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Automated procedure to assess the susceptibility of forest to fire

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ABSTRACT: The paper deals with the introduction of DSS tools and methodological approach that was developed in the framework of a dissertation thesis, aimed at the problem of assessment of forest susceptibility to forest fire. To automate the assessment procedure, a decision-making model was developed in the NetWeaver environment, organized in a hierarchical network. In the assessment, an approach was applied that is based on multicriteria assessment of various factors, assumed to have an impact on the occurrence and spread of fire in the natural environment. In the article original results of susceptibility assessments are presented, performed for an area situated in the Slovensky raj Mts. territory, which is known as the most fire risky territory in Slovakia.

Keywords: NetWeaver; protection of persons and property

Over the past decade, the number of forest fires in the world has been constantly increasing. It is now believed that due to the forest fires on average 600,000 ha of forests are damaged or even destroyed each year (Albers 2012).

In Europe, and also all over the world, the situation regarding the occurrence of fires has been constantly deteriorating, and the consequences can be severe. In the current situation, there arise suitable conditions for fires due to several factors. Natural and particular climatic factors usually predetermine the likelihood of forest fires, the management measures in forests are other factors influencing the accumulation of fuel in the forest, and especially because of the suppression of fire and gradually expanding transit zones between urban areas and the natural environment (Rigolot et al. 2009, Vélez 2009). Consequently, the distribution of forest fires in the area is specified not only by the climate but also by socio-economic factors (San Miguel, Camia 2009; Majlingová, Sedliak 2010). And the socio-economic factors can be described as the most important in terms of the fire occurrence.

The need to tackle the problem of forest fires seems not to be so urgent in conditions of Central Europe, see the trend of fire occurrence in the natural environment in Slovakia in Fig. 1, but there is an assumption that it is going to be a real problem, in particular in view of the actual prognoses of climatologists about global warming, and also weather extremes (in case of fires the long-lasting periods of drought and warmth) that occur more and more frequently.

The fire risk analyses are an important component of risk prevention and risk management. Here we introduce two approaches to an assessment of the risk components – the susceptibility to fire, us-

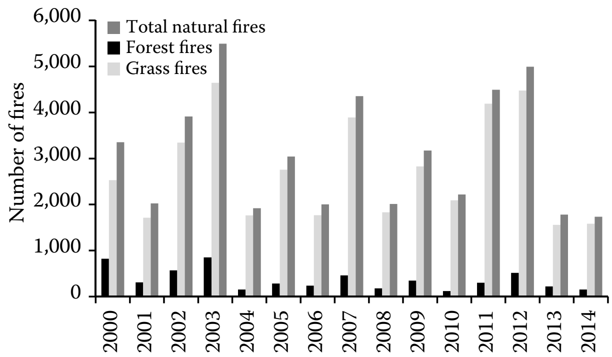

Fig. 1. Natural environment fires in the period 2000–2014 (Fire Research Institute of the Ministry of Interior of the SR 2015)

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ing the tools of decision support systems (DSS) and geographical information system (GIS).

The susceptibility to fire is a risk component expressing system (forest) characteristics closely related to the system sensitivity to be destroyed by fire in accordance with the factors of the environment in which the system (forest) exists. The fire risk is often expressed as the probability of hazard occurrence and sometimes it is also expressed as the probability of hazard occurrence multiplied by its consequences (Šimak 2006; Thywissen 2006).

The one of the above-mentioned approaches to forest fire susceptibility assessment is based on the statistical processing of historical data on fire occurrence (Holecy et al. 2003; Tuček, Majlingová 2009; Sedliak 2014) and the other uses multicriteria assessment of individual factors and group of factors with an influence on fire occurrence or further spreading (Majlingova 2014). Both approaches were processed into the form of decision-making networks to automate the assessment process in the spatial decision support system (SDSS) environment.

Spatial decision support systems (SDSS) represent information systems used to support the decision-making in the case of object oriented problem. They are applied everywhere where it is not possible to use an automated system to solve the entire decision-making process. In comparison with DSS, the SDSS must also: provide a mechanism for the input of spatial data; allow the representation of spatial relationships and structures; include analytical techniques for spatial and geographical analyses; provide tools for the output of different forms of spatial data, including maps.

For a comparison of the results of both approaches, a part of the Slovensky raj Mts. National Park territory was chosen as an experimental area.

