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INTEGRATED APPROACH USING GEOGRAPHIC INFORMATION SYSTEM AND MULTI CRITERIA DECISION ANALYSIS METHOD FOR FOREST FIRE RISK MAPPING IN NORTHWESTERN ALGERIA

Youcef FEKIR[1,2*], Mohammed Amine HAMADOUCHE[1] and Djamel ANTEUR[3]
[1]University of Mustapha Stambouli, Mascara 29000, Algeria
[2]Geomatics and Sustainable Development Laboratory, University of Tiaret 14000, Algeria
[3] Faculty of Nature and Life Sciences, University of MoulayTaher, Saida 20000, Algeria
*email: youcef.fekir@univ-mascara.dz;
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ABSTRACT

In recent years, the forest ecosystems of Mediterranean basin countries such as Algeria have experienced massive degradation as a result of fires that continue to destroy forest areas from year to year. Yearly, 36000 ha are burned due to fires, with over 13414 ha burned in 2017. Approximately 29 percent of Algeria's forest cover is located in the western part of the country, where fires continue to be the most threatening factor. With regard to this critical situation, actions must be taken as urgently as possible to fight against this phenomenon. The assessment and the mapping of the Forest Fires Risk (FFR) to highlight vulnerable areas appear to be the most efficient ways. Last years, several models were developed to assess the forest fire risk each of which involves a certain number of parameters which influence differently on the fire spread. The evolution of geospatial techniques such as geographic information systems (GIS) and Multi Criteria Decision Analysis (MCDA) methods have effectively improved solving this type of problem. In this paper we aim to assess the risk of forest fires using GIS-based MCDA model. The approach consists, in the first step, of a spatialization of the FFR parameters by integrating different factors into a GIS. In the second step, the Analytic Hierarchy Process (AHP) MCDA method was used to calculate et assign weights to each factor to produce a FFR potential map. The obtained FFR map shows that 28.87% and 25% of the study area is dominated by Moderate and High FFR. The spatial analysis of the produced map with the actual fires limit reveals a significant correlation through an overall accuracy of 62.60%. This study is carried out in the forest of Nesmoth located in the Mascara province in northwestern Algeria. The obtained results show that the combination of GIS and MCDA methods can be a very useful tool for forest managers and decision-makers in reducing fire risk.

***Keywords*:** GIS, Multi Criteria Decision Analysis, AHP, Forest fires, Nesmoth

Introduction

Forest ecosystems by their role in ecology and socio-economy are considered as very important. For decades, they keep undergoing a remarkable degradation due to wild land fires. Every year, 6-14 million of hectares of forested areas were affected around the world by this phenomenon (Encinas *et al*., 2007).

Mediterranean basin does not escape from this problem. It has experienced extremely fires events that continue to destroy the forest areas from one year to another (Fekir *et al*., 2020). These fires are the main cause of destruction of Mediterranean forests (Vélez, 1999).

Algeria, like other Mediterranean countries, is characterized by an extremely hot summer and an expansion of human activities such as overgrazing and clearing, which amplified the ignition of forest fires and exacerbated the situation. It is regarded as a country that is severely impacted by this phenomenon (Belgherbi *et al*., 2018). According to Arfa *et al*. (2009), approximately 36000 ha of burned zones are recorded annually, with the General Directorate of Forests (DGF) recording over 13414 ha only in 2017. (Benguerai *et al*., 2019).

About 29% of the Algerian forest heritage is located in the west of Algeria (DGF, 2018) which corresponds to 193674 ha where 13% of this area was subjected to forest fires.

Faced with this situation, it becomes necessary to intervene as urgently as possible to fight against this phenomenon and its consequences. The prediction and the assessment of the FFR can be done and will help forest managers and decision makers to locate forested vulnerable areas and meet against fires. Producing a FFR map becomes a necessity, which requires choosing the most effective tools to do this.

The evolution of geospatial techniques such as Geographic Information Systems (GIS) and Remote Sensing has effectively improved solving problem with spatial multi-criterion nature.

Spatial decision problems are generally characterized by their heterogeneous aspect, which takes into account several factors that change in time and space. In order to deal with the complex situation, researchers used techniques and procedures that allow for the management of the problem's spatial dimension on the one hand, and tools for the aggregation of decision data on the other. Indeed, GIS is frequently acknowledged as a geographic decision support system (Malczewski, 2006). These tools, however, lack the ability to incorporate the decision maker's preferences and reach a conclusion in the context of objective assessment and contradictory criteria (Molines and Chevalier, 2002).

