MODELLING OF FOREST FIRE RISK SPATIAL DISTRIBUTION IN THE REGION OF AURES, ALGERIA

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The objective of this study is to model and map the forest fire risk in the region of Aures situated in the northeast of Algeria, through the application of Analytical Hierarchy Process (AHP) method to integrate geographic information systems (GIS) and remote sensing. The methodology is based on a weighted linear combination of three parameters, namely, vegetation, topography and the anthropogenic factor which influences the initiation and propagation of a forest fire. The result is a risk map with four classes according to pixel values, whereas very high-risk class takes up 18.28% of the study area, high-risk class takes up 42.42%, moderate risk class takes up 5.24% and low-risk class takes up 34.05%.

Key words: modelling, forest, fire, risk, Analytic Hierarchy Process (AHP), GIS, remote sensing.

INTRODUCTION

In the Aures region (northeast of Algeria), forest fire causes huge environmental damage. Each year a lot of forest areas are destroyed, and this has been happening especially over the last seven years. The anthropic pressure is the main factor of forest fires in the Mediterranean basin with at least 95% of fires are caused by man. The most frequent human activities that cause forest fires are: the extraction of non-woody plants, clearing due to agricultural activities, arson, negligence, and hunting. The economic losses due to forest fires are not estimated only in terms of burned area, but also in terms of loss of production, degradation of the environment and the social impact (*Fire management – global assessment 2006*, 2007). The spread and intensity of forest fires are related to climatic, topo-morphological conditions, the type of vegetation and anthropogenic factors (Faleh et al., 2012).

The Mediterranean climate of the study area is characterized by a dry summer period with an extreme flammability of the vegetation during this season, the increasing rugged character of the field and human activities make this region an area of a repetitive risk of forest fires (*Fire management – global assessment 2006*, 2007). Conventional methods generally used in the study area for the prevention and the firefighting are time-consuming and are not always reliable due to the complexity and diversity of forest ecosystems. According to the FAO, the fire risk is the chance of fire starting as determined by the presence and activity of causative agents, a causative agent, a number related to the potential of firebrands to which a given area will be exposed during the rated day (*Wildland fire management terminology*, 1986).

In this context, the modelling of forest fire risk allows on one hand to guide and optimize in short and medium term the rate of investment including infrastructure, equipment and fire development operations (Assali et al., 2016). On the other hand, it allows the involvement of managers in their activities of prevention, intervention and territorial planning for identification of the areas most vulnerable to fire.

Various methods can be implemented in order to model and localize the hazard. Those vary according to the aims, the means and various forms of modelling used. In our study, the Analytic Hierarchy Process (AHP) integrated with Geographic Information Systems (GIS) was applied in modelling and mapping the forest fire risk in the Aures region. The study was carried out considering objective parameters that can influence vulnerability to forest fire such as the ecological parameters (the combustibility of the vegetation formations), the site parameters (slope, exposure, and topo-morphology) and anthropogenic factors.

The Analytic Hierarchy Process (AHP), introduced by T. Saaty (1977), is a method which provides a technique based on a mathematical model for analyzing complex situations and is sophisticated in its simplicity. This technique has become very successful in helping decision makers to structure and analyze a wide range of problems (Golden et al., 1989).

According to researchers (Dagorne et al., 1994; Erten et al., 2004; Adab et al., 2013; Assali et al., 2016), the modelling of risk of forest fires incorporating three sub-indices, which is: topo-morphology, combustibility and the anthropogenic factor as parameters to which weights have been assigned in accordance with the importance of each parameter in forest fire risk. The aim of the study is to provide managers a tool to help them in their planning, prevention and fight against fires in the forests in Aures region taking into account that this paper deals with long-term hazard assessment.

PRESENTATION OF THE STUDY AREA

The study area is located at the eastern Aures, part of the Saharan Atlas which is located geographically in northeastern Algeria (Fig. 1). It is situated between Arris and Khenchela, ranging from the Chelia mountain in the north, to the oasis of El Ouldja (Taghzout) on the southern part of the massif of Aures, it extends

