

# GIS Multi-Criteria Analysis for Identifying and Mapping Forest Fire Hazard: Nevesinje, Bosnia and Herzegovina

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**Abstract.** Fire risk management starts with an assessment of the most flammable places. In this paper, identification, classification and mapping of forest fire risk is completed with an aim of reducing the ratio and ecological damage caused by the fire. Suggested model is based on the combination of Geographical Information Systems and multi-criteria decision analysis using Analytic Hierarchy Process for mapping and assessment of forest fire risk in the area of Municipality Nevesinje, Bosnia and Herzegovina. The process was developed with an aid of 8 criteria grouped in four clusters. The weights are determined using AHP. Final map of forest fire risk is classified in 5 categories, from very low to very high risk, and indicates that 13.2% of Municipality area is in very high forest fire risk zone. The proposed method and the results of this study can be used for a policy of sustainable development at all levels of government.

**Keywords:** Bosnia and Herzegovina; forest fire; Geographic Information System (GIS); multi-criteria; Nevesinje; risk map

## 1 INTRODUCTION

Forest fires are considered to be natural disasters, which can endanger human life [1]. The causes of fire are most often directly related to human activities, such as negligence, carelessness, accident or arson on the forest areas. On the global scale, the fire destroys biodiversity and thus makes a great damage on ecosystem and intensifies the greenhouse effect [2, 3]. Fire releases large volumes of aerosols contaminants (CO, CO<sub>2</sub>, SO<sub>2</sub>, AM, PNE and OC), that significantly influence the Earth's atmospheric chemistry impacting on air quality and raising concern about risks to human health [4, 5, 6]. On local scale fire causes landslides, changes in the structure of soil and changes in vegetation [7, 8, 9].

Recent research of JRC Technical Reports shows that, due to climate change increasing air temperature and decreasing of humidity, the area affected by forest fires in Europe could be doubled [10]. This fact rises concern and initiates serious analysis of this phenomenon and preventive modelling of forest fire risk. The aim is production of forest fire risk map. Forest fire risk zones are locations where a fire is highly likely to start, and from where it can easily spread to neighbourhood area. Identification of these zones helps us to discover areas with increased risk of forest fire occurrence and its development, which is the basis for emergency intervention planning. This creates favourable conditions for minimizing the number of fires and removing conditions for their formation.

Modern tools and technologies in combination with traditional knowledge could have great importance in prevention and forest fire control. Geographic information systems (GIS), in combination with other forms of technology such as remote sensing and computer modelling, are being used increasingly in all aspects of wildland fire management. Analysing scientific papers, in combination with GIS, several techniques were used for forest fire modelling, from logistic regression [9, 11], Analytic Hierarchy Process - AHP [12-18], AHP and Fuzzy analysis [18-23], neural network [24] to classification tree method [25].

Based on reference papers and experts opinion, Multi-criteria Decision Making (MCDA) in combination with GIS technology is the most often used method for cartographical forest fire risk modelling.

Bosnia and Herzegovina (B&H) is a country with a high risk of forest fires. On its territory in the period from 2007 to 2013 there was 177 182 ha area burned to the ground, of which 115 548 was forest [26, 27]. According to the European Forest Fire Information System's report, Bosnia and Herzegovina is on the high fourth place, right behind Algeria, Spain and Portugal, of the areas which were burned by fire [10]. In regional scale, the area of East Herzegovina is affected with the largest number of open fires (forest holdings Trebinje and Nevesinje).

In this study GIS-AHP MCDA model for forest fire risk mapping was presented in order to identify and classify suitability of zones on the occurrence of fire in the Nevesinje Municipality. Forest fire risk map will reduce risk of fires and improve activities of prevention [19].