MCDA techniques and procedures are appropriate to the decision-making processes since it provides all appropriate means related to the collective choice to include decision problem data. Therefore, the integration of GIS and Multicriteria analysis is a preferred way to develop a spatial decision support system (Laaribi 1995).

These two distinct tools can complement one another. On the one hand, GIS provide robustness techniques for manipulating, managing, and analysing spatial decision problems. MCDA, on the other hand, is appropriate for structuring decision problems, designing, evaluating, and ranking alternative decisions.

Remote sensing through its power to acquire data in several spectral bands with a regular temporal frequency became a very complementary technique to GIS and MCDA methods. It was widely used in discriminating forested areas and highlighting burned zones. Numerous methods and models were proposed by researchers to assess and quantify forest fire's severity where most of them are spatially based structuration.

The goals of this study are to assess and map the FFR using the AHP MCDA method as a weighting tool to assign weights to model factors. These factors are divided into three major criteria: vegetation, topography, and human activities, as well as seven sub-criterions. Each sub-criterion was introduced into a GIS as a thematic layer to create a synthetic fire risk map in order to differentiate forested areas based on their vulnerability to fire. This research was carried out in the Nesmoth forest, which is located in the province of Mascara in western Algeria.

Materials and Method

Study area

Located in the Mascara province of north-western of Algeria, the forest of Nesmoth is geographically located between 0° 25' 56" East and 0° 16' 37" West Longitude and between 35° 10' 16" and 35° 16' 11" North Latitude. It's part of Saida Mountains with an altitude ranging from 648 to 1221 m and an area of approximately 4935 ha (Fig. 1). Over 37% of the study area is characterized with a slope gradient greater than 15%.

The forest of Nesmoth belongs in the semi-arid climatic floor with two important periods: cold from November to April, and hot and dry from May to October with an average annual rainfall of 418 mm (station of Nesmoth) and a temperature range from 0° to 34°. The forest cover is mainly dominated by *Pinus halepensis*, *Eucalyptus globules* and *Tetraclinis articulate* species.

The exposure of the study area for a long hot period, the hard topographic parameters and the excess of human activities made the forest face to a high rate of forest fires every year. The General Directorate of Forest (GDF) records several forests fires each season (Table 1).

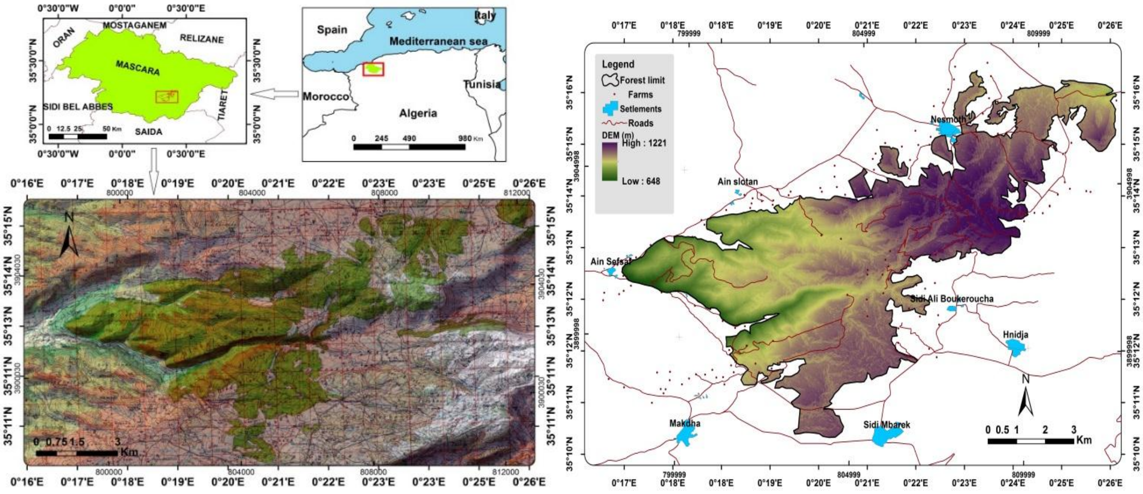

Fig. 1: (a) Geographic location of the forest of Nesmoth, (b) characteristics of the study area

