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Research Article

Fire Risk Mapping for Holm Oak Forests in El Hassasna Region as Part of the Ecosystem Restoration Programme

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Abstract
In the context of the restoration of the holm oak forest ecosystem, which has suffered damage from wildfires, and with the aim of reducing the wildfire risk, the primary threat to these natural habitats, this study seeks to establish a systematic approach to map areas at risk of forest fires. This approach relies on the use of remote sensing data, including Landsat 8 satellite images and digital elevation models using Geographic Information System (GIS). Factors influencing the ignition and spread of forest fires were assessed, including vegetation cover, topography, and human factors. A forest fire risk map has been created for the Holm oak forest in the Al Hassasna region (Saida province), enabling local authorities and forest managers to implement more effective fire prevention and management measures.

Keywords: Remote Sensing, GIS, Forest fire risk index, EL Hassasna, Algeria.

Introduction

For many decades, the Algerian forest has been facing an exacerbation of deteriorating factors such as overgrazing, attacks by the processionary caterpillar, deforestation, and illegal logging, but wildfires remain the most formidable among the threats to the Algerian and Mediterranean forests. The latter benefit from favorable physical and natural conditions for their emergence and spread [1,2].

The regions with a Mediterranean climate have experienced numerous wildfires since prehistoric times, as demonstrated by various archaeological studies. Heavily populated and transformed in terms of land use, the Mediterranean rim is subjected to a summer drought, sometimes very pronounced and lasting, just during the period when plants need water the most [3,4]. Forest fires cause significant damage to natural resources and human lives. It is a natural and recurring phenomenon in Algeria, particularly over the last two decades [5,6].

As part of the ecosystem restoration efforts for the Holm oak and with the goal of reducing the forest fire risk as a source of degradation, it is essential to develop a forest fire risk mapping using data from geographic information systems and remote sensing. This mapping will help identify areas with varying levels of risk, enabling forest management authorities to design a fire prevention and protection plan. This plan aims to ensure the

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safety of individuals, protect property, and preserve vegetation formations [7].
At the national level, wildfires are considered the most devastating threat to Algerian forests, with over 30,000 hectares being ravaged annually. Faced with this situation, it is impossible to remain indifferent to the eradication of vegetation cover, which could threaten the country's balance [8]. According to the General Directorate of Forests, approximately 53,975 hectares were burned in 2017, and in 2021, fires scorched 89,000 hectares across 35 provinces, resulting in at least 90 deceased. The most affected areas are the eastern and central regions of the country during the summer period.
At the local level, in the province of Saïda, anthropogenic degradation, overgrazing pressure, and repeated wildfires are linked to severe ecological conditions, rendering the forests particularly vulnerable [9,10]. This alarming situation, exacerbated by forest fires, calls for the rapid and effective implementation of protection, conservation, and restoration measures. Among these conservation and restoration measures is the reduction of the forest fire risk [7,11,12]. In recent years (2019-2022), this region has been less affected by wildfires, with 119 fires recorded, affecting 925 hectares according to data provided by the Saïda Forest Conservation in 2023.

In the context of restoring and preserving the Holm Oak ecosystem in the Saida province and significantly mitigating the danger posed by forest fires as the primary degradation factor, this study aims to develop a map of forest fire risk zones based on the level of risk (very high, high, moderate, low, and very low). The objective is to establish a plan for the preservation, protection, and firefighting against forest fires to reduce the deterioration of this forest ecosystem caused by fires. To achieve this objective, the study relies on the use of data from geographic information systems and remote sensing. These technological tools allow an in-depth analysis of the territory and provide crucial information to establish effective fire management strategies.

Materials and methods

Presentation of the study area

The Holm oak forest of El Hassasna is located in the northwest of Algeria, between longitudes 0°23'30" and 0°27'30" E, and latitudes 34°39'30" and 34°51'30" N. It is considered one of the most important natural Holm oak forests, covering an area of 28,000 hectares (Figure 1). Its topography varies from 1005 meters to 1336 meters above sea level. It is characterized by a semi-arid continental climate with rainy winters (360 mm/year) and cold, dry summers. The dry period extends for 6 months [13].

