends in climate change, complete, high-precision, and reliable data is needed. The period 1985-2021 covers a very dynamic period for industry and technology changes with a beginning, coinciding with the popularization of the global warming notion

(Ungar, 1992). The daily data provides enough detail to trace the weather circumstances accompanying occurrence of fire, which is very valuable information. Meteoblue platform provides historical weather simulation data, based on the proprietary global numerical weather model NEMS with a high-grid cell size of 4 km. The data is consistent, without any gaps and is acquired with temporal resolution of 1 day.

Table 1. Content of the weather information from Meteoblue, 1985-2021

Temp	Temp	Precipitation Total	Snowfall Amount	Relative Humidity	Relative Humidity	Relative Humidity	Wind Speed	Wind direction
°C at a height of 2 m	°C	mm	cm	%	%	%	km/h	°
min	max	mean	mean	min	max	mean	mean	

The area of interest is located in the national zone with high risk of forest fires and is characterized by mountain relief. The processing and analyzing the data is realized considering geographic specifics and the use of simulated input parameters.

The area of interest is located in the alpine biogeographic region of the mountain zone in Rila with an elevation of 1200-1300 meters, part of Natura 2000 protected area BG0000496 Rilski Manastir. It is characterized by steep hills with vegetation dominated by dwarf mountain pine and juniper. This is an area with an intense history of forest fires – 7 since 2012, according to the sensors MODIS (NASA, 2022) and VIIRS (NASA, Earthdata, 2022), and a recent one from 2022. It is proven that the occurrence and spread of forest fires is a result of the interaction of many factors – climate, vegetation, topography, and human activities (Quan, 2022). Here the focus is on the most variable of the important abiotic factors – weather. The region is characterized by mountain climate, with higher humidity and precipitation in the winter months.

The Angström index was used to make a connection between the weather indicators and the potential for a wildfire outbreak. The Angström index is used to calculate and define the fire danger at a particular moment. It is supposed to be calculated daily and works better with the values of the parameters at 1:00 pm. It is based only on the air temperature and relative humidity and does not take into consideration fuel moisture or evapotranspiration as other indices. It does not accumulate the danger ratings over time, it is a daily index with climatic approach. It was tested in Sweden and Germany and elaborated in 1949, studied in polar climate with high precipitation and humidity (Hamadeh, 2017) . It categorizes the fire conditions in 4 classes, the lower the index – the higher the risk of fire occurrence.

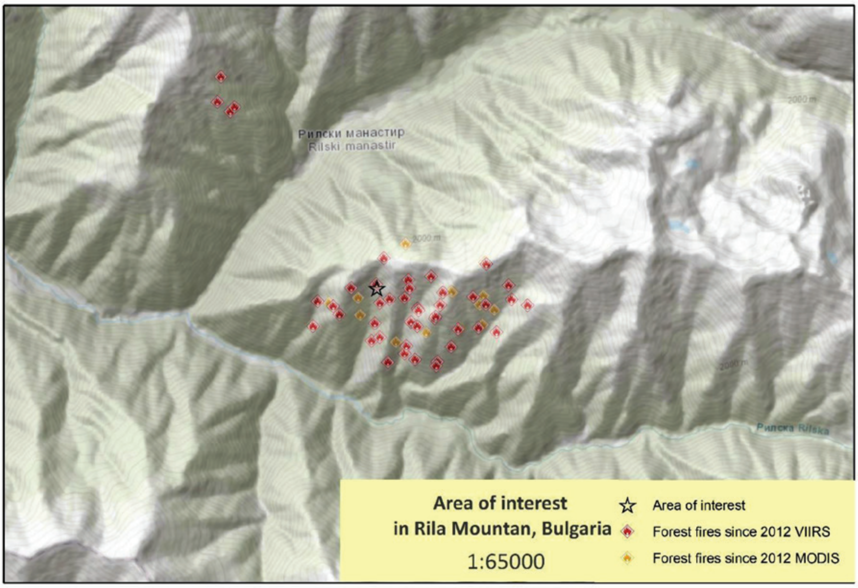

Figure 1. Area of interest in Rila Mountain, Bulgaria and history of forest fires since 2012, historic data for forest fires from VIIRS and MODIS, basemap – Google Maps

This index shows good results in research in Slovenia, when it was tested along the Nesterov and Baumgartner indices. It proved to be the most sensitive measure of fire occurrence risk forecasting (Skvarenina, 2003). Furthermore, it was tested in Greece (Mavrakis, 2007) for investigating the prognostic forest fire risk in 2007, when the territory was threatened by huge forest fires, and again gave good results.