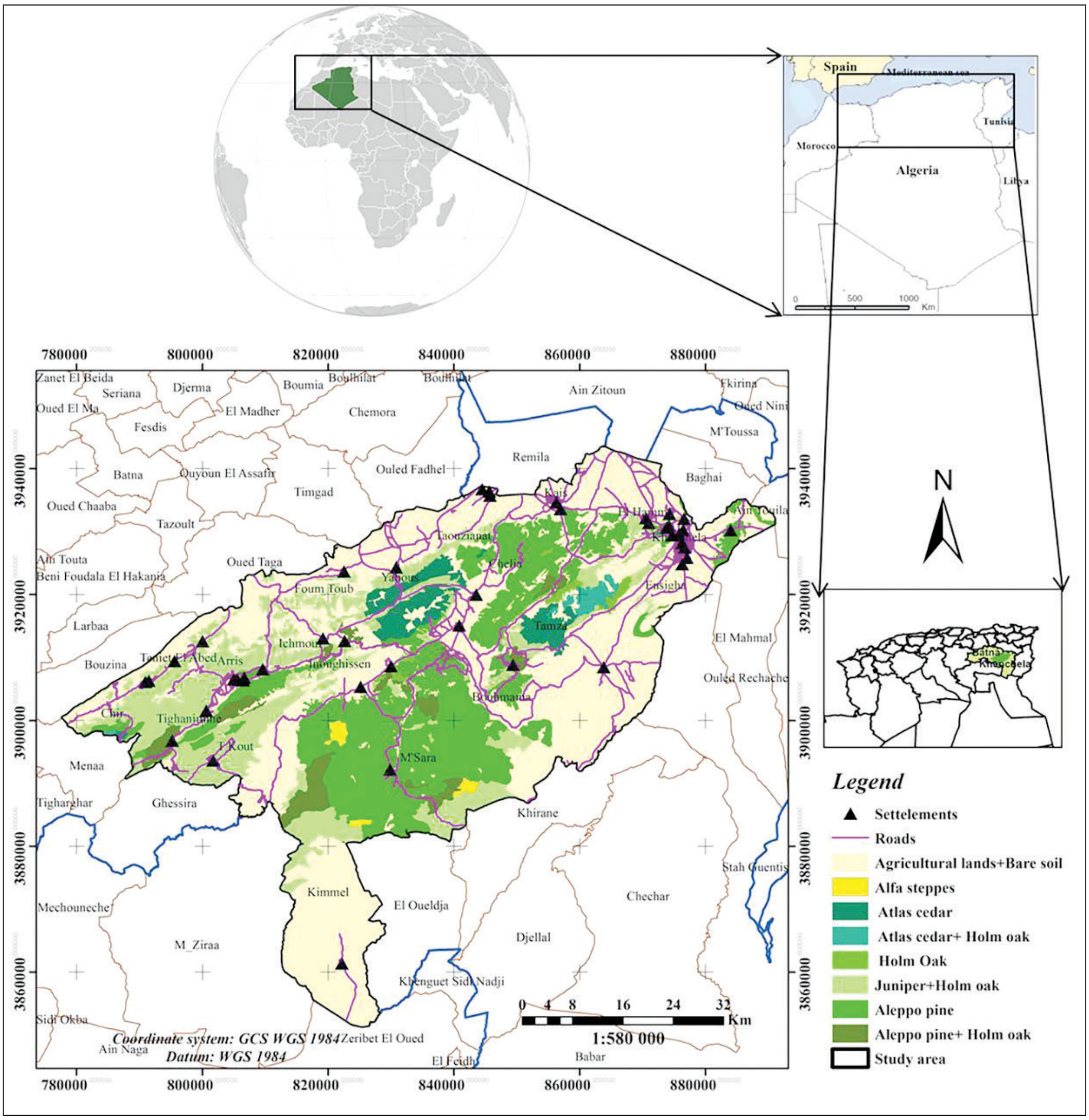


Figure 1 *Geographic localization and the land use of the study area*

between the 35 ° 00' and 35 ° 18' north lattitude and 6 ° 22' and 6 ° 52' longitude.

This area is composed of four contiguous mountains: BeniImloul with more than 75,000 hectares, the Ouled Yagoub which counts 45,000 hectares (Garah et al. 2016) and the forest of the southern area of Aurès with 61885.04 hectares. The complex of Aures landscapes is composed of different interacting vegetation patches. Aleppo pine (*Pinus halepensis*) and holm oak (*Quercus ilex*) ecosystems form contiguous patches within these landscapes, or as mixed pine–oak and *Cèdre de l'Atlas (Cedrus atlantica)* ecosystems located between 600 and 2300 meters above sea level. The study area is known for its sensitivity to very frequent fires in the summer, and these vegetation types are mainly distributed from the Bouhmama series with an altitude of 1736 m to the first Saharan oasis of Kheirane at the altitude of 662 m (Helal, 2010).

The study area consists of a set of hilly reliefs of direction general south and north, ranging in altitude from 662 to 2300 m, with an average slope of 30%. The field of study is characterized by the Mediterranean climate corresponding to bioclimatic vegetation floors ranging from semi-arid to the sub-humid and varied precipitation depending on the altitude and exposure.

MATERIALS AND METHODS

The approach adopted for this study is based on the integration of geographic information systems (GIS) and Analytical Hierarchy Process (AHP) to estimate *forest* fire *risk* zones in Aures region.

The aim of the present study is to propose a methodology based on the previously presented researches related to modelling and mapping of forest fire risk by identifying three principal criteria, that are linked to forest fire: topography, vegetation and human factor using *fire*-related *risks* parameters and indices that are adapted to the Mediterranean semi-arid and sub-humid areas of North Africa (Boultif, Benmessaoud, 2017), with the use of land management expertise weighting, Analytic Hierarchy Process (AHP) and GIS (Fig. 2).

The first step in the pre-treatment of image data is the delimitation of the study area after the mosaicking of 2 scenes, as well as in the atmospheric correction of images. The second step is to produce a thematic map showing the distribution of vegetation classes in the study area by using supervised classification method with ENVI 5.1 software. The classes were determined based on the spectral characteristics of geographical objects, and validated by the information collected in the study area. This information is essentially summarized in the description of vegetation formations, and taking their geographical coordinates GPS (Global Positioning System). Using the Google earth program, additional sampling points were taken and the on-site situation was examined for places with difficult access.

