

# Geospatial Modeling of Wildfire Susceptibility in Coastal Mediterranean Region: A Case Study of El Marsa (Algeria)

Amina Abdelbaki<sup>1,2,3\*</sup>, Abdelkader Bouthiba<sup>4</sup> & Abdelkader Benfatmi<sup>2</sup>

<sup>1</sup>Department of Agronomy, Hassiba Benbouali University, PB 78C Ouled Fares, 02180 Chlef, Algeria;

<sup>2</sup>Department of Forest Resources, Faculty of natural and life sciences, earth and universe sciences, Abou Bakr Belkaid University, Pole 2 of the ring road, Mansoura, BP 13000. Tlemcen, Algeria;

<sup>3</sup>Laboratory of Conservatory Management of Water, Soil and Forests. Department of Forest Resources, Abou Bakr Belkaid University, Pole 2 of the ring road, Mansoura, BP 13000. Tlemcen, Algeria;

<sup>4</sup>Department of Biology, Hassiba Benbouali University, PB 78C Ouled Fares, 02180 Chlef, Algeria.

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## Abstract

The coastal region of Chlef, in northwestern Algeria, is frequently impacted by wildfires, yet there remains a significant gap in the existing literature regarding this natural hazard. To address this issue, our study focused on El Marsa municipality in the province of Chlef, that suffered the most extensive forest loss between 2000 and 2023. By integrating Geographic Information Systems (GIS) with remote sensing data, the Hybrid Fire Index (HFI) was adopted. This model effectively synthesizes six variables, across three axes: vegetation, topography, and human activity. Using a multi-criteria weighted overlay analysis, we generated a high-resolution risk susceptibility map. The results indicate that 59.59% of the study area is located in zones of "medium," "high," and "very high" risk. These results underscore the urgent need for targeted fire management and localized prevention strategies along this vulnerable Mediterranean coastline.

**Key words:** Wildfire, Hazard assessment, Geospatial modeling, El Marsa, Algeria.

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## INTRODUCTION

As one of the major natural disasters, wildfires often lead to ecosystem imbalance and local structural damage [1]. These events not only destroy forested areas but also cause significant damage to habitats and, most critically, human lives [2]. While causes vary by region and are often difficult to identify with certainty, they also evolve over time; nonetheless, anthropogenic influence remains the primary driver of global fires. Approximately 90% of wildfires are linked to human activities, ranging from accidental ignitions and agricultural practices to deforestation and arson. However, the serious forest fires that have broken out in different parts of the world have had very negative consequences for the environment and have attracted international attention. According to [3], during the 2023-2024 fire season,  $3.9 \times 10^6 \text{ km}^2$  burned globally. Fire carbon (C) emissions were 16% above average, totaling 2.4Pg C.

In the Mediterranean basin, wildfires are an indissociable component of the local ecosystem [4] [5] [6]. The average annual number of these events throughout the region has increased significantly in the past 50 years [7]. As part of the Mediterranean region, Algeria is experiencing a constant increase in the frequency, intensity, and extent of wildfires, driven by global warming and increasingly long, intense heatwaves, as confirmed by the study of [8].