Figure 1 Map of Municipality of Nevesinje

## 2 MATERIALS AND METHODS

### 2.1 Study Area

Municipality Nevesinje is located in the south-east part of the Republic of Srpska (B&H), east from Mostar and south from Sarajevo. Nevesinje lies between 17°58'

and 18°25' longitude and 43°04' and 43°29' latitude. It belongs to the area of high Herzegovina with an average altitude of 860 m and it is characterized by the large karst field area of 17 000 ha. Total area of the Municipality Nevesinje is 923.4 km<sup>2</sup> (Fig. 1).

63.34% of the Municipality territory is covered with forest and it represents a potential forest fire risk zone [27], especially in the period of July-August when there are the highest air temperatures and the lowest amounts of rain [28].

## 2.2 Methods

Methodological hierarchical model in this paper is based on the spatial structure of the MCDA. Spatial multicriteria decision analysis (SMCD) consists of procedures that involve the sharing of geographic data and preferences DO, and the manipulation of data and preferences according to specified decision rules [29]. The main advantage of the integration of GIS and MCDA is to have unique capabilities that complement each other. GIS has great possibilities for the manipulation, storage, management, analysis and visualization of geospatial data, while the MCDA provides a collection of procedures, techniques and algorithms for structuring decision problems, and designing, evaluating and prioritizing decision alternatives [30].

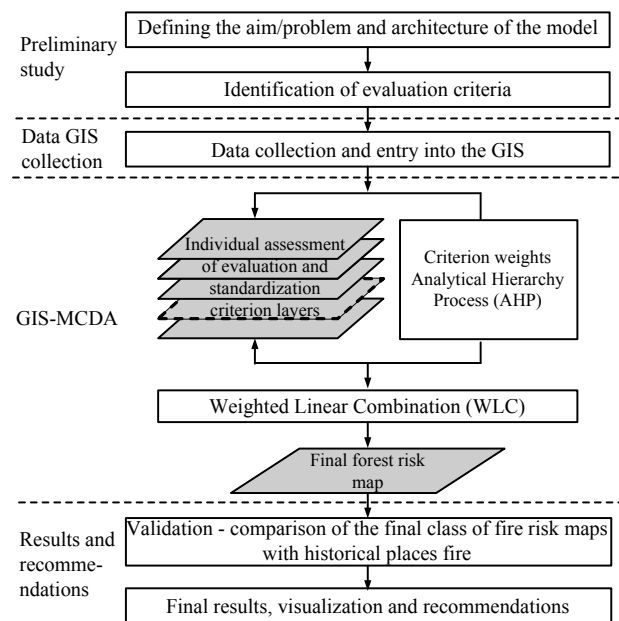


Figure 2 GIS-AHP MCDA of defining the critical zones for fires

Forest fire risk modelling has considered a wide range of hazard variables. The AHP method reduces complex decision in series of simple comparison and allows quantitative and qualitative comparison of criteria but there is not measurement of uncertainty in comparison and number of comparison significantly increases with the number of alternatives and criteria, which can be a big challenge [31]. From a methodological point of view, the proposed GIS AHP MCDA model defining fires crisis zones comprises the following steps (Fig. 2):

- Defining of aim/problem and defining of the architecture of model;

- Identification of criteria;
- Preparation of criterion layers for GIS;
- Multi-Criteria GIS evaluation (individual evaluation - standardization, determination of criteria weights (AHP) and aggregation criteria (WLC);
- GIS visualisation of final solution and recommendation.

*Identification of criteria.* In Bosnia and Herzegovina there is an accurate and reliable statistics on the occurrence of forest fires that could provide information about the locations of fire, therefore it is not possible to make an accurate location risk assessment at the level of smaller entities in order to make an assessment of their suitability to fire. Therefore, in order to reach the right conclusions, regardless of subjectivity in the evaluation, based on previous GIS MCDA study (Tab. 1) assessment was made of causative factors for spreading of fires and the possibility of their extinguishing. The study included six experts with experience in the field of risk management and environmental protection. During interviewing the experts collected data that are processed and aggregation of their opinions was made. Eight criteria grouped in four clusters, which are vital for starting of fire and forest fire risk assessment in the Municipality Nevesinje, are shown in Tab. 2.