The Angström index (I) is calculated according to the formula:

$$I = (\frac{R}{20}) + (\frac{27-T}{10}),$$

where R is relative humidity (%)
and T is the air temperature °C.
The results are interpreted as follows:
Index > 4.0 Fire occurrence unlikely
4.0 > index > 2.5 Fire conditions unfavorable
2.5 > index > 2.0 Fire conditions favorable
Index < 2.0 Fire occurrence very likely.

Because the index works better with the daily data taken at 1:00 pm, the maximum values for temperature and minimum for moisture were used to get closer to these conditions.

This index was calculated for each day in the period 1985-2021, generating a series of 13667 records to analyze. This data is processed in excel via pivot tables and the tendencies for the index for this period are illustrated via charts. Correlation analysis was used to determine the direction and strength of the relations among the key parameters.

A supposition of the index data results, and the real forest fire event is made to outline the climate conditions that contribute to fire ignition.

In high-temperature, dry and windy weather, the moisture content of combustibles is low, and their own temperature is high, so that little energy is required to reach an ignition point, which greatly increases the risk of forest fires (Quan, 2022). That is why, additional review of the weather parameters was made to outline any patterns. Hot weather, strong winds under low air humidity play a significant role in the occurrence of extensive fires (Semenova, 2022). Kutiel (2012) confirms that the most important parameters for rapid fire propagation are the wind speed, temperature, relative humidity but also the number of dry days since the last rain. Using these findings, the research is also focused on a 5-day buffer period before the fire event, looking for some pattern in the key weather parameters that could be outlined and that could serve as a warning for high caution.

Of course, when looking for these patterns the influence of factors other than the weather should be taken into account. Koutsias (2013) studied the relationships between forest fires and weather conditions in Greece from long-term national observations (1894–2010). The findings suggest that weather is an important factor that controls to some extent the fire occurrence in Greece. Fire regime in the Mediterranean is influenced by factors beyond those related directly to weather conditions (e.g. socioeconomic, land use–land cover changes, anthropogenic pressures and intensive human influences), however climatic and weather conditions have a profound effect on fire occurrence over time.

Results

The suggested analysis of long-term high-precision weather data gives an opportunity to track the relations among parameters and look for patterns and trends. Looking at the data from a climate change perspective and the notion of global warming, the probability that the average temperature has increased had to be first checked. Global surface temperature has increased by at least 1.1° Celsius (1.9° Fahrenheit) since 1880 (NASA) and 0.2°C per decade since 1985 (Hansen, 2006). To follow these studies, the change in maximum temperature per decade for this particular location was calculated.

Period	Mean temperature for the period (°C)
1985-1995	9.97
1996-2005	9.72
2006-2015	10.4
2016-2021	10.7
Trendline	

Figure 2. Trend in mean temperature for the period 1985-2021 (°C)

For 1985-2021 the mean temperature per decade shows a trend of increase. Considering the climate variability, this timeframe is relatively short for climate perspective to outline a definitive trend and more observations are needed to confirm its direction and its volume. Nevertheless, the increase of the period of interest is confirmed and will be taken into consideration in the further analysis.

To determine the long-term trend of the weather conditions that favor the occurrence of fire and verify whether climate change has a tangible effect in this aspect, the Angström index was calculated on a daily basis for the period 1985-2021.