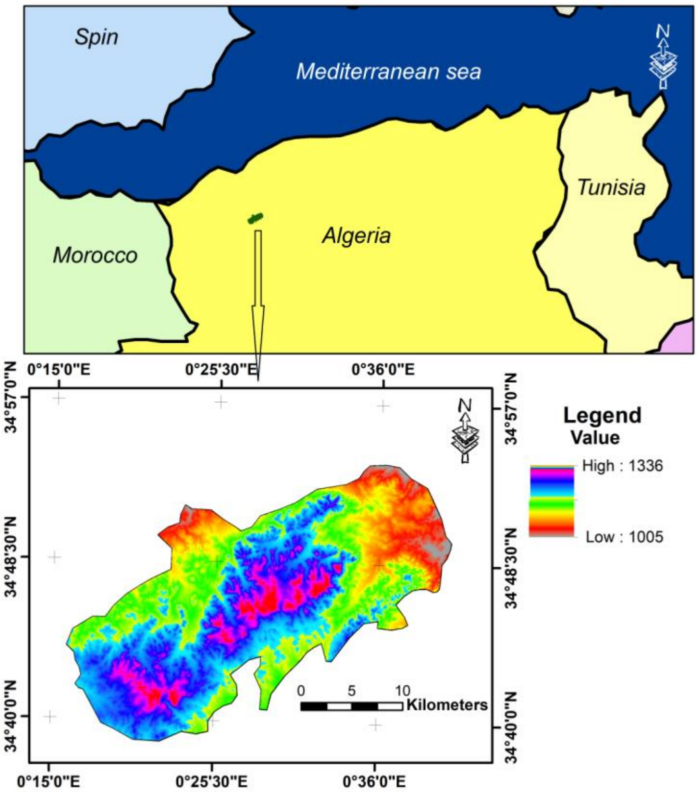


Fig.1. Geographical location of green oak grove (El Hasassna – Saida)

Description of model used

The model (1) applied in this research is based on the approach used by Erten et al. [14]. Its advantage lies in the fact that it is not overly demanding in terms of data, especially when it comes to forest fire-related data, which are often quite incomplete. The literature review in this field has shown that this model is relatively widely used and generally exhibits a certain level of consistency with reality [15].

$$RC = 7 * VT + 5 * (S + A + E) + 3 * (DR + DS + DF) \quad (1)$$

Where: RC = Forest Fire Risk Factor, VT = Vegetation, S = Slope, A = Aspect or Exposure, E = Elevation, DR = Distance from Roads, DS = Distance from Urban Areas, DF = Distance from Houses and/or Cultivated Lands.

The application of model (1) is closely tied to the values in the data table created by Anteur et al. [16]. Each of these factors is categorized into several intervals.

Methodology

The study method included (Figure 2): (i) gathering all remote sensing data, (ii) extracting fire risk factors (vegetation, topographic factors, anthropogenic factors), (iii) applying the adopted model (1), and (iv) creating the fire risk map.