*GIS MCDA.* This phase involves standardization, determination of weight and summary analysis of all the criteria, which are considered in the decision-making process. Application of weighted linear combination (WLC) requires that all data sets are standardized (reclassified) [30] in units that are comparable. There are a large number of approaches that can be used in order to make map attribute layers comparable, and some of them are described in Malczewski [32]. In accordance with the practice, the experts' experience and literature, the suitability of criteria, in this study, was performed using linear standardization on a score from 1 to 5, where 5 is the highest risk and 1 is the lowest risk value of alternatives (a cell) for the ignition of the fire. Standardized criteria, with a defined class values are shown in Tab. 4. In this way, reclassified maps are transformed in GIS operational raster basis for the application of AHP multi-criteria process (Fig. 3.).

*Determination of criteria weights AHP.* In the process of solving real problems, the criteria do not have the same degree of significance, so it is necessary that decision maker define the significance of particular criteria by calculating the corresponding weight coefficient (weight) or weights of the criteria. Normalized weight of criteria is calculated by using multi-criteria technique in the form of AHP [31]. Methodologically speaking, the AHP is a multicriteria technique based on the comparison of elements in the same level of hierarchy relative with regard to the elements on a higher level. The goal is on the very top, under the criteria (sub-criteria, if any) and at the bottom of the alternatives. AHP first requires comparison of criteria and calculate their weight with regard to goal. Alternatives are then compared in pairs in respect to each criterion and in analogical process their relative weights are determined.

**Table 1** Criteria used in MCDA modeling for mapping forest fire risk

Authors	Land use	Soil types	Drainage	Climate	Elevation	Slope	Aspect	Distance from roads	Distance from communities	Distance from streams
Hernandez-Leal et al.(2006) [9]	*				*	*	*	*		
Mahdav (2012) [12]	*			*	*	*	*		*	
Ariapour et al. (2014) [13]	*				*	*	*	*	*	*
Chavan et al. (2012) [14]	*		*			*	*	*	*	
Setiawan et al. (2004) [16]	*				*	*	*	*		
Yakubu et al. (2013) [17]	*				*	*	*			
Vadrevu et al. (2009) [20]				*	*	*	*			
Garavand et al. (2015) [23]					*	*	*	*	*	*
Adab et al. (2011) [33]	*				*	*	*	*	*	
Rajabi et al. (2013) [34]	*			*		*		*	*	*
Kanabkaew et al. (2014) [35]	*	*						*	*	*

**Table 2** Criteria description

Klaster	Criteria	Criteria description
K1 Land use	C1	<i>Vegetation.</i> The main factor that affects the spread of a forest fire is the type and the characteristics of the vegetation. The Vegetation is crucial for the fire spreading because it represents the total fuel available for the fire [36].
K2 Topography	C2	<i>Aspect.</i> Generally, in the north hemisphere, south and southeast aspects are the most suitable for both, ignition and spreading of fire [37], they receive more direct sunlight and because of that they have a higher temperature and a minor humidity.
	C3	<i>Slope.</i> The slope influences the fire behaviour. Steep slope can increase the rate of the fire spread [33]. Slope affects speed and capability of firefighter and equipment movement and there for speed of fire extinguishing. 10% increase of the slope can double the rate of the fire spreading.
	C4	<i>Elevation.</i> Elevation is a crucial physiographic variable that is associated with wind behaviour and fire spreading. Therefore it affects the structure of vegetation, total fuel available for fire, air humidity and temperature [38].
K3 Climate	C5	<i>Mean annual air temperature.</i> Air temperature is one of the most important climate factors. Fires can occur at any temperature, but their number depends on increasing of the temperature [39].
	C6	<i>Mean annual precipitation.</i> Precipitation is an important factor that influences suitability for ignition and fire spreading. It appears in the form of air humidity, humidity of habitat and fuel. If fuel is dry, fire will spread faster [20].
K4 Socioeconomic	C7	<i>Distance from roads.</i> 95% of forest fires in the Mediterranean are caused by the human negligence. The roads are a significant factor because their presence means human activity, therefore the forests near roads have a higher risk of forest fires [27].
	C8	<i>Distance from settlements.</i> It was found that the man is the main cause of the fire, so it was logical that with increasing of distance from human residence the number of fires would decrease [32, 40].