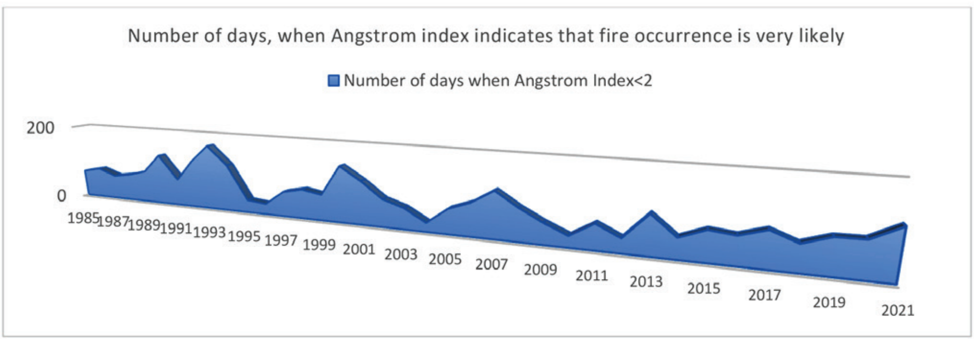

Figure 3. Number of days, when Angström index indicates that fire occurrence is very likely, data by Meteoblue

The data, visualized in the chart, does not confirm any clear long-term rise of the levels of risk that the weather conditions generate. In the beginning of the 1990's there was a 5-year period (1990-1994) with an average of 124 days with very likely fire occurrence. From this data, there are two possible trends that are interesting to discuss. The first is the cyclic nature of the climate balance that shows highs and lows every 4-6 years. And the second is the stability and upward trend that breaks this pattern after 2012. Actually 2012 and 2015 are years with intense wildfires in these regions.

To have a more detailed insight into the relation humidity – temperature – Angström index and its direction, a breakdown of the three indicators was made and they were reviewed in parallel. The chart in Figure 3 is generated on the summed yearly statistics.

This disassembling of the index shows clearly how the weather, favorable for fire occurrences, is influenced by the temperature. The vague upward direction of the maximum temperature is resonated by the Angström index and is well pronounced after 2012, when there is a certain stability in the figures. Once again it

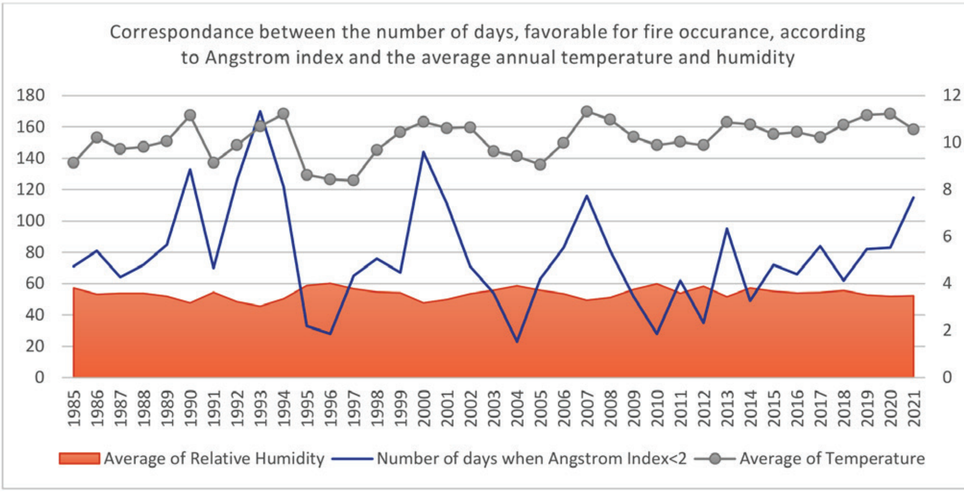

Figure 4. Correspondence between the number of days, favorable for fire occurrence, according to Angström index and the average annual temperature and humidity

must be outlined that a longer line of observations is needed, to confirm that this is a trend.

The chart shows the relationship between the index and its compound parameters. To investigate deeper into these relations a correlation analysis was made. It is generated from the daily statistics of the 1985-2021 period.