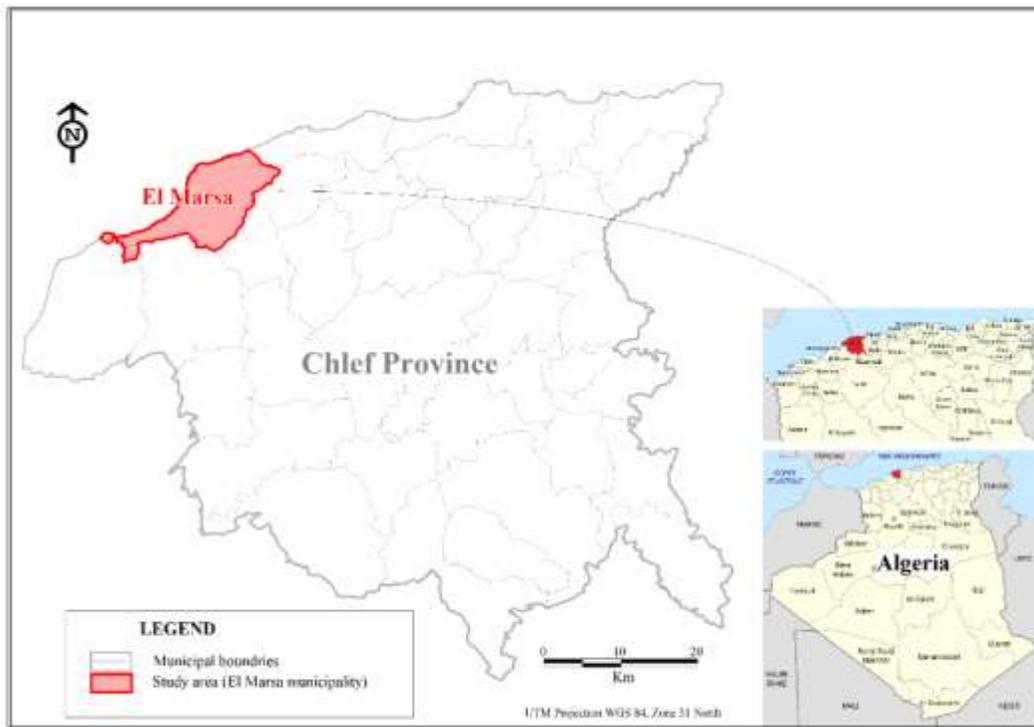
According to [9], historical data from 1985 to 2023 reveal a total fire-affected area of 1,408,547ha, across 76,427 recorded fire events, representing an average of 18.43ha/fire. These figures underscore a critical environmental challenge for a nation highly susceptible to desertification, an issue compounded by a marginal reforestation rate of 1.76%, which fails to offset the rate of forest loss.

While forest fires represent a major concern at the national level, analytical precision is significantly enhanced when conducted at a local scale. Between 1985 and 2023, the province of Chlef (a coastal region in Algeria) recorded 18,413.33ha of burnt forest area (2,879 fires). Among the 35 municipalities within the province, El Marsa is the most severely impacted, with 2,892.59ha destroyed, accounting for 24.45% of the province's total burnt area. Consequently, El Marsa serves as a highly pertinent research site, as it integrates anthropogenic and environmental risk variables typical of the nation's most vulnerable regions. This area was specifically selected due to its critical coastal location and the current dearth of scientific literature addressing its specific fire dynamics.

Modern assessment of this phenomenon in Algeria relies heavily on the integration of GIS and remote sensing. The transition toward these decision-support systems represents a necessary methodological shift, widely supported by recent literature attesting to their effectiveness: [10] [11] [12] [13]. Numerous fire risk models have been established by leveraging environmental variables that drive wildfire activity, quoting: [14] [15] [16] [7]. This research employs advanced geospatial modeling (Hybrid Fire index) to identify fire-prone sectors within El Marsa municipality. The generated susceptibility maps act as a crucial decision-making instrument, enabling local authorities to optimize the distribution of manpower and logistical assets for enhanced wildfire mitigation.

**MATERIALS AND METHODS**

**Study Area:** El Marsa is a municipality covering 124.81km<sup>2</sup> located in the province of Chlef, Algeria, around 275km west of Algiers and 95 km northwest of the provincial seat (see Figure 01). Within the 129.5km of Mediterranean coastline that makes up Chlef, it is one of six coastal municipalities. The area has a semi-arid climate with moderate winters and a "W.A.S.S." (Winter-Autumn-Spring-Summer) seasonal precipitation regime. The region's average annual rainfall is 460mm, and its summer temperatures often reach 26.6°C. The majority of this municipality is covered by forests, which make up 49.33% of the total area. Conversely, agricultural lands make up 19.32%, while thick and clear maquis occupy 18.52% and 0.86% of the land, respectively. Seventy percent (70%) of the land on the topographic map is below 400m in elevation, with the highest point reaching 875m at the Djebel Sabor, which overlooks El Marsa's beaches.



**Figure 01:** Geographic location of El Marsa municipality.

**Methodology:** Following the methodology established by [15], the Hybrid Fire Index (HFI) was implemented. The HFI combines 6 parameters of forest fire susceptibility to create risk map for the municipality of El Marsa, according to the framework presented in Formula (1).

$$HFI = \frac{(100v+50s+10(r+c)+5e)}{10} \dots\dots\dots (1)$$

Where:

v: Vegetation moisture; s: Slope gradient; a: Topographic aspect; r: Distance from road networks; c: Distance to human settlements; e: Topographic elevation level.