Table 1 : Historical fires events in the forest of Nesmoth (Source: DGF, 2019)

Place	Date	Hour
Chemoukh	26/07/2016	18:30
Chemoukh	18/08/2016	11:05
SidiGheriben	01/08/2016	12:05
FD Nesmoth	27/08/2016	13:50
SidiGhriben	05/09/2016	13:40
DjebelMediouna	06/07/2017	13:00
Hailafen	26/07/2019	16:30
FD Nesmoth	06/08/2019	10:30
FD Nesmoth	14/08/2019	18:00

Data sources

Throughout this study, several data from various sources were used. These data are classified into four categories:

- Satellite images: a satellite image was used and issued from Sentinel 2 Multispectral Sensor Instrument (MSI). It's used specially to characterize forest vegetation cover and to extract the corresponded forest fires risk of the study area.
- Digital Terrain Model (DTM): it's used to characterize the topography effect expressed in three derived parameters, i.e., elevation, slope and aspect.
- Mapping data: concern roads network, settlements limit and farm location within the study area limit. These data were extracted by digitizing from Google Earth images.
- Forest fires data: the historical data of the forest fires events occurred in the forest of Nesmoth were collected from forestry managing services.

Methodology

The adopted methodology used along this study comprises three important steps. The first step consists of ranking and weighting of the effective factors of the forest fire modeling using the AHP method. The next step aims to produce a FFR synthetic map by overlaying all layers' factors. The last step consists to the evaluation of the obtained results against a map of actual fire occurred in the study area. The flowchart that illustrates the three steps applied in this research is presented in figure 2.

FFR Modeling

(i) Data preparation

As shown in Table 2, seven factors are taken into the FFR modeling process. Each factor was divided and weighted into five levels ranging from 1 to 5 basing on its influence on the fire spread and propagation from very low, low, moderate, high, and very high, respectively.

The seven factors are regrouped into three major criteria such as Vegetation, Topographic and Human activity factors, and seven sub-criteria. Depending on the study area and conditions, the level of influence of these criteria and sub-criteria may vary (Eskandari and Miesel, 2017). The major and sub-criteria maps were created in a GIS environment.