Table 2. Correlation between the Angström Index, average temperature and relative humidity in Rila mountain, based on daily data 1985-2021 from Meteoblue

	Relative Humidity (%)	Temperature (°C)	Angström Index
Relative Humidity	1		
Temperature	-0.59882	1	
Angström Index	0.971443	-0.39169	1

As the formula suggests, the index is directly proportional to relative humidity and inversely proportional to temperature. This analysis shows a much stronger dependence of the index on the relative humidity parameter than the temperature. The results should be interpreted with extra attention, because the higher the index, the less fire risk. That is why the correlation of the index and the relative humidity in the correlation analysis are directly proportional.

To consider another perspective of the fire occurrence the study investigates how the Angström index is distributed seasonally. The review is done quarterly, calculated as a summary of days with index more than 2 for the period 1985-2021, and as a mean number of days.

Table 3. Angström index by quarters of the year

Quarter of the year for the period 1985-2021	Number of days when Fire occurrence is very likely	Mean number of days when fire occurrence is very likely
Jan-March	563	6
April-June	732	8
July-Sept	855	10
Oct-Dec	775	9

This analysis shows that the period July-September offers the most favorable conditions for fire occurrence. The period October-December is interesting, because in this climate zone, it offers more days with weather conditions that facilitate fire ignition.

To test whether these observations correspond to the conditions with real fire events, we made a review of the key weather parameters and Angström index for 4 forest fires that took place in the area of interest.

Table 4. Key weather parameters and Angström index in the days of wildfire event and a buffer of 5 days before the event, Source: Meteoblue

Date of fire event for 4 close mountain locations	Temp. max (°C)	Range max temp. for the previous 5 days	Precipitation min (%)	Range Precipitation min for the previous 5 days (%)	Relative Humidity	Range relative humidity for the previous 5 days	wind speed mean (km/h)	Range wind speed mean (km/h) for the previous 5 days	Angstrom Index	Range Angstrom Index the previous 5 days
19/08/2012	**18.29**	18.29-20.93	0	0-0	**51**	42-51	**7.7**	6.5-7.7	**1.68**	1.34-1.67
23/08/2012	**25.35**	18.29-25.35	0	0-0.8	**32**	32-51	**4.5**	2.6-7.7	**1.44**	1.38-1.67
23/07/2015	**22.27**	22.16-24.13	0	0-0	**35**	35-42	**5.7**	5.8-8.9	**1.28**	1.27-1.66
9/09/2012	**23.08**	21.60-26.13	0	0-4.4	**34**	32-46	**8.5**	3.7-9.9	**1.30**	1.28-1.76

The first thing that could be confirmed is that the Angström index for all is very low (high risk), and not only for the day of the fire, but also for the 5-day buffer before the event. The second important factor is the lack of precipitation again, both on the day of fire and 5 days before the fire. Another important observation is that the low relative humidity does not exceed 50 %. The range of temperature and wind is also narrow. All the fires happened in the summer months – July, August and September.

Discussion

Detailed weather data is a powerful source of knowledge, especially in the times when climate changes and alters the ecosystem balance as we know it. The insights about the patterns, trends and relations between weather parameters and disaster events may be used as the instrument to predict, avoid, and minimize the negative consequences.

The present study steps on detailed weather information for a 36-year period that allows for looking into certain relations and patterns that would help explore the fire risk and the weather conditions that lead to wildfires.

The analysis of the data shows a rise of average temperature for the period and this is directly related to an increase of the fire risk that the Angström index detects. The trend is ambiguous and needs further research in time to determine whether the number of days with fire danger alert continues to intensify.