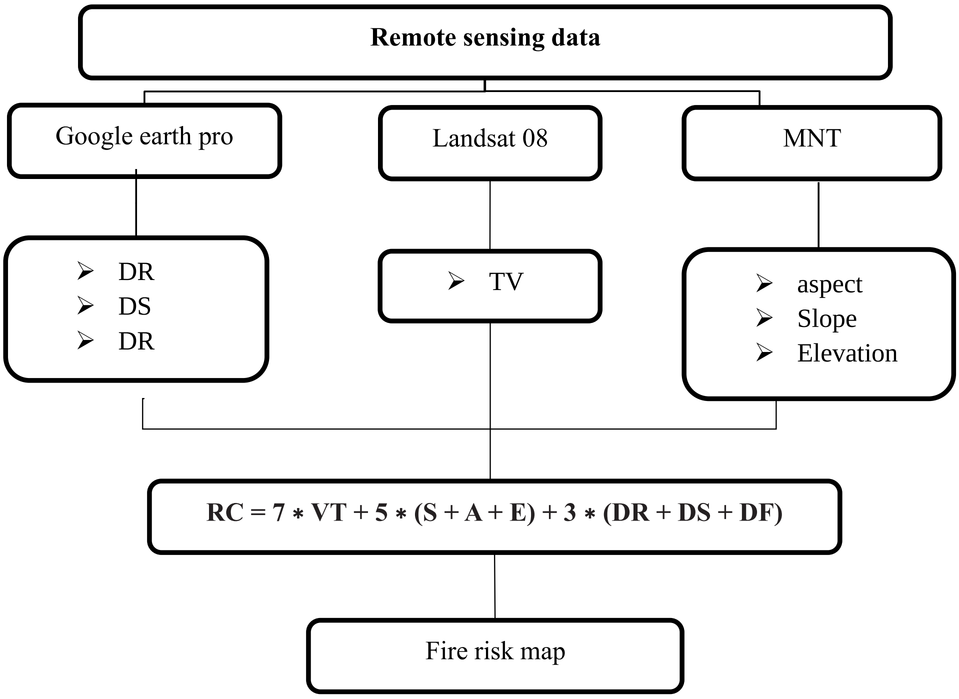


Fig. 2. Flow chart of the methodological approach applied to draw up a fire risk map for El Hsassna forest, Saida

Remote Sensing Data Sets

Satellite Image: For mapping vegetation and its coverage rate, we used a recent Landsat 08 satellite image from July 10, 2022. This image, downloaded from the Google Earth Engine platform, has a resolution of 30 meters. Additionally, during this period, chlorophyll activity is minimal for the vegetation, considered non-combustible.

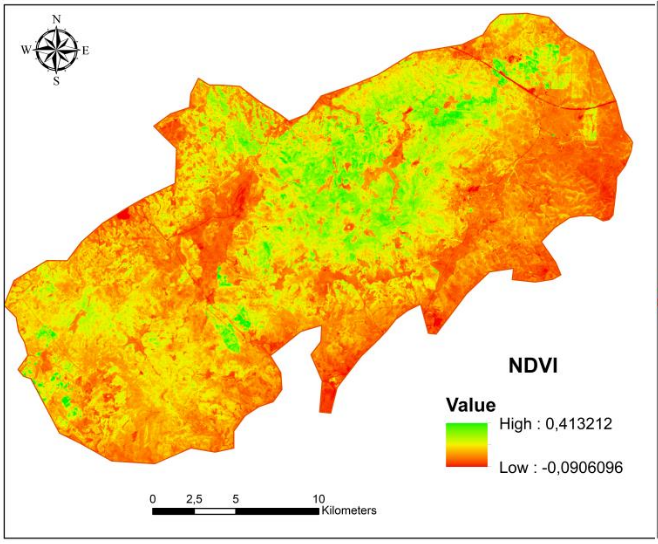
DTM (Digital Terrain Model): Concerning topography, we utilized a digital terrain model (see Figure 1) with a 30-meter resolution to extract geographical data related to slope, aspect, and elevation. This digital terrain model was downloaded from the Google Earth Engine platform.

Human Activity Data: Using Google Earth Pro, we digitized the road network, agricultural lands, dwellings, and the urban area within our study region.