DEVELOPMENT OF CRITERIA

In the case of this study three criteria chosen in our analysis (AHP), topo-morphology, vegetation combustibility and the anthropogenic factor. These criteria were extracted from the sentinel satellite data, digital elevation model (DEM) and

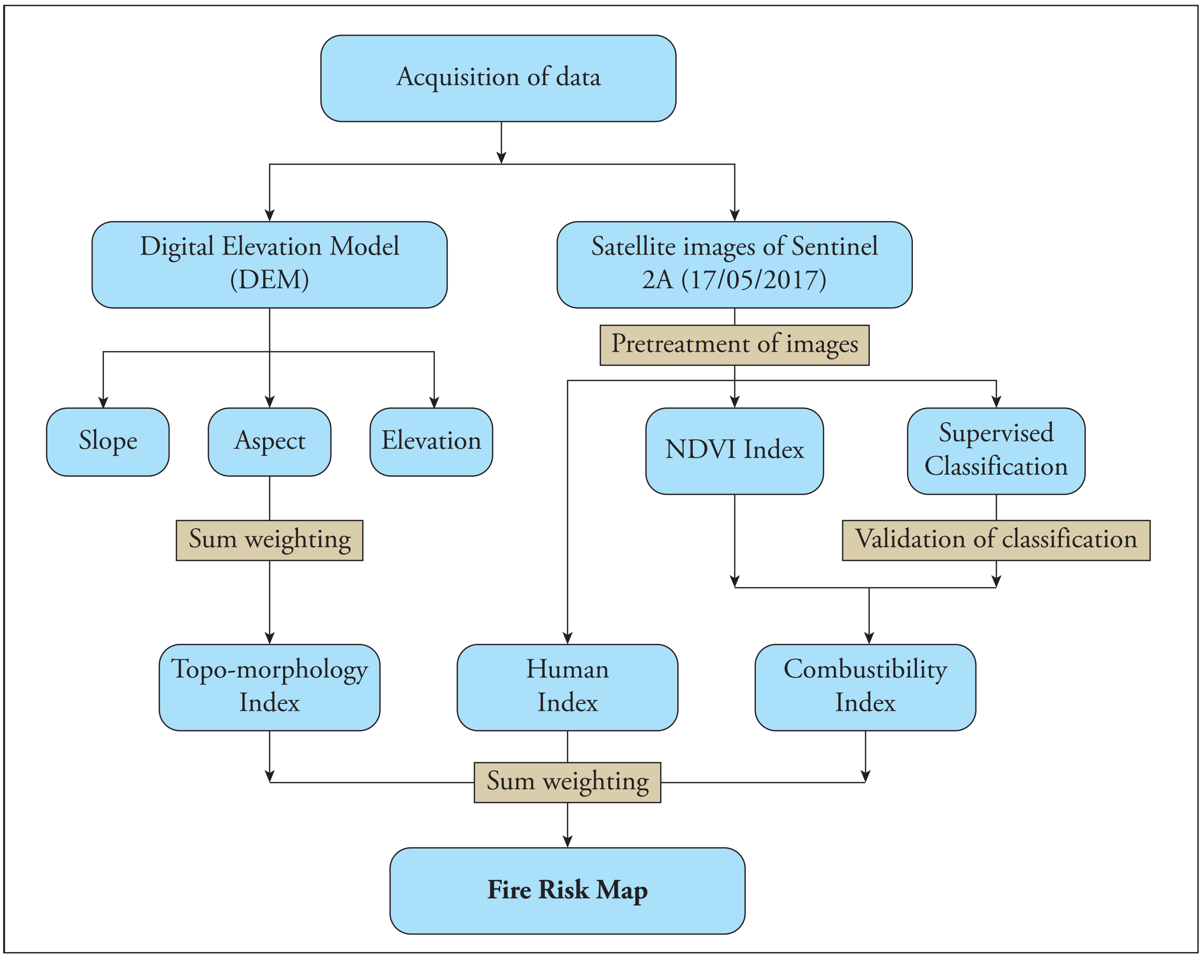


Figure 2 *Methodology chart of the fire risk mapping in the study area*

SRTM respectively and were measured using the spatial analysis capabilities of GIS.

1. Vegetation combustibility

The combustibility indicates the ability of vegetation to spread fire, and to release quantities of heat more or less important during combustion, depending on the structure and the dominant plant species of the forest (Faleh et al., 2012). The combustibility index or the index of potential fire intensity was estimated by the formula below (Equation1), which was proposed by (Mariel, 1995).