Meanwhile, the Angström index pays more attention to relative humidity as a factor that contributes to fire risk with a correlation coefficient of 0.97. Relative humidity and temperature are certainly among the main fire risk factors, but which of them is more significant is a controversial topic. In order to identify the ideal weather conditions for fire breakouts, Tošić et al. (2019) test different combinations of input variables, e.g., meteorological variables (mean temperature, precipitation, relative humidity, maximum temperature, minimum temperature and wind speed), fire danger indices or a combination of both, for the Belgrade area during the period 1986–2017. It was found that using relative humidity or precipitation as a predictor only generates a satisfactory model for forecasting of the number of forest fires. Konca-Kedzierska (2018) also concludes that low relative air humidity not only accompanies the occurrence of forest fires but is also inseparably connected with it. On the other hand, research for the Mediterranean region found out that three parameters (Temperature, Soil Temperature and Dew point) are the most influential ones that induce fire occurrences. These parameters show a good correlation with fire occurrence, while the other parameters (Humidity, precipitation, and wind speed) demonstrate limited weak correlations with fire occurrence (Hamadeh, 2017). Arpaci et al. (2013) found that in the summer season, the mean daily temperature is a good proxy for fire danger for Austrian conditions. Most probably the specifics of the terrain play the most important role for the variance of the impact of the two factors. What is important to be underlined in this study is if the Angström index behaves well and could be a reliable source for fire risk alert for the area of interest.

Therefore, a test was made of the Angström index on weather conditions of 4 real wildfire events that took place in the area of interest and its vicinity. The results show that the index detects that the fire occurrence is very likely on the day of fire ignition and 5 days in a row before the event. Based on these results, it could be concluded that the index is reliable for the conditions of the area of interest, and it could be used as an instrument for detecting weather conditions that lead to fire risk in the low parts of Rila. After applying this instrument for 1985-2021, the period of the year with the most intense fire risk is July-September. Generally, in Bulgaria, the forest fires take place in the summer because of the significant impact of the heat waves. More, longer and having higher air temperatures, heat waves provide more favorable conditions for the occurrence and development of forest fires (Nojarov, Nikolova, 2022). In this mountainous area, though, October-December should also be considered as a period with raised fire risk. These findings could help fire monitoring, prioritization of prevention measures and overall channeling of the efforts of all parties involved.

These conclusions are a good basis for further and more complete analyses and review of the weather conditions. The Angström index does not include the potential evapotranspiration parameter, soil temperature, soil moisture, dewpoint temperature and vapor pressure, sunshine duration, wind – these are factors all influencing fire ignition. According to Arpaci et al. (2013) the Angström index might be good if there are rapid changes in weather situations, which increase the fire danger situation so quickly that fuel or soil moisture models are not able to capture that moment. Nevertheless, it was proven that the Angström index works in these conditions of the selected mountain area. So, it could at least serve as a base for furthermore detailed studies that narrow down the risk to a more specific time slice.

Another important observation is the very similar and constant weather conditions in terms of precipitation, relative humidity, wind speed and maximum temperature during the 4 wildfire events that took place in the area of interest and its vicinity. In the days before and the day of each of the fire events, there was stable warm temperature and no precipitation which leads to low humidity. These circumstances also affect other factors, important for fire occurrence such as soil temperature, soil moisture, fuel moisture, that were not studied in this paper. As visible from the data extreme temperatures and heat waves are not the case in these wildfires. The maximum temperatures in July-September for this area are 25-30 °C, while the observed range from 18°C to 26°C. The relative humidity for this area for the July-September period is 82.6% and the observed is way below this average, ranging from 32-51%. The wind speed is below the average of 10 km/h and does not show any extremes and patterns in this case. A closer look at the wind direction would give another meaning of this factor.

Conclusion

This study proved the Angström index to be a reliable source for determining the potential weather conditions for fire occurrence in the area of interest, part of protected area BG0000496 Rilski Manastir. It could serve as a good base for further studies and be refined and supplemented with data for other factors. Low relative humidity was distinguished as the main factor, influencing fire occurrence in the four reviewed wildfires. The very similar weather conditions in terms of precipitation, relative humidity, and air temperature in the analyzed real fire events allow to identify specific ranges for the values of these parameters for that territory that could be an alarm for fire danger.

These findings could be a good resource when elaborating a forest fire alarm system and may help for appropriate prioritization of factors and management of resources. The present study also shows the importance of climate data as a powerful source of knowledge that may be critical for gathering and applying information needed to develop disaster risk reduction plans (Sarafova, 2022). Considering the prognosis for intensifying wildfire risk (C2ES, 2022) this might become an even more tangible need.

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