MATERIAL AND METHODS

Experimental area. An experimental area is represented by forests managed by the state enterprise Forests of the Slovak Republic, situated in the Spis-Gemer Karst forest district, and having the extent of 9,346 ha. Forests are located in the following forest management units: Hrabusice, Hranovnica, Ladova, Mlynky and Smizany. Since 1988, the area has been a part of the Slovensky raj Mts. mainly due to the unique nature of the country, the occurrence of a number of endemic plants and a number of indigenous forest communities.

From a geomorphological point of view, the territory of the Slovensky raj Mts. is situated in the northeastern part of the Slovak Ore Mountains and the eastern part of the Fatra-Tatra region. The central part of the territory consists of a vast karst plateau with lots of surface and subsurface karst formations. In areas that are built of less permeable rocks, there is a wider set of mountain ridges and valleys within the uplands. The highest peak is Haniskova – 1,259 m above sea level.

Dominant soils are forest soils, especially Lithosols, Rendzinas and Pararendzinas. Cambisols with Fluvisols are also represented to a lesser extent (Šály, Šurina 2002). The area is drained by the rivers Hornad and Hnilec in the north of the southern part of the territory.

Most of the investigated area belongs to a moderately cold climate zone C, with an average annual temperature of 5–6°C. Higher-lying areas with altitudes above 650 m a.s.l. belong to a moderately moist zone with cold winters. Mountain areas and ravines with altitudes ranging from 650 to 900 m above sea level have an average annual temperature of 4–5°C. The climate circuit C 1 has a predominant representation – slightly cold, very wet with temperatures in July ≥ 12–16°C (Huna et al. 1985, Šťastný et al. 2002). The average annual precipitation is in the range of 600 to 900 mm due to the rain shadow of the Tatra Mts.

Among the most dominant tree species belong: *Picea abies* and *Fagus sylvatica*, followed by *Pinus sylvestris*. From the typology aspect the following groups of forest types are dominant: *Fagetum quercino-abietinum*, *Fagetum abietino-piceosum*, *Fagetum pauper*, *Fagetum typicum*, *Pinetum dealpinum*, *Fagetum dealpinum*, *Fageto-Picetum*, *Pineto-Laricetum*, *Abieto-Fagetum*, *Fageto-Abietum*, *Fageto-Aceretum*, *Fraxineto-Aceretum*, *Alnetum incanae*, *Betuleto-Alnetum*, etc.

The area is relatively poorly opened up by a public road. This deficiency is compensated by forest roads to some extent. The low level of opening up is given by the fact that the area is a part of national park, with a high proportion of strictly protected areas, reserves and protection forests where the wide poorly opened up areas occur.

In the experimental area, in total 16 forest fires broke out in the period 1976–2014, in which totally 28 forest stands were affected by fire. This number represents an insufficient data file to produce statistical analyses, therefore the multicriteria analysis (MCDA) method was applied.

Material. To process the analysis in the spatial decision support systems, it was necessary to process the input data at first. In the analyses we applied the following data and geodata: geographical vector layers representing the forest stands in the experimental area, geographical vector layer of forest types and soil types, geographical vector layer of forest road network; digital relief model with spatial resolution of 10 m, geographical vector layers of the Central Spatial Database representing the settlements, building outlines, water bodies, roads provided by the Topography Institute in Banska Bystrica; and tourist trails and recreation sites geographical vector layer provided by the Mountain Rescue System.

For data pre-processing the ArcGIS environment was used. In the NetWeaver environment an independent hierarchical network was built to automate the procedure of forest fire susceptibility assessment. The assessment process was carried out in an EMDS (Ecosystem Management Decision Support) system, a spatial decision support system which was used in the form of extension to the ArcGIS environment, in which the visualisation of assessment results was provided.

Methodology. The presented approach to assessment of forest susceptibility to fire is based on a method of multicriteria assessment of various factors which are assumed to have an impact on the formation and spread of fire in the natural environment. For this purpose a decision model was created in the NetWeaver environment using fuzzy logic principles. The susceptibility analysis was carried out in the EMDS environment based on the defined logical and mathematical relations between the factors assessed.

The susceptibility of a specified forest area to fire was assessed on the basis of two groups of factors: natural and social (Fig. 2).

The group of natural factors was represented by factor of terrain landforms, terrain slope factor, factor of terrain aspect and factor of tree species composition and stand age, forest health condition factor, identification of damaged forest stands (e.g. by windbreaks or bark beetles) and factor of forest fuel (fuel model representing fuel type and height of fuel occurring in the analysed area).