IC = 39 + 0,23 BV (E1 + E2 - 7,18) (Equation 1)

Where:
BV: Bio volume of the plant formation.
E1: Note of combustibility for dominant tree tops
E2: Notes of combustibility for dominant low woody or herbaceous plants

In this study, the calculation of combustibility is based on combination of dominant vegetation classification of the study area by using the supervised classification (maximum likelihood) tool in Arc GIS 10.2.2 software, and the *quantities of combustible biomass* that is estimated from the vegetation index normalized difference (NDVI) using raster calculator tool in ArcGIS. The NDVI is defined as the difference between the red and near infrared (NIR) reflectance divided by their sum (Tucker, 1979), and it is calculated from these individual measurements as follows (Equation 2):

$$NDVI = \frac{(NIR - NED)}{(NIR + NED)} \quad \text{(Equation 2)}$$

This step of calculation of combustibility was done from two recent satellite images taken in 17 June 2017 from the new satellite SENTINEL2A, acquired in the dry season, where one can distinguish the various types of land cover. The *satellite* carries a wide swath high-resolution (10 m) multispectral imager with 13 spectral *bands*, and its wide swath width (290 km).

2. Topo-morphological index

The topography is also one of the main factors that affect the spread of a forest fire. The slope determines the flames inclination and thus their rate of spread (Merdas, 2007). The exposure also has an indirect role in the progression of the fire, because it determines the type of vegetation (Baara, 2014), the influence of the winds and sun radiation. So the topo-morphological index is calculated by the combination of three physical parameters, such as the slope, exposure and altitude, and these three components were extracted from digital elevation model or DEM of the study area.

3. Human index

The anthropogenic factor is one of the main factors that aggravate the spread of the fire. The human index related to the occupation and human activity, this index was conducted by calculating the index of normalized difference built NDBI defined by (Zha et al., 2003). The development of NDBI index was based on the unique spectral response of built-up land that has stronger reflectance in the range of MIR (medium infrared) wavelength in the range of wavelength NIR (near radiation infrared). This index was expressed by the following formula (Equation 3):

NDBI = B6 - B5 / B6 - B5 (Equation 3)

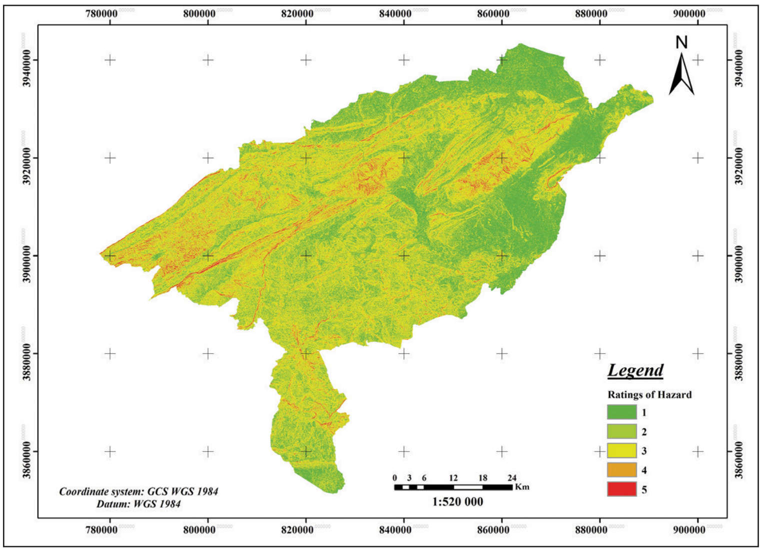
The Normalized Difference Build-up Index value lies between -1 to +1. Negative values of NDBI represent water bodies while higher values represent build-up areas. NDBI value for vegetation is low (Zha et al., 2003).