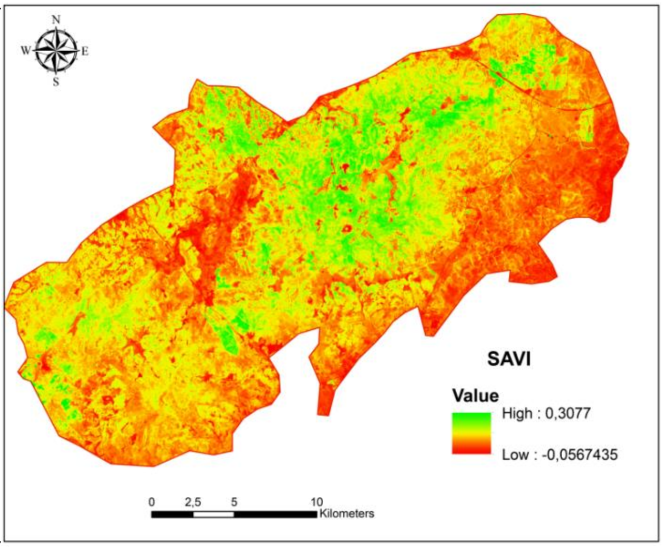
Extraction of Fire Risk Factors

*Vegetation**:*** The primary factor influencing the spread of forest fires is the type of vegetation and its characteristics. After performing the necessary pre-processing, we used satellite images from the Landsat 8 satellite to assess this parameter. Initially, we identified the forest vegetation in our study area.

Due to the absence of a more precise vegetation map for the study area, we calculated several indices, including the Bare Soil Index (BSI), the Normalized Difference Vegetation Index (NDVI), the Leaf Area Index (LAI), and the Soil-Adjusted Vegetation Index (SAVI). These indices provide an overview of land cover in our study area, allowing us to distinguish major classes, including forest vegetation, bare or built-up areas, as well as cultivated areas (Figure 3).



(a)



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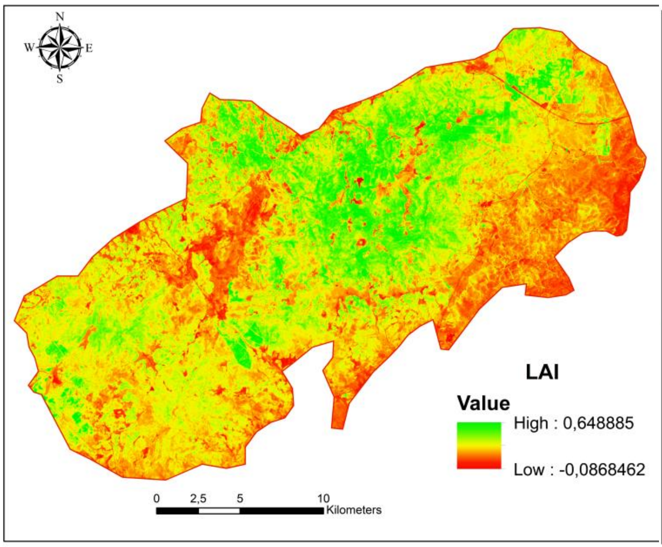
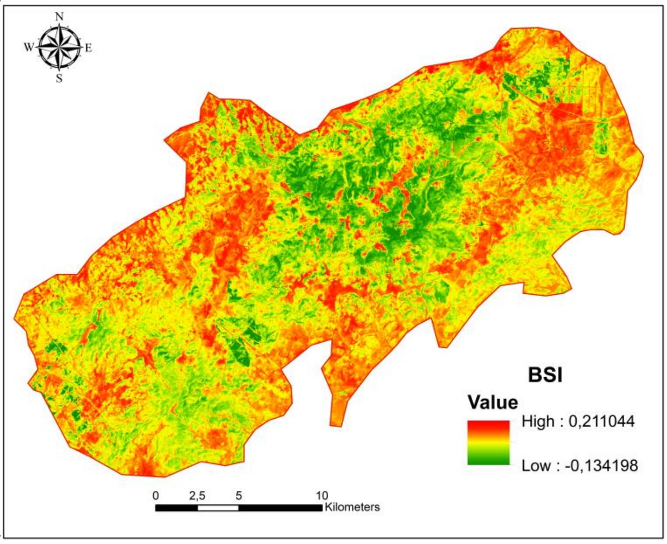


(c)



(d)

Fig. 3. Maps NDVI (Normalized Difference Vegetation Index) (a); SAVI (Soil-Adjusted Vegetation Index) (b); LAI (Leaf Area Index) (c); Bare Soil Index (BSI) (d)

To obtain the final map of forest vegetation coverage in accordance with the thresholds specified in Table 1, we conducted a classification of the NDVI data using the classification features available in ArcGIS 10.8.2.