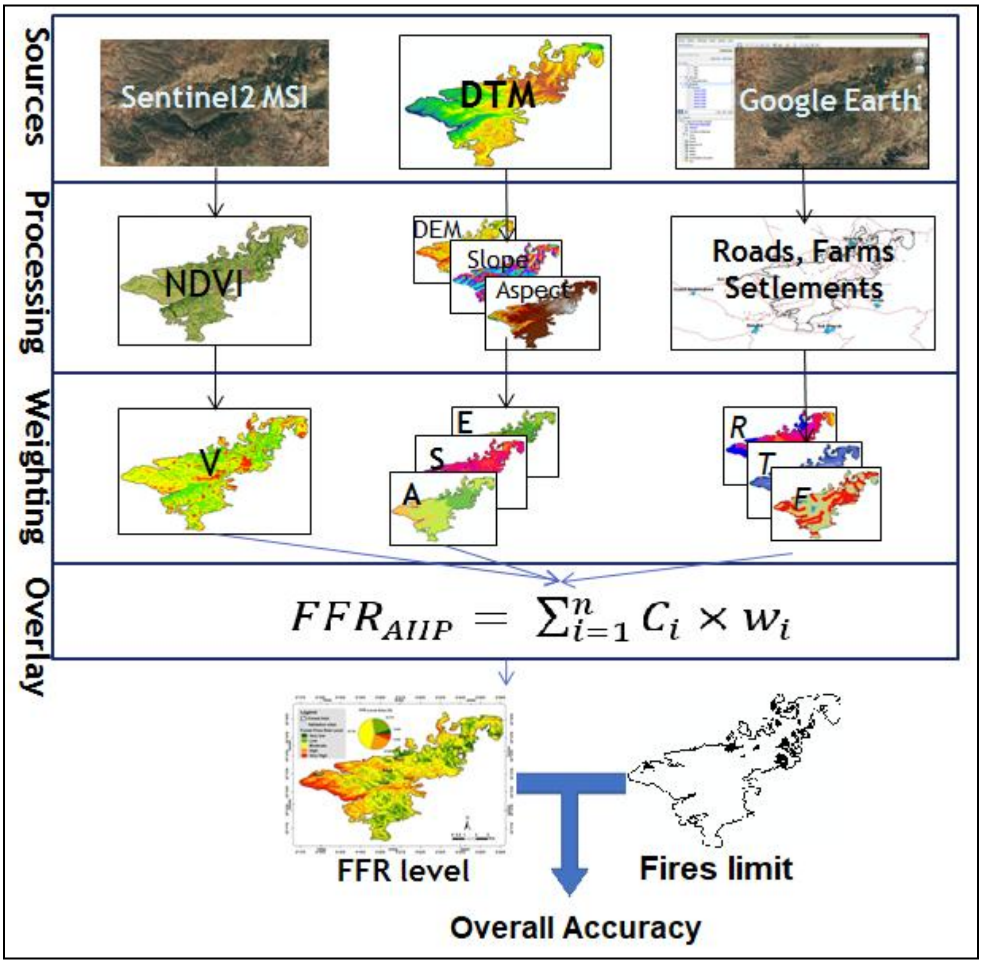

Fig. 2 : Flow chart of the methodological approach

Table 2 : Classification and weighting of the forest fire risk factors

Vegetation density	**Fire risk**	**Weight**	**Elevation (m)**	**Fire risk**	**Weight**
Little Medium Hard	Low Moderate High	1 2 3	>1000 850-1000 700-850 600-700 <600	Very low Low Moderate High Very high	1 2 3 4 5
Slope (%)	**Fire risk**	**Weight**	**Aspect (degree)**	**Fire risk**	**Weight**
0 - 5 5 - 10 10 - 25 25 - 35 > 35	Very low Low Moderate High Very high	1 2 3 4 5	315-45 (North) 45-135 (East) 225-315 (West) 135-225 (South)	Low Moderate High Very high	1 2 3 4
Distance from roads (m)	**Fire risk**	**Weight**	**Settlement's proximity (m)**	**Fire risk**	**Weight**
>1000 600 - 1000 400 - 600 200 - 400 <200	Very low Low Moderate High Very high	1 2 3 4 5	>4000 3000-4000 2000-3000 1000-2000 <1000	Very low Low Moderate High Very high	1 2 3 4 5
Farms proximity (m)	**Fire risk**			**Weight**	
>2000 1000-2000 400-1000 100-400 <100	Very low Low Moderate High Very high			1 2 3 4 5	

(ii) AHP Method

Several multicriteria methods have continued to evolve in the multiple choice'scontext based on a set of criteria for evaluating alternatives.The subjective parameters of the decision problem strongly influence these choices (weights and different thresholds). Through its analysis functions, it contributes to the alternatives' evaluation, according to the criteria defined by the decision-makers. They can synthesize this information to aid in decision-making interpretation (Roy 1985). Also, MCDA methods preserve the data in their initial form. It takes into account both the criterion effect (Maystre *et al*., 1994) and the uncertainty of the evaluation to brig closer to the real-world by introducing different thresholds in the process (Schärlig 1985).

Most territorial problems are complex and use many qualitative income mensurable characters or quantitative criteria. In this case, researchers use methods that ensure the integration of all subjective information about the problem (Joerin and Musy, 2000). Consequently, the MCDA outranking tools are usually, applied in territorial contexts (Ben Mena, 2000; 2001; Guinting, 2000; Schärlig, 1996; Jafari and Zaredar, 2010; Mendas *et al*., 2007; Hamadouche *et al*., 2010).

In a complex MCDA problem, assigning weights directly to the criteria is difficult. However, it is able to arrange them in a preferred growing direction, where they can be compared. There are many MCDA methodologies available to solve complex decision problem with multiple criteria (Keeney and Raiffa, 1976; Saaty, 1980; Chankong and Haimes, 1983). The analytic hierarchy process (AHP) method is based on a series of pairwise comparisons between criteria to create a matrix. The AHP algorithm is a tried-and-true method for dealing with complex decision-making problems. It can aid in identifying and weighting selection criteria, analyzing data collected for the criteria, and speeding up the decision-making process. The weights parameters were determined using the pairwise analysis of the parameter, based on the scale of relative importance (Saaty 1980). The scale recommended by Saaty (Saaty 1994; Didier *et al*., 2002) is from 1 to 9 (Table 3).