**Table 3** Standardization criteria

Criteria	Intensity of importance				
	1 very low	2 low	3 moderate	4 high	5 very high
C1*	(512)	(112,332,333)	(211,242,243)	(222,231,321,324)	(311,312,313)
C2	N	NE, NW	E, W	Flat, SE	S, SW
C3	0-5°	5-15°	15-25°	25-35°	>35°
C4	>800 m	600-800 m	400-600 m	200-400 m	0-200 m
C5	< 10 °C	10-15 °C	15-20 °C	20-25 °C	>25 °C
C6	>1750 mm	1500-1750 mm	1250-1500 mm	1000-1250 mm	< 000 mm
C7	>1200 m	900-1200 m	600-900 m	300-600 m	0-300 m
C8	>2000 m	1500-2000 m	1000-1500 m	500-1000 m	0-500 m

\* Third level CORINE nomenclature

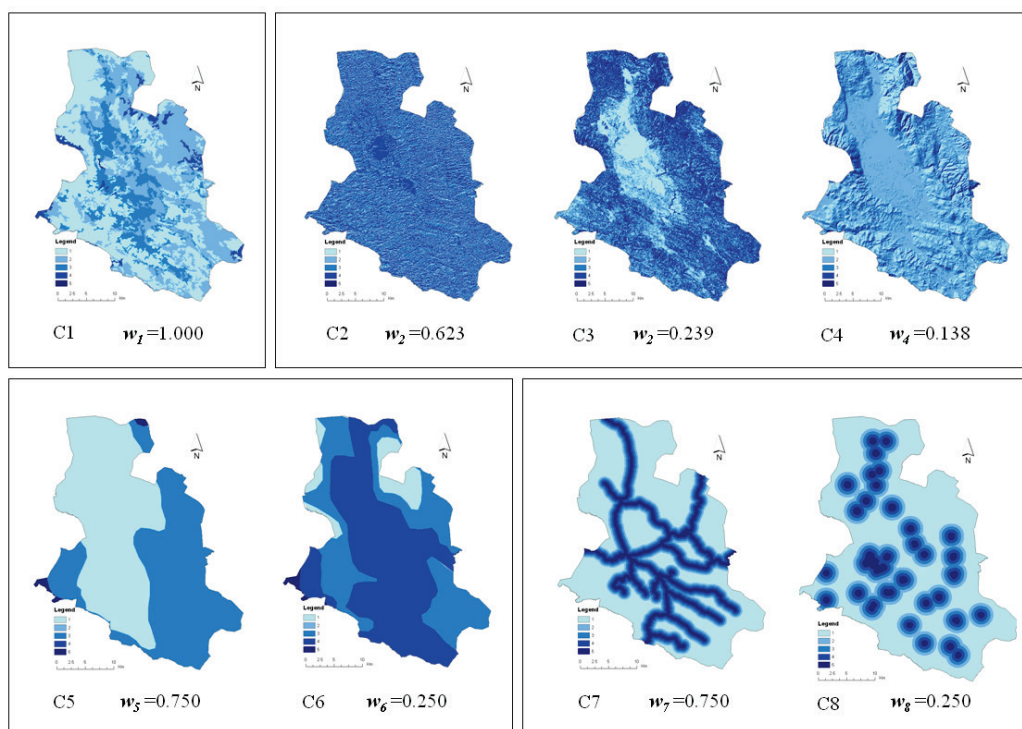


Figure 3 Standardized criteria

Observing the defined goal, for each pair of the criteria, the importance of one over the other are entered in the matrix of comparison. In this way, the amounts of cells along the matrix's diagonal is 1 (Tab. 4).