As for the application of the model used, only the coverage classes were retained: High, Medium, and Low. These classes represent the potential risk of forest fires associated with vegetation (Table 1). Consequently, we were able to generate the map (Figure 4) illustrating the areas at risk of forest fires based on vegetation as a combustible factor.

Topographic Factors: Topography plays a role in wildfire behavior by influencing the morphology and speed of fire propagation. Three topographic parameters influence wildfires, namely: terrain slope, slope exposure to sunlight and wind, and

elevation of the terrain. Unlike atmospheric agents, topography is a constant factor whose influence can be determined [17]. Steep slopes are a crucial factor, both promoting the spread of fires and impeding firefighting efforts.
Exposure, on the other hand, is closely related to drying rates and fire propagation. Finally, higher altitudes are associated with greater availability of cool air and a higher likelihood of rain, resulting in less severe fires. The altitude-related risk is very low when the altitude value exceeds 1000 meters, as indicated in Table 01. There is no impact of altitudes on fires in our study area. Using GIS, these three parameters were generated from the digital terrain model. Thresholds were adopted (Table 1) for processing and visualization (Figure 5).

Table 1. Parameters and their weights in determining fire risk

Parameters	**Weight**	**Classes**	**Values**	**Degree of risk**
Vegetation	7	high density	3	high risk
		medium density	2	medium risk
		low density	1	low risk
Slope (%)	5	>35	5	very high risk
		25-35	4	high risk
		10–25	3	medium risk
		5–10	2	low risk
		0-5	1	very low risk
Aspect (°)	5	N.W(0-90)	1	low risk
		S.W (90-180)	3	high risk
		S.E (180-270)	4	very high risk
		N.E (270-360)	2	medium risk
Elevation (m)	5	<600	5	very high risk
		600-700	1	high risk
		700-850	3	medium risk
		850-1000	2	low risk
		>1000	1	very low risk
Road distance (m)	3	0-200	5	very high risk
		200-400	4	high risk
		400-1000	3	medium risk
		1000-2000	2	low risk
		>2000	1	very low risk
Distance from houses/cultivated land (m)	3	0-100	5	very high risk
		100-400	4	high risk
		400-1000	3	medium risk
		1000-2000	2	low risk
		>2000	1	very low risk
Distance from settlements (m)	3	0-1000	5	very high risk
		1000-2000	4	high risk
		2000-3000	3	medium risk
		3000-4000	2	low risk
		>4000	1	very low risk