The essence of AHP calculations is a solution of an eigen value problem involving the reciprocal matrix of comparisons (equation1) which is characterized by (Saaty, 1994):

$$\left.\begin{aligned} &\forall i, j \in [1, n_c]^2 ; a_{ij} = \frac{1}{a_{ji}} \text{ with } i \neq j \\ &\forall i \in [1, n_c] ; a_{ii} = 1 \end{aligned}\right\} \quad (1)$$

Where: n_c : number of criteria. a_{ij}: matrix values introduced by the decision-makers, according to the scale of Saaty.

Table 3 : Saaty Rating Scale: A basic, but very reasonable, assumption is that if attribute A is absolutely more important than attribute B and is rated at 9, then B must be absolutely less important than A and is valued at 1/9.

Intensity of importance	**Remark**	**Explanation**
1	Equal	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

The consistency of the assessment for this study was evaluated and confirmed using the Consistency Ratio (CR) and Consistency Index (CI) (equations3-4) (Saaty 1980). This measure examines the extent to which the submitted finding is consistent. The CI is zero if all the judgments are completely consistent.

$$\lambda_{max} = \sum_{i=1}^{n} X_{ij} * W_{ij} \quad (2)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

Where: λ_{max}: the average of the eigenvalues of the normalized comparison matrix (equation 2), CI: the Consistency Index, n : number of criteria, CI: the Consistency Ratio, RI: the random index (Saaty, 1990) (Table 4).

Table 4 : Value of RI for the corresponding number of criteria/alternatives (n)

n	3	4	5	6	7	8	9	10
RI	0.85	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Results and Discussion

Vegetation FFR map

The vegetation FFR map of Nesmoth's forest was created based on the degree of vegetation cover density. This latter can be estimated using spectral indices calculated from the combination of spectral bands from satellite images. The NDVI is the most widely used vegetation metric. As a result, an NDVI layer of the study area was derived using the equation below from the Red and Near Infrared bands of a Sentinel 2 image acquired on 28/08/2019 (Fig. 1.a).

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (5)$$

The derived NDVI index values range from -0.003 to 0.689, with the lowest values representing bare soil and urban areas and the highest values representing dense forest cover. The corresponding vegetation density map was created by categorizing NDVI values into three classes and weighting them based on their fire risk level (Fig. 1.b).

The spatial distribution of the obtained map shows that over 35% of the study area is characterized by a high FFR level, which is generally located in the central and southern parts of the forest and corresponds to closed cover trees of the *Pinus halepensis* specie. The moderate level area accounts for 13.34 percent of the total area and is composed of a mix of moderately tall trees and herbaceous species with a moderate density cover. The lowest risk level, accounting for more than 51 percent of the total, corresponds to agricultural lands and nude soil, which are concentrated in the west part of the study area.

Topographic factors FFR maps

Topographic features play a significant role in the forest fire process by influencing fire ignition and flame spread (Fekir *et al*. 2020). The elevation, slope angle, and aspect extracted from a DTM allow us to create digital maps of these parameters. The terrain elevation with moderate and high forest fire risk (700m) accounts for approximately 15.0 percent of the total study area, compared to 25.1 percent and 53.9 percent for the low end very low fire risk (Fig. 3.c). Furthermore, moderate, high, and very high fire risk levels based on slope steepness dominate our research study with more than 78 percent (Fig. 3.d). The steepest areas, which are at high risk of fire, are in the center and western parts.

The South and West aspects, which correspond to high and very high risk levels, occupy an area of 2729.61 ha, equivalent to 55.11 percent of the study area (Fig. 3.e).

The combined effect of elevation, slope, and aspect can create very favorable conditions for fire occurrence and accelerate spread speed (Fekir *et al*. 2020).

Human activities factors FFR maps

Access to the forest area is facilitated by roads and footpaths. Furthermore, areas near settlements and agricultural activities may have intentional human activities that cause forest fires.

The road network, settlement location, and farming lands for the study area were digitized as vector layers from Google Earth images. They were used to calculate distance and proximity from them using the Euclidean distance function of ArcGIS software's Spatial Analyst toolbox.