For more details regarding the methodology, please refer to [15].

## RESULTS AND DISCUSSION

According to the wildfire risk map, for the vegetation moisture parameter (NDMI), 76.3% of the total area in the municipality of El Marsa is exposed to a high to very high risk. Regarding slope: 47.1% presents a high risk. The study area is dominated by a north-facing aspect (42.41%), where the risk is low, while areas with significant risk (south and west) together account for 43.18%. In terms of altitude, high and very high risk zones are predominant, with 82.33% of the total area located between 0 and 500m above sea level. Within 200m of roads, 66.07% of the study area has a high probability of fire ignition. Regarding proximity to built-up areas, 71.55% of the total area is located within 1000m of buildings.

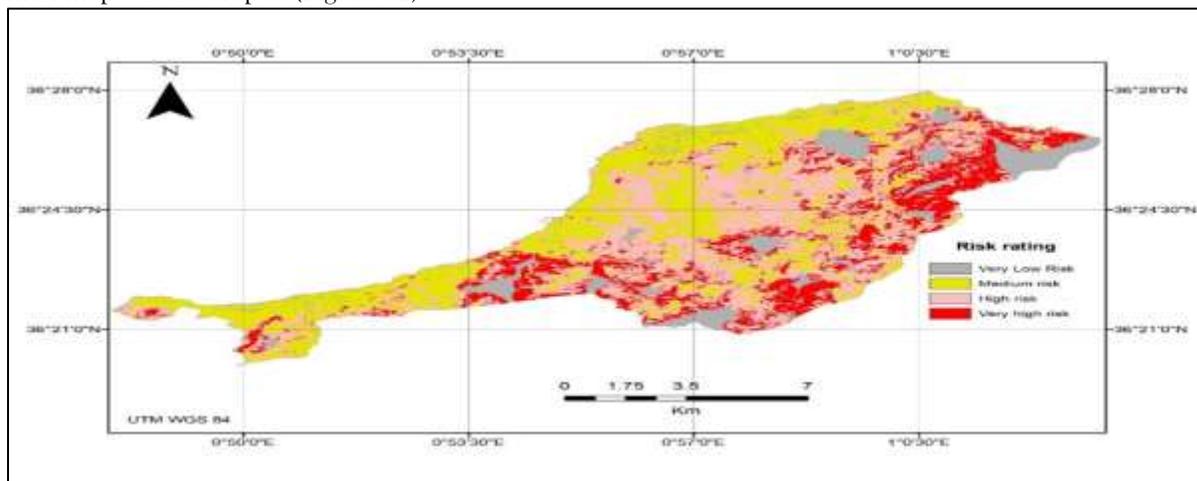
Based on the HFI model formula mentioned previously (1), the 6 variables were ranked based on subjective weights. The risk level assessment is illustrated in table 1, the risk classes at the model output are five in number, from the lowest risk ( $HFI \leq 22.5$ ) to the very highest ( $80 < HFI \leq 100$ ).

**Tableau 1:** Framework for risk level determination

Hazard susceptibility levels	Risk index	v	s	a	r	c	e
Very high	100	5	5	5	5	5	5
High	80	4	4	4	4	4	4
Medium	60	3	3	3	3	3	3
Low	40	2	2	2	2	2	2
Very low	22,5	1	1	2	1	1	1

Each class has its own weight, indicating the degree of fire susceptibility. The input raster for each variable was reclassified by modifying the original values. The weighted raster overlay of all 6 parameters was performed using the raster calculator in the GIS software (Model formula loaded). The resulting map illustrates the five risk levels, with values ranging from  $\leq 22.5$  to 100, categorized as: very low risk ( $HFI \leq 22.5$ ), low risk ( $22.5 < HFI < 40$ ), medium risk ( $40 < HFI < 60$ ), high risk ( $60 < HFI < 80$ ), and very high risk ( $80 < HFI \leq 100$ ).

The creation of the final wildfire risk map for the study area, based on a weighted overlay of the 6 parameters, highlights significant variation in the area's susceptibility to wildfires. Priority areas for fire prevention and management can be quickly identified using this geographic representation, facilitating intervention planning and resource allocation. To analyze the wildfire risk in the municipality of El Marsa, using the HFI model, a final map was developed (Figure 02).