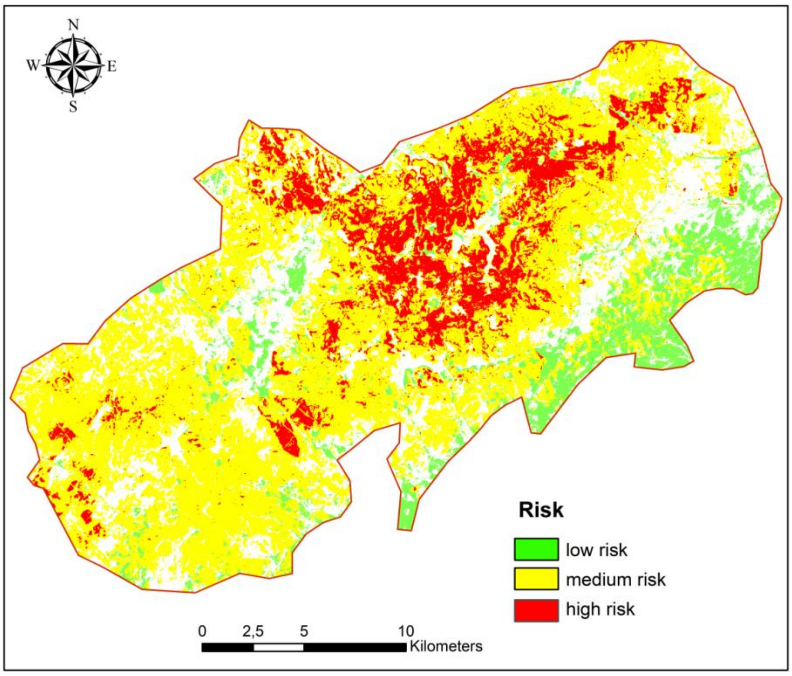
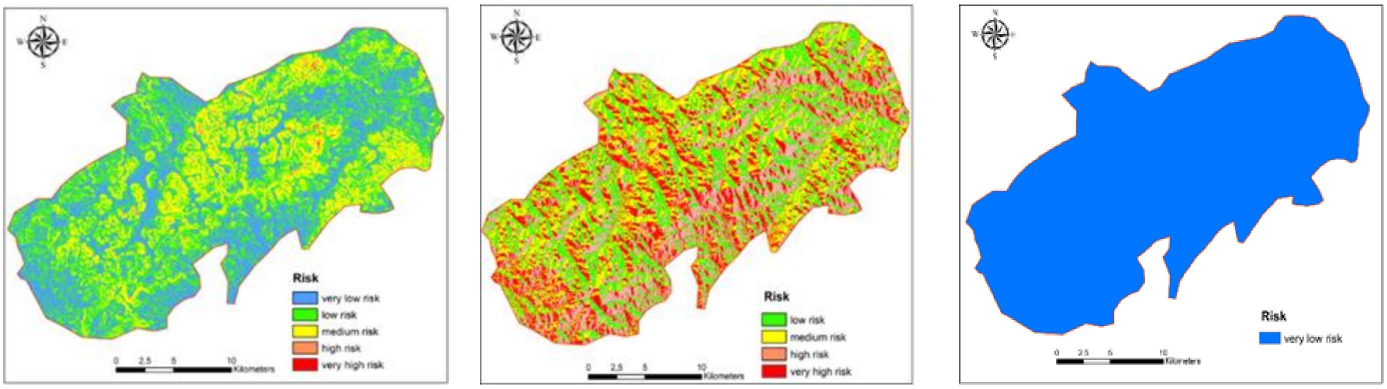


Fig. 4. Risk map related to vegetation



(a) (b) (c)

Fig. 1. Risk map related to the slope (a), exposure (b) and elevation (c)

Results and discussion

Regarding our findings, all geographic information layers related to each variable in model (1) are available. To assess the overall risk, we integrated all parameters by applying the model equation. The outcome is manifested through the creation of a map depicting fire risk zones associated with anthropogenic, topographic, and vegetation factors (Figures 4, 5, 6). To enhance visualization, we adopted five levels of fire risk, represented by a color palette evoking fire. Furthermore, users have the flexibility to perform various customized analyses, such as applying alternative classification thresholds, conducting spatial analyses, and creating different map presentations.