High and very high fire risk associated with distance from roads, settlement proximity, and farmlands characterize 24.88 percent, 64.4 percent, and 46.2 percent of the total study area, respectively. (Fig. 3.f, 3.g, 3.h).

Weights of major-criteria and sub-criteria based on AHP method

AHP primarily employs the expert-proposed score to rank the importance of fire risk factors. The pairwise comparison matrix is then used to calculate the weight of each element. The normalized pairwise comparison matrix and the calculated weights of sub-criteria and major criteria based on AHP method have been shown in Table 5. The major criteria indexes and the fire risk model have been presented based on obtained AHP weights (equations 6–8):

$$Topography = 0.633 \times Slope + 0.260 \times Aspect + 0.106 \times Elevtion \quad (6)$$

$$Human\_Index = 0.648 \times Roads + 0.230 \times Settlements + 0.122 \times Farms \quad (7)$$

$$FFR = 0.525 \times Vegetation + 0.142 \times Topography + 0.334 \times Human\_index \quad (8)$$

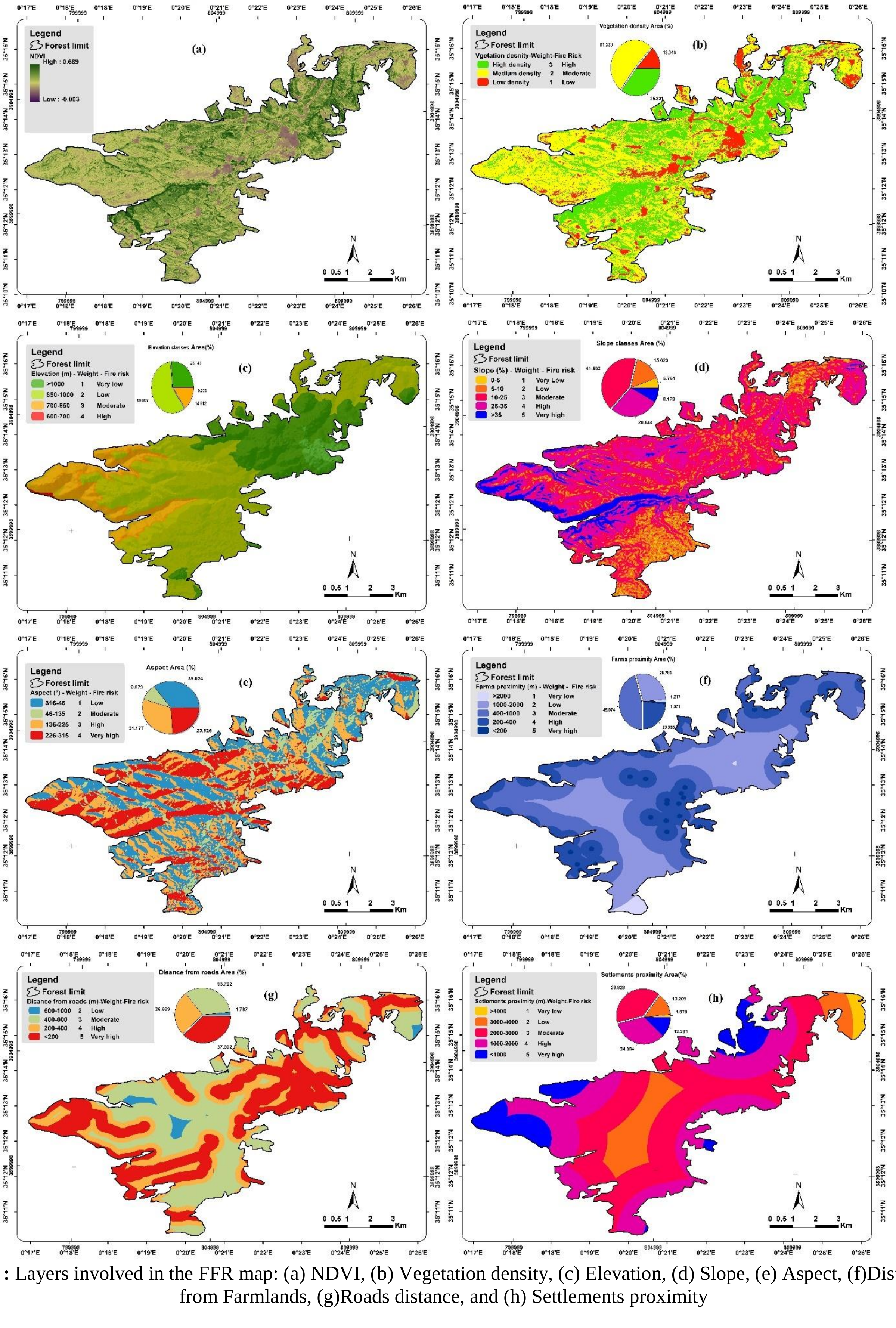

Fig. 3 : Layers involved in the FFR map: (a) NDVI, (b) Vegetation density, (c) Elevation, (d) Slope, (e) Aspect, (f)Distance from Farmlands, (g)Roads distance, and (h) Settlements proximity

Obtained FFR map

The FFR was assessed by the combination of the prior factors. These factors were introduced as raster layers into ArcGIS Raster Calculator toolbox to obtain FFR values and classified into five levels.

The obtained FFR map, as shown in figure 4, shows a dominance of the moderate FFR level with over 28.87 percent, followed by the high and very high-risk levels, which represent 23.94 percent and 11.22 percent, respectively. The low and very low-risk levels occupy a percentage of less than 36 percent (Table 6).