Table 4. Comparison matrix and weights to criteria

Criteria		C2	C3	C4	$w_i$
Aspect (C2)		1	3	4	0,623
Slope (C3)		1/3	1	2	0,239
Elevation (C4)		1/4	1/2	1	0,138
$\lambda_{max}=3,026$ CI= 0,013 CR= 0,022					

Criteria	C5	C6	$w_i$
Mean annual air temperature (1981-2010) (C5)	1	3	0,750
Mean annual precipitation (1981-2010) (C6)	1/3	1	0,250

Criteria	C7	C8	$w_i$
Distance from roads (C7)	1	3	0,750
Distance of settlements (C8)	1/3	1	0,250

After entering the value from Saaty's fundamental scale [32, 39] in Comparison matrix, weights of criteria ( $w_i$ ) are calculated. Comparison matrix at the cluster level is shown in Tab. 5.

Table 5 Comparison matrix and weights to clusters

Klaster	K1	K2	K3	K4	$w_i$
Land use (K1)	1	3	4	2	0,450
Topography (K2)	1/3	1	2	1/3	0,142
Climate (K3)	1/4	1/2	1	1/4	0,087
Socioeconomic (K4)	1/2	3	4	1	0,321
$\lambda_{max}=4,108$ CI= 0,036 CR= 0,040					

### 2.3 Data Collection and Input into a GIS

Each of the defined criteria is represent in GIS in the form of spatially defined vectors, whose cells represent

different alternatives. The used data and their sources are given in Tab. 6. All GIS processes (digitization, conversion, etc.) of inputting and spatial base of criteria building were accomplished using the integrated tools of ArcGIS 10.2. software of company ESRI. This area consists of 1 477 440 cells (resolution 25×25 m) representing alternative target by analysis.

Table 6 List of criteria their data and sources

Criteria	Data	Source
Distance from roads	Prostorni Plan Republike Srpske [41]	Ministry of Spatial Planning, Civil Engineering and Ecology
Distance from settlements		
Vegetation	CORINE Land Cover 2006 [42]	European Environment Agency
Aspect	Digital Terrain Model (DTM) [43]	Republic administration for geodetic and property affairs
Slope		
Elevation		
Mean annual air temperature (1981-2010)	Prostorni Plan Republike Srpske [41, 44]	Ministry of Spatial Planning, Civil Engineering and Ecology
Mean annual precipitation (1981-2010)		

### 3 RESULTS AND DISCUSSION

In the final realization is used Weighted Linear Combination (WLC) that is integrated into Spatial Analyst tools, according to the formula [16]:

$$S = \sum w_i x_i, \tag{1}$$

where  $S$  is the fire hazard rating,  $w_i$  is normalized weight of factor  $i$ , and  $x_i$  is the criterion score of factor  $i$ . As a result of multiplying weight criteria obtained as a result of

AHP, with a cell's score of each criterion the final forest fire risk map is generated.