**Figure 02:** Map of wildfire risk zone for the municipality of El Marsa

According to table 2, the high and very high risk categories represent 17.46% (21.79km<sup>2</sup>), located mainly in the west (Ouzidane Forest and Djbel Hammamou) and the center (El Guelta Forest), defined as sensitive areas, highlighting the importance of implementing appropriate prevention measures. The largest portion, 52.58km<sup>2</sup> (42.13%), is classified as medium risk, distributed mainly in the center (El Marsa Forest, Ouled Boufrid) and the east (Ouzidane Forest). The low and very low risk areas cover 50.44km<sup>2</sup> (40.41%), and are mainly located in the northern (Ain Hammadi and El Marsa) and northwestern (Messâadia and El Guelta) parts of the municipality.

**Table 2:** Wildfire risk in the municipality of El Marsa according to HFI.

Risk Level	Surface Area (km <sup>2</sup> )	Percentage (%)
Very high	01.72	01.38
High	20.07	16.08
Moderate	52.58	42.13
Low	37.49	30.04
Very low	12.95	10.37
<b>Total</b>	<b>124.81</b>	<b>100</b>

Validating a forest fire risk model is a crucial but delicate step. MODIS hotspot data and historical fire data have been used in many previous studies, including [17] [15] [16]. In our case, to validate our results, we used two data sources: the metric geographic coordinates (x,y) of historical fire starting points provided by the Forestry Department of the Chlef province (1999-2020); and thermal anomaly data (2000-2022) downloaded from <https://firms.modaps.eosdis.nasa.gov>. These data were analyzed, processed, and then imported into a GIS software as vector layers, in the form of point features.

The final wildfire risk map, created for the municipality of El Marsa, was overlaid with the two data sources mentioned previously. An examination of table 3 provides a deeper understanding of the probability of fire outbreaks in the area, where 48.49% of the outbreak points are located in areas of high and very high fire risk. This highlights the need to establish strategies for preventing and controlling fires in these highly vulnerable areas. The total for moderate-risk areas is 30.30%. This means that a significant proportion of historical fires are concentrated in areas of medium risk, clearly showing that 1/3 of historical fires occur in an area with a normalized HFI value of "Medium".

**Table 3:** Validation of the HFI model for the municipality of El Marsa.

Risk Level	Percentage (%)
Very high	12.12
High	36.37
Moderate	30.30
Low	18.18
Very low	03.03
<b>Total</b>	<b>100</b>

## CONCLUSION

This paper, a seminal study for the municipality of El Marsa, establishes new findings in the field of forest fires and paves the way for future priority research. Forest fire risk modeling using the Hybrid Fire Index (HFI) model reveals that 59.59% of the studied area (74.37 km<sup>2</sup>) is classified as medium, high, or very high risk.

The validation phase of the adopted model confirms its reliability. 48.49% of historical fires were recorded in areas with normalized HFI values of "high to very high," a finding that validates the use of the HFI model

for mapping priority zones. This mapping highlights a dual reality: localized high and very high fire risk requires the mobilization of emergency firefighting and development resources, while a large-scale medium risk requires a targeted prevention policy at the interface between forests and human activity. Effective risk management will involve minimizing anthropogenic factors in medium-risk areas and structurally modifying physical variables through forest management to create fuel discontinuities in high and very high-risk areas.

The major importance of this work is twofold. Operationally, it constitutes a precise decision-making tool, providing the managers of the municipality of El Marsa with risk zoning that allows them to strategically target prevention actions and firefighting infrastructure, thus shifting from reactive management to truly preventative planning. Scientifically, the effectiveness and robustness of the approach for analyzing, mapping, and modeling forest fire risk is validated, guaranteeing the reproducibility and accessibility of the methodology.

Looking ahead, it would be relevant to:

- Encourage the use of advanced technologies to optimize forecasting, strengthen prevention, and increase the effectiveness of firefighting;
- Focus research more on understanding human-forest interactions to better define the subject, which implies increasing case studies and prioritizing applied research to address specific problems;
- Expand the mapping and wildfire risk modeling framework to all municipalities in the Chlef province;
- Develop a specific wildfire risk prevention plan for each municipality, tailored to local characteristics, ensuring a sustainable balance between needs and resources;
- Implement regular updates to land-use mapping to optimize the management of forest/human-impact interfaces.

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