Furthermore, it should be noted that the very vulnerable areas, which correspond to high and very high-risk levels, are concentrated in the western and central parts of the forest massif. The dominance of the *Pinus halepensis* specie, which is known for its high flammability and combustibility, may explain these findings. Furthermore, the steepest topographical conditions, access to forested areas, and farming activities (beekeepers, burning agricultural residues) within forested areas increase this risk.

Table 5 : Normalized pairwise comparison matrix of major criteria and sub-criteria and the assigned weights

Major Criteria	**Vegetation**	**Topography**	**Human**	**Weight**		
Vegetation	0,545454545	0,428571429	0,6	0,525	**CI=**	0,026909276
Topography	0,181818182	0,142857143	0,1	0,142	**RI=**	0,58
Human activity	0,272727273	0,428571429	0,3	0,334	**CR=CI/RI=**	0,046395303

Topographysub-crit	**Slope**	**Aspect**	**Elevation**	**Weight**		
Slope	0,652	0,692	0,556	0,633	**CI=**	0,01935734
Aspect	0,217	0,231	0,333	0,260	**RI=**	0,58
Elevation	0,130	0,077	0,111	0,106	**CR=CI/RI=**	0,033374725

Human sub-crit	**Distance from roads**	**Settlement's proximity**	**Farms proximity**	**Weight**		
Distance from roads	0,652	0,667	0,625	0,648	**CI=**	0,001848334
Settlement's proximity	0,217	0,222	0,250	0,230	**RI=**	0,58
Farms proximity	0,130	0,111	0,125	0,122	**CR=CI/RI=**	0,003186783

Table 6 : FFR levels and the corresponded areas in the study site and burnt zones

FFR level	**Study area**		**Burnt area**	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**
Very low	556,00	11,27%	32,27	12,24%
Low	1219,22	24,71%	103,08	39,11%
Medium	1424,51	28,87%	51,74	19,63%
High	1181,25	23,94%	57,70	21,89%
Very high	553,70	11,22%	18,81	7,14%

Table 7 : Burnt and non-burnt areas in high to very high-risk zones and other zones

FFR level	**Burnt area (ha)**	**Non-burnt area (ha)**	**Total area (ha)**
High to Very High	76,51	1658,44	1734,95
Others	187,09	3012,64	3199,73
Total area (ha)	263,60	4671,08	4934,68