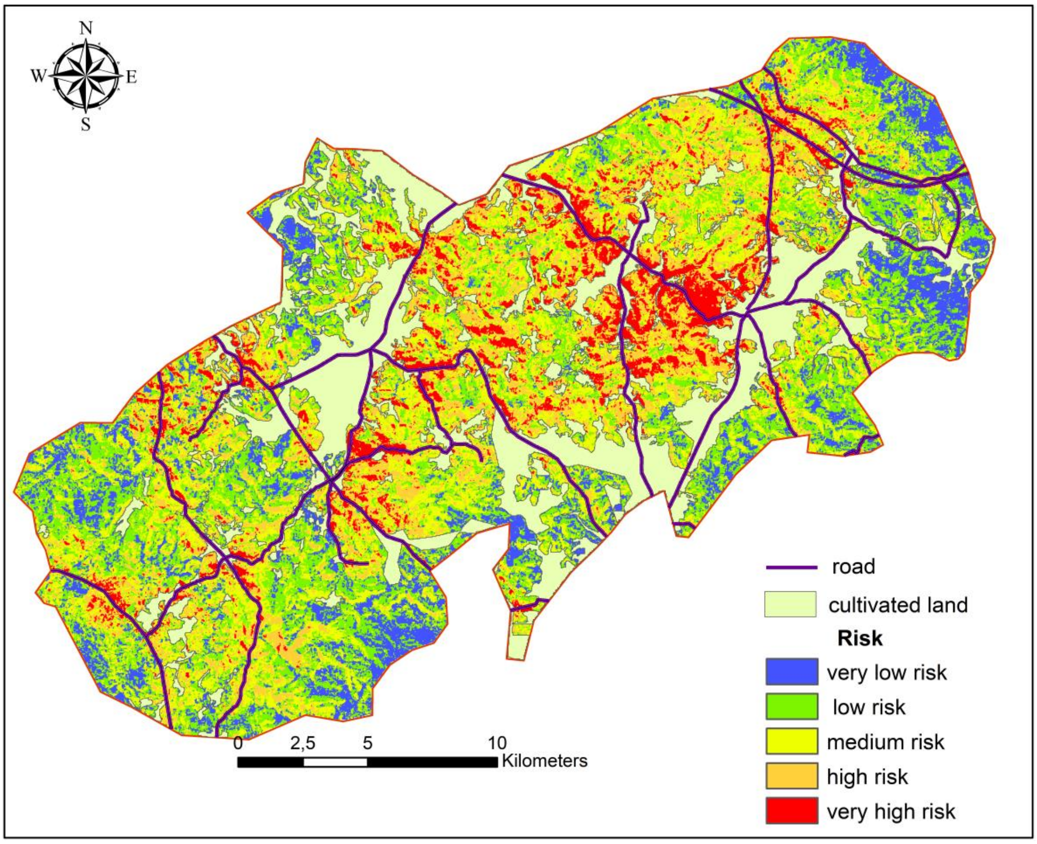


Fig.6. Map of fire risk zones

Topographic Factors Risk

Topographic factors play a significant role, either promoting or slowing down the progression of wildfires depending on the circumstances [18]. They have a significant influence on forest fires due to their impact on local weather conditions, fire spread, and fuel availability. Mountainous regions, in particular, often pose an increased risk due to these factors. It is crucial to consider these elements in wildfire management planning and fire prevention measures [19].

The influence of exposure, expressed as high to very high risk, covered approximately 46.83% of the total forested area, with rates of 22.3% and 24.53% for each category, respectively (Table 2). These areas represent the most favorable conditions for rapid ignition and fire propagation. In our study area, the influence of slope is very low, with a high to very high risk covering no more than 1.6% of the total forested area, with rates of 0.7% and 0.9% for each category, respectively (Table 2).

Risk related to human activity

The results obtained in this study, which encompass the impact of human factors on the ignition and spread of fires, indicate that the influence of roads poses a very high and high risk, covering approximately 25.11% of the total forest area (Table 2). These results are consistent with several studies that report that the majority of fire ignitions (85%) occur around roads and tracks, as found in Arfa et al. [20], Ganteaume et al. [21], and Safa et al. [22]. It is therefore considered a significant factor in the initiation and spread of fires in this area. According to Matin et al. [23], the primary reason for the high incidence of forest fires is the hot and dry weather, as well as the proximity of forests to inhabited areas, roads, and agricultural lands.