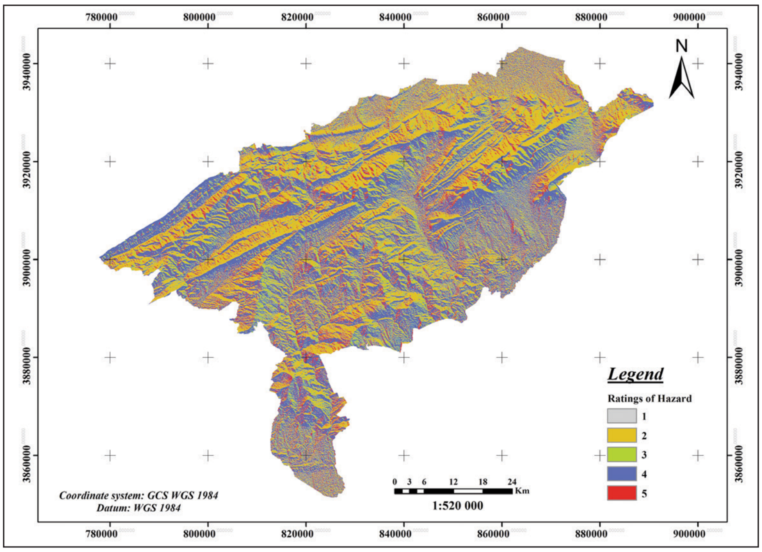
MULTIPLE CRITERIA DECISION MAKING

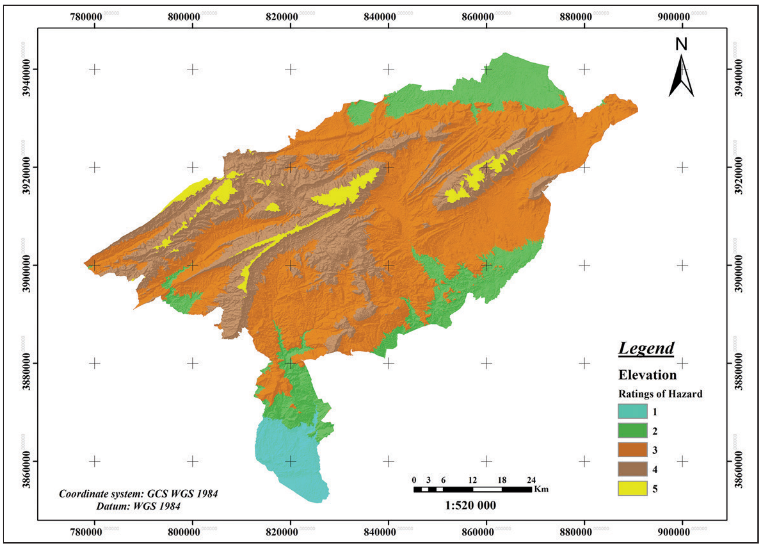
Sub criteria mapping and scores assigning

At first, all indices and parameters were mapped to form sub-criteria layers that will enter in the assessment of final forest fire risk (Fig. 3).

The next step is to reclassify each sub-criteria layer into value intervals using ArcGIS reclassifying tool (Tab. 1), then, scores from 1 to 5 were assigned to each class according to the intensity of each class on the risk, where 1 stands for a favourable value class.







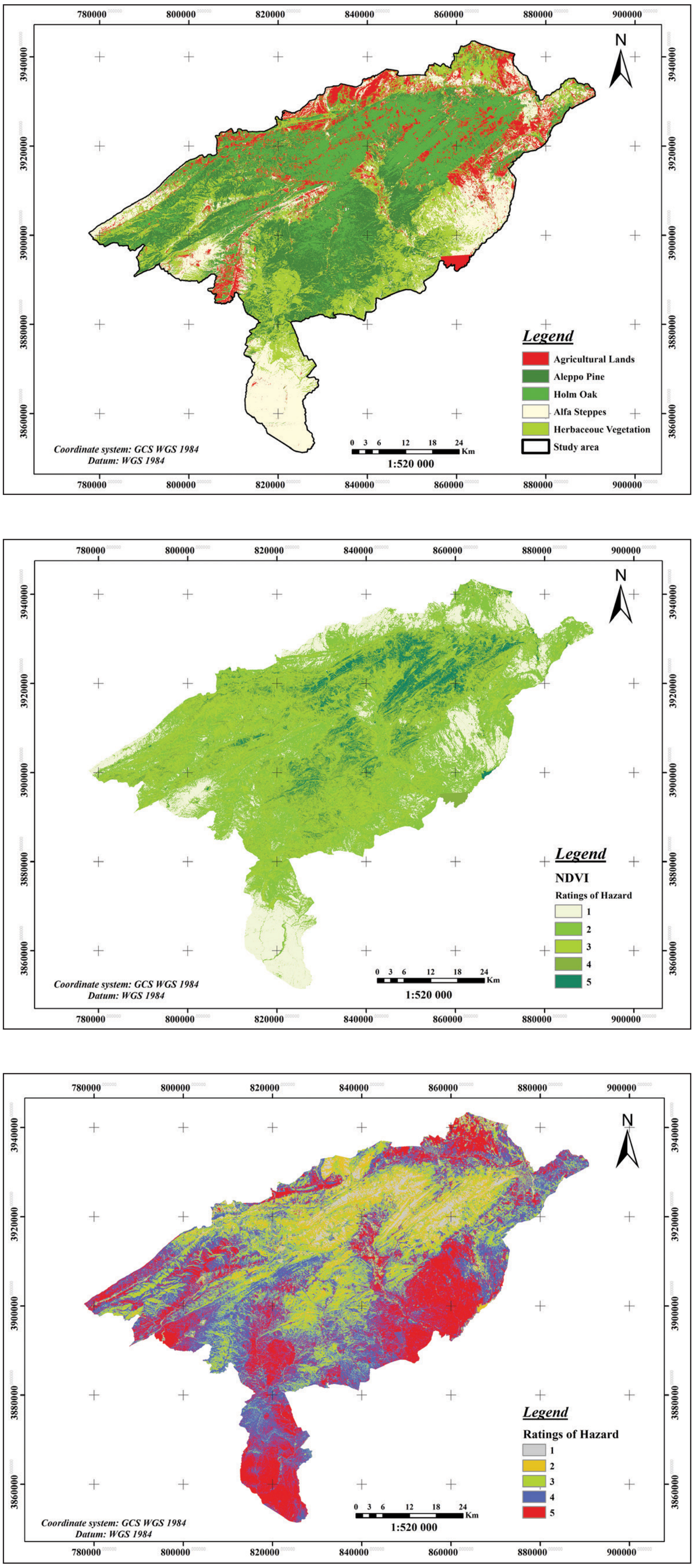


Figure 3 *Slope, aspect, elevation, land use, NDVI index and Human index of the research area*