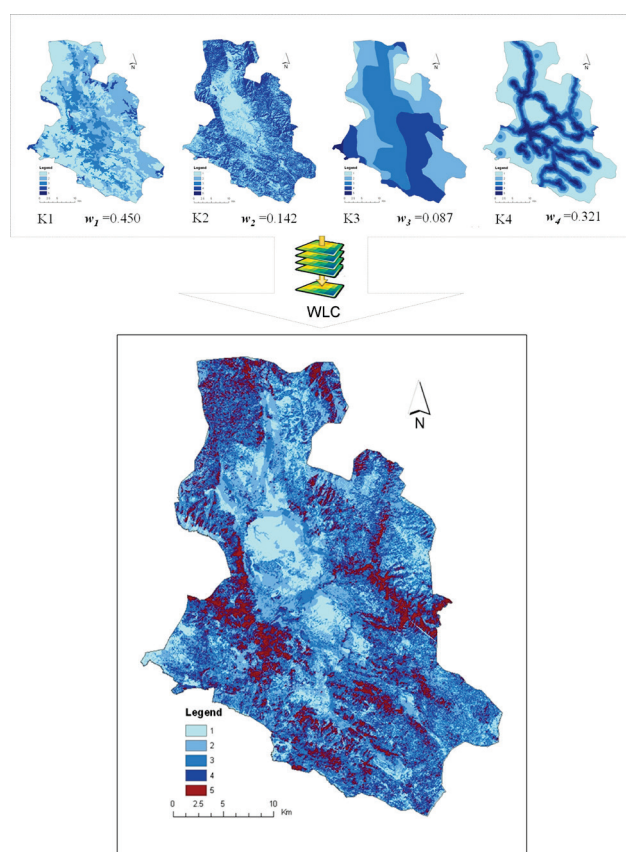
Based on defined criteria and clusters, final map is represented in the same score as criteria from 1 to 5 (Fig. 4). Larger values of cells score are characterized for location with high risk of fire ignition. On Fig. 4 areas that are the most critical when it comes to the spread of fire are represented with dark colours.

Study area, according to the cell's value of forest fire is shown in Tab. 7.

**Table 7** The areas of classes of final forest fire risk map

Classes		Area (km <sup>2</sup> )	%	Number of cells (25×25)
1	Very low suitability	47,2	5,1	75.505
2	Low suitability	197,0	21,3	315.233
3	Moderate	287,6	31,1	460.149
4	High	270,2	29,3	432.357
5	Very high	121,4	13,2	194.196

Analysing the results, the total area of the most endangered area (value of cell 5) of forest fire in Nevesinje municipality is 121.4 km<sup>2</sup>, which is about 13.2% of its territory. Mainly, those areas are the parts of the municipality which are located near settlements on steep slopes and that are mostly covered by pastures and conifer forests.



**Figure 4** Aggregation of forest fire risk map, municipality of Nevesinje

#### 4 VALIDATION OF RESULTS

Historical data about forest fire was collected according to European Forest Fire Information systems report from 2010 to 2015 [10, 45, 46, 47, 48]. In 2012 and 2015 the study area was affected with 3 and 2 large forest

fire respectively. Validation of proposed method was performed by establishing spatial relationship between historical data and forest fire map. For each historical data cell class of final forest fire risk is extracted by "Extract by Mask" algorithm (ArcGIS 10.2.). Results of analysis is shown in Tab. 8.

**Table 8** Extracted level of forest fire risk for historical data cells

Class	Very high	High	Moderate
%	82	13	5

Analysing the results, 82% of cells of historical data has very high suitability, 13% has high and 5% moderate suitability.

#### 5 CONCLUSIONS

The success of extinguishing forest fires and damage caused by them depends on the thoroughly studied and developed preventive measures. In this paper, combination of GIS and AHP MCDA method is used to determine forest fire risk zone in the municipality of Nevesinje. Prediction of forest fires was carried out on 8 criteria grouped in four clusters (land use, topography, climate and socio-economic). The AHP multicriteria method is used to calculate a correspondent weight of criteria. Comparison matrix are based on the experience of experts, literature and current practice. The final risk map is obtained in the WLC method. Approximately 13.2% of the municipality of Nevesinje area belongs to the zone of very high, 29.3% of the zone of high, 31.1% moderate zone, 21.3% of the low zone and 5.1% zone of very low risk of fire. For validation spatial relationship between forest fire risk map and historical data was performed. Results show that 82% of historical data cells are related to very high suitability so proposed model and map provide valuable information about the areas most likely to be affected by fire. It will be a useful tool in forest fire prevention and management in order to minimize forest fire hazard. Existing methodology can be applied to areas with similar geographical features.

Model shown in this paper can be improved by analysing new and modified criteria that are significant for this issue. In future, sensitivity analysis can be performed or AHP can be integrated with other MCDA techniques (FAZZY AHP, TOPSIS, VIKOR ect.).

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