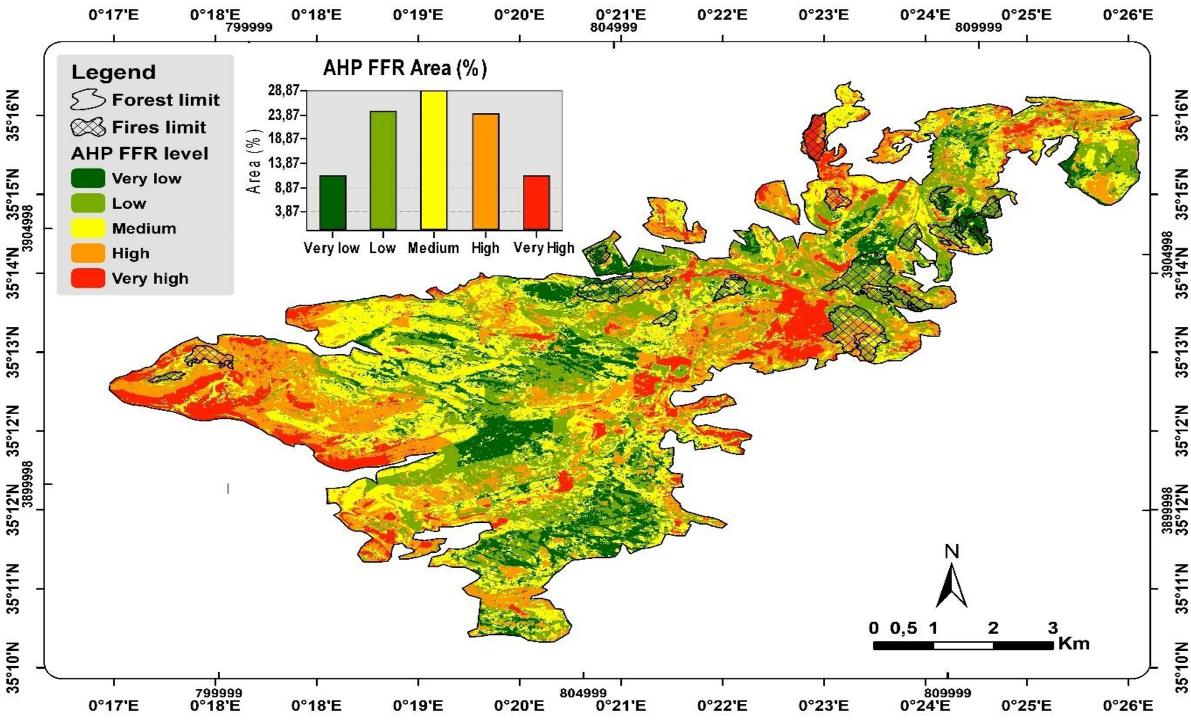

Fig. 3 : AHP FFR synthetic map of the forest of Nesmoth

In the current study, the spatial statistical method is used to calculate the overall accuracy of the resulting map. The size of the burning in the study area is represented by two variables: the level of fire risk (high to very high-risk zones and other zones) and the occurrence of fires (burnt forest area and non-burnt forest area). The equation below is used to calculate overall accuracy.

$$Overall\ Accuracy = \frac{Burnt\ areas\ in\ High\ to\ Very\ High\ zones + Non\_burnt\ areas\ in\ other\ zones}{Total\ area\ of\ the\ study\ forest} \quad (9)$$

According to the validation results, 48.65 percent of the actual burnt area is located in moderate, high, and very high-risk zones, while 39.54 percent is located in low to very low risk zones. The calculated overall accuracy is approximately 62.60 percent.

Conclusion

Forest fires are a major problem in western Algeria, destroying the environment's ecosystem. Overcoming this issue has become an important requirement of forest management in order to limit and reduce resource degradation and extend faunistic and floristic life. As a result, forest fires, due to their spatial and temporal characteristics, necessarily require the use of techniques and tools that can collect and process spatial data sources. GIS and remote sensing appear to be the most effective tools for resolving multi-decisional spatial problems.

In this work, the MCDA AHP method was used to calculate and assign weights to FFR factors. The involved model considers seven factors as being responsible for forest fire ignition, which are divided into three major criteria and seven sub-criteria. Geomatics tools such as GIS were used to extract and create thematic layers for each factor, as well as to generate a synthetic FFR map. The obtained map revealed a predominance of Moderate, High, and Very High risk classes, with more than 64 percent of the study area classifying the Nesmoth forest as more vulnerable to fire ignition.

The incorporation of multicriteria analysis methods such as AHP has significantly improved its efficacy. The obtained results were consistent with and closer to those obtained from the spatial analysis of the FFR map.

The FFR modeling and analysis based on GIS can help forest managers understand the spatial patterns of the forest's vulnerability to fires. As a result, they will be able to create a management plan to prevent and fight forest fires. We emphasize the effective contribution of MCDA approaches in conjunction with GIS in delivering a very helpful solution for decision-makers throughout this study.

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