Table 1 *Weight of parameters in determination of fire risk areas*

Factors	Parameters and indices	Values	Scores
Topo-Morphology	slope	Very Low	1
		Low (P<15%)	2
		Medium (15<P< 30%)	3
		High (30<P< 45%)	4
		Very high (P>45%)	5
	Aspect	Dish	1
		North	2
		East	3
		South	4
		West	5
	Topo-morphology	Plain (P <3%)	1
		Low piedmont (3< P <12.5%)	2
		Medium piedmont (12.5< P <25%)	3
		High piedmont (25< P <35%)	4
		Mountain (P> 35%)	5
Combustibility	land use	Agriculture	1
		Alfa steppe	2
		Herbaceous vegetation	3
		Holm oak	4
		Aleppo pine	5
	NDVI	Very Low	1
		Low	2
		medium	3
		High	4
		Very high	5
Anthropogenic	Human index	Very low	1
		Low	2
		Medium	3
		High	4
		Very high	5

Table 2 *Assigned weight according to Saaty scale*

Criterion	Combustibility	Topo-morphology	Anthropogenic
Combustibility	1	3	5
Topo-morphology	1/3	1	3
Anthropogenic	1/5	1/3	1

Multicriteria decision making

The method of Analytical Hierarchy Process (AHP) produces standardized weights whose sum is equal to "1." The method is based on a series of pairwise comparisons of these criteria from the construction of a square matrix taking into account the relative importance of a criterion relative to another (Bouzekri, 2015) for the establishment of such measures using Saaty scale (Tab. 2).

Weighting of criteria

For estimating the weighting coefficient requires the calculation of the eigenvector (Vp) of the comparison matrix in pairs, the values of these eigenvectors (Vp) are determined by calculating their geometric mean by cork for each criterion and the weighting coefficient for each criterion is deduced by standardizing the eigenvector by dividing each eigenvector by their sum and provided that the sum of the weighting coefficients must be equal to 1 (Tab. 3).

Table 3 *Weight values for the different criteria.*

Criterion	Weight
Combustibility	0.63334572
Topo-morphology	0.26049796
Anthropogenic	0.10615632
Total	1

The final step is to calculate a consistency ratio (CR) to measure how consistent the judgments have been relative to large samples of purely random judgments. Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent unreliable. And if CR equals 0 then that means that the judgments are perfectly consistent (Saaty, 1977). The consistency ratio (CR) in this study is equal 0.09.

RESULTS AND DISCUSSION

In the final step, the decision criteria were aggregated and combustibility, topo-morphology and the human index were compiled (Fig. 4) by the method of the weighted sum based on their weights. Each standardized test layer was multiplied by its coefficient of corresponding weighting.

Index of forest fire risk in the region of Aures

The combination by the method of the weighted sum based on their weights the three resulting layers (combustibility index, index of topo-morphology and the human index) were used to determine the level of risk to forest fires in the Aures region (Fig. 5).

According to the final map (Fig. 5) and the calculation of the areas of each level of risk, we can say that the map highlights the dominance of high risk class with an area of over 169,541.34 ha, (rate of 42.42%). All these areas are covered with Aleppo pine. Low risk class represented 34.05% of the total surface area; it is covered with farmland, bare land and built-up areas. High risk class is well represented with an average of 18.28% of the area; there is a mixed stand of Aleppo pine and holm oak. Medium risk class is important, but it has only 5.24% of the area, and there is only herbaceous vegetation.

The bar chart below (Fig. 6) shows the different forest fire risk levels in the study area.

In Algeria, many studies were conducted to assess forest fire risk and (Guettouche, Derias, 2013) and (Okacha et al., 2017) have conducted similar studies on other regions of the Algerian forest (the region of Bouzareah Clump and the Forests of Saida) and they found that the total of forest fire risk is highly influenced by vegetation, given the value of the weight assigned to this parameter. However, this influence is diminished