Agricultural activity also accounts for a percentage of very high (22.68%) and high (20.85%) risks associated with agriculture, significantly higher than other factors. These risks represent approximately 43.53% of the total forested area. Risks related to agricultural activity play a significant role in the ignition and spread of fires in this area. About 45% of forest fires originate from adjacent agricultural lands, primarily during the cereal harvest period, due to embers emitted by the exhaust gases from harvesting machines, according to statistics from the Forest Conservation of the Saïda Province (CSP). This situation underscores the importance of implementing prevention and awareness measures to reduce these incidents.

Table 2. Percentages of risks for each factor

	Degree of risk				
Parameters	**very high risk (%)**	**high risk (%)**	**medium risk (%)**	**low risk (%)**	**very low risk (%)**
Vegetation	-	16.18	71.16	12.65	-
Slope (%)	0.7	0.9	22.5	39.53	37.4
Aspect	**24.53**	**22.3**	23.89	29.5	-
Road distance	**13.07**	**12.04**	29.47	29	14.51
Distance from houses	0.6	6.48	19.52	31	42.98
Distance from cultivated land	**22.68**	**20.85**	20.26	17.19	18.81

Table 3. Percentage and area for each degree of fire risk

Degree of risk	**Area (ha)**	**Area (%)**
very high risk	6166.7	14.29
high risk	12171.33	28.21
medium risk	12158.92	28.18
low risk	8599.62	19.93
very low risk	4046.75	9.37

Fire risk map

Regarding the result obtained on the final wildfire risk map of our area (Figure 6), it is evident that the overall wildfire risk level is strongly influenced by vegetation cover, as indicated by the weight assigned to this parameter. However, this influence diminishes when several other parameters are considered for the same area. The fire risk categories ranging from high to very high represent approximately 29.3% of the total forest area, which corresponds to an estimated 18,338.03 hectares, with respective rates of 19.93% and 9.37% for each of them (Table 3). It is also important to note that these categories are primarily concentrated along the boundaries of the forested areas, which are susceptible locations for fire ignition before spreading within the forest massif.

The final map highlights the correlation between factors related to human activity, namely agricultural lands, the road network, and wildfire-prone areas [24]. It is clear that areas with very high and high risks are associated with these activities. Agricultural lands cover a total area of 1,106.60 km^2 and are directly adjacent to forested areas. Furthermore, the total length of the road network reaches 214.60 km, which explains the presence of these high risks.

In the absence of similar studies, we based our attempt to validate the results on the input from experts from the Forest Conservation Department of the Wilaya of Saïda (C.F.S.). They emphasized the utility of this approach and the effectiveness of the model in terms of simplicity and speed. It was noted that the results were consistent with the reality on the ground, as the classes ranging from moderate to very high risk did indeed correspond to the areas where the majority of wildfires had been recorded. Additionally, it was observed that there was a significant amount of forest management work, such as the creation of firebreaks, in these areas.

Conclusions

The development of a reliable and continuously updated assessment of forest fire risks is a crucial and fundamental step in creating an ecological restoration program. The need to safeguard our country's resources necessitates the use of effective methods and means.

In this context, the characterization and mapping of forest fire risk areas are essential elements, especially in the context of firefighting and prevention operations. However, it is important to note that our study primarily focused on the geospatial aspect, demonstrating the vital contribution of Geographic Information Systems (GIS) and remote sensing in this field. These tools have proven to be indispensable.

The use of GIS significantly simplifies the descriptive and quantitative mapping of the studied phenomenon. Model parameters can be

integrated, modified, simulated, and updated at will. This allows specialists to independently visualize the effect and importance of each variable, particularly regarding vegetation.
Furthermore, remote sensing has been a powerful tool for the extraction and updating of geographical information. It has greatly contributed to our understanding of the trends and changes in forest fire risk areas.
In terms of future perspectives, a deeper collaboration with other specialists and potential users is necessary to refine the results. This includes adjusting the numerous empirical thresholds that form the basis of the model used. Additionally, it would be beneficial to work towards generalizing this model at the national level to ensure effective and sustainable environmental protection.

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