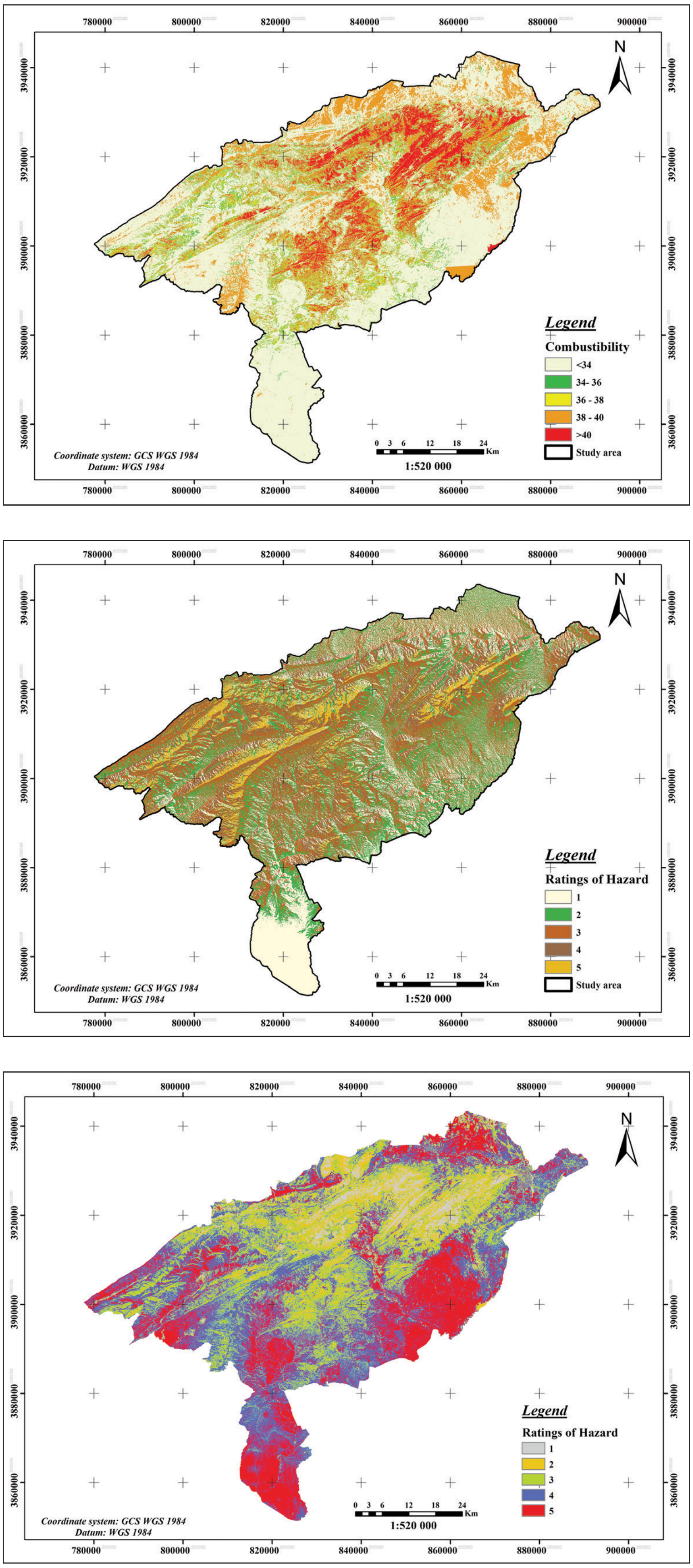


Figure 4 *Spatial sensitivity criteria of Aures region. Combustibility, topo-morphology and anthropogenic factor*

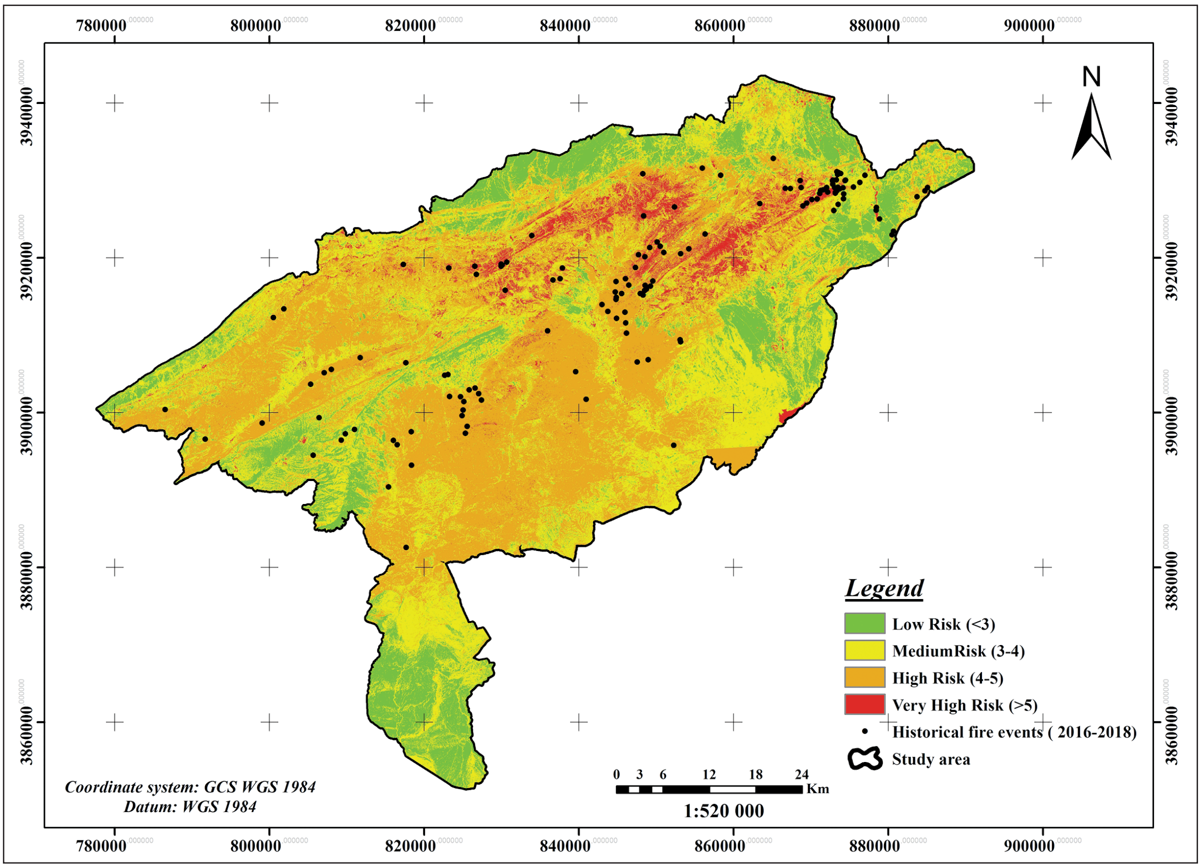


Figure 5 *Map of forests fire risk in Aures region*

when there are several other parameters for the same zone.

In this study, according the indices related to the risk of fire, risk analysis was subject to vegetation combustibility (Aleppo pine and holm oak) which are the most dominant species in the study area, the dominance of south exposition which sets out more favourable conditions for rapid inflammation and the spread of the flames, and anthropogenic factors such as habitat/forest interfaces that can be singled out as vulnerable to fire and so as a source of hazard. In the absence of a similar study in the study area, the risk map produced in this study will be of vital interest to the

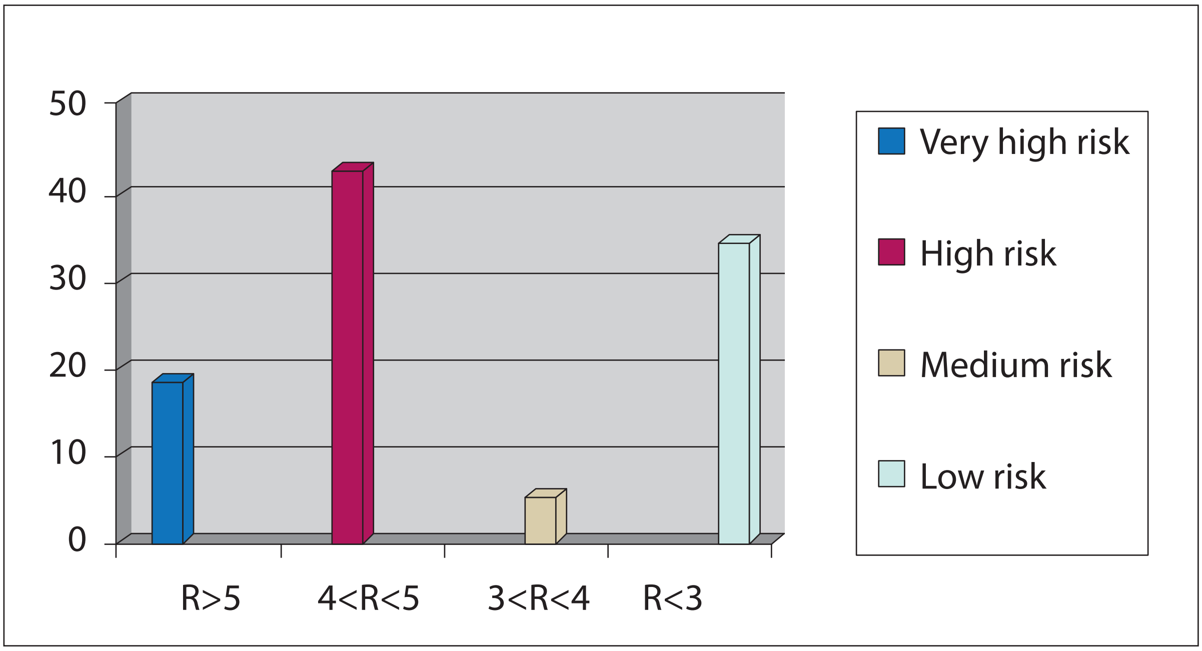


Figure 6 *Different forest fire risk levels in the study area*

firefighting and development services, because the model adopted in the methodology gave important and convincing results characterized by its adaptability to the area of study. Therefore, the mapping model allows highlighting the most sensitive areas and to identifying and clarifying priority protection areas better. This map can be used for equipment installation, firewall trenching and the establishment of trails.

CONCLUSION

The remote sensing and GIS are techniques with considerable contribution in the context of sustainable management of natural resources. GIS and methods of hierarchical multi-criteria (AHP) analysis were used in this study, we took into account the criteria of topography, combustibility and the anthropogenic factor, as the integration of these three parameters into GIS can be very useful to determine risk map and to plan forestry management after fire. According to the final map that shows the vulnerability of the study area to forest fire, we found that very high risk and high risk class take up 18.28% and 42.42% of the total surface respectively, medium risk class takes up 5.24% and low risk class takes up 34.05%. The risk map is not a means of firefighting, but it helps foresters and decision makers to: identify and prioritize fire risk areas, in order to intervene in the environment with sustainable management, put in place a reasonable policy for the fight and prevention against forest fires, and establish a development plan and a suitable land control according to the risk. The vulnerability of study area, notably its highly combustible vegetation composition makes it desirable to improve this study with other models which would incorporate other parameters such as meteorological data like temperature, air humidity, the speed and direction of wind, precipitation. We have proposed strengthening of the emergency response, the implementation of the access roads especially where the risk is high, monitoring, water stations, raising public awareness in order to reduce the risk of fire and to limit the consequences.

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