The group of social factors consisted of the following factors: distance from the nearest settlement, distance from the nearest road (state, forest, hiking trails and bike trails), factor of forest fruit collection, factor of harvesting and silvicultural (cultivation) activities and a factor of tourism and recreation.

Intervals and intervals of fuzzy values, as well as their weights with which they entered the evaluation process, were assigned to particular factors.

Finally, the accuracy of associated susceptibility assessment results was verified. The verification was provided on the basis of identification of stands affected by fire. Those stands were compared with the results of associated susceptibility assessment. The results are shown in a tabular form in the following chapter.

RESULTS

According to the methodology described above the assessment of forest susceptibility to fire was processed for an area situated in the territory of the Slovensky raj Mts. National Park.

For the purposes of automated assessment of the susceptibility to fire, a decision model was built in the NetWeaver environment.

Via interconnections of the decision model with the analytical environment of EMDS, which is available as an extension to the ArcGIS Desktop environment, an automated tool for spatial analysis was obtained aimed

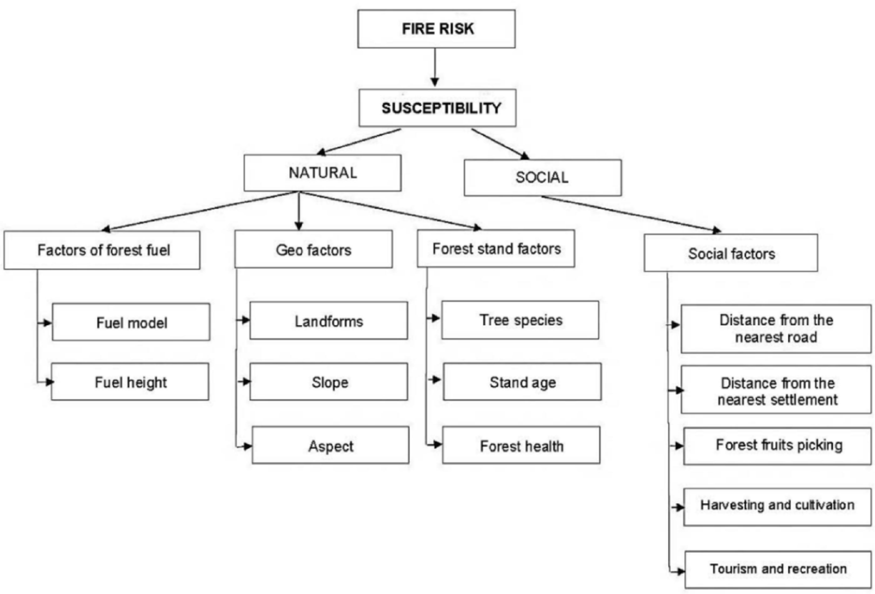

Fig. 2. Scheme of the model to assess the susceptibility of the area to forest fire

at assessing individual risk factors and their groups, up to the determination of associated susceptibility of the area to fire. Fig. 3 shows a decision model.

Results of the analyses are documented both in the graphical and tabular form.

First, we present the results of the analysis of associated susceptibility (Fig. 4), calculated as the sum of the fuzzy values of groups of factors (fuel, natural, forest vegetation and social). The raster representing the spatial distribution of the values of this sum was again subjected to the process of fuzzification (process of editing the values using the fuzzy logic). Consequently, these new fuzzy values were extracted for the centroids of individual stands.

An overview of the associated susceptibility assessment results is shown in Table 1. The results of assessment of particular groups of factors are documented in Table 2. The results of the associated analysis of susceptibility to fire show that more than 61% of the area falls within the medium degree of susceptibility to fire and 20% of the area even to a high degree of susceptibility. A higher degree of susceptibility of the area is mainly due to the fuel factors.

Individual groups of factors were also assessed. The results of the assessment of susceptibility of the area in terms of factors of forest fuels showed that up to 68% of the area of the territory of Slovensky raj Mts. National Park belongs, in terms of the composition of forest fuel and its height, to a very high degree of susceptibility. It should be noted that these factors are also very much dependent on the relative humidity of fuel.

The results of the analysis relating to geographical factor assessment indicate that almost 50% of the area belongs to a very high degree of susceptibility to fire. The reason is mainly the increased value of susceptibility due to the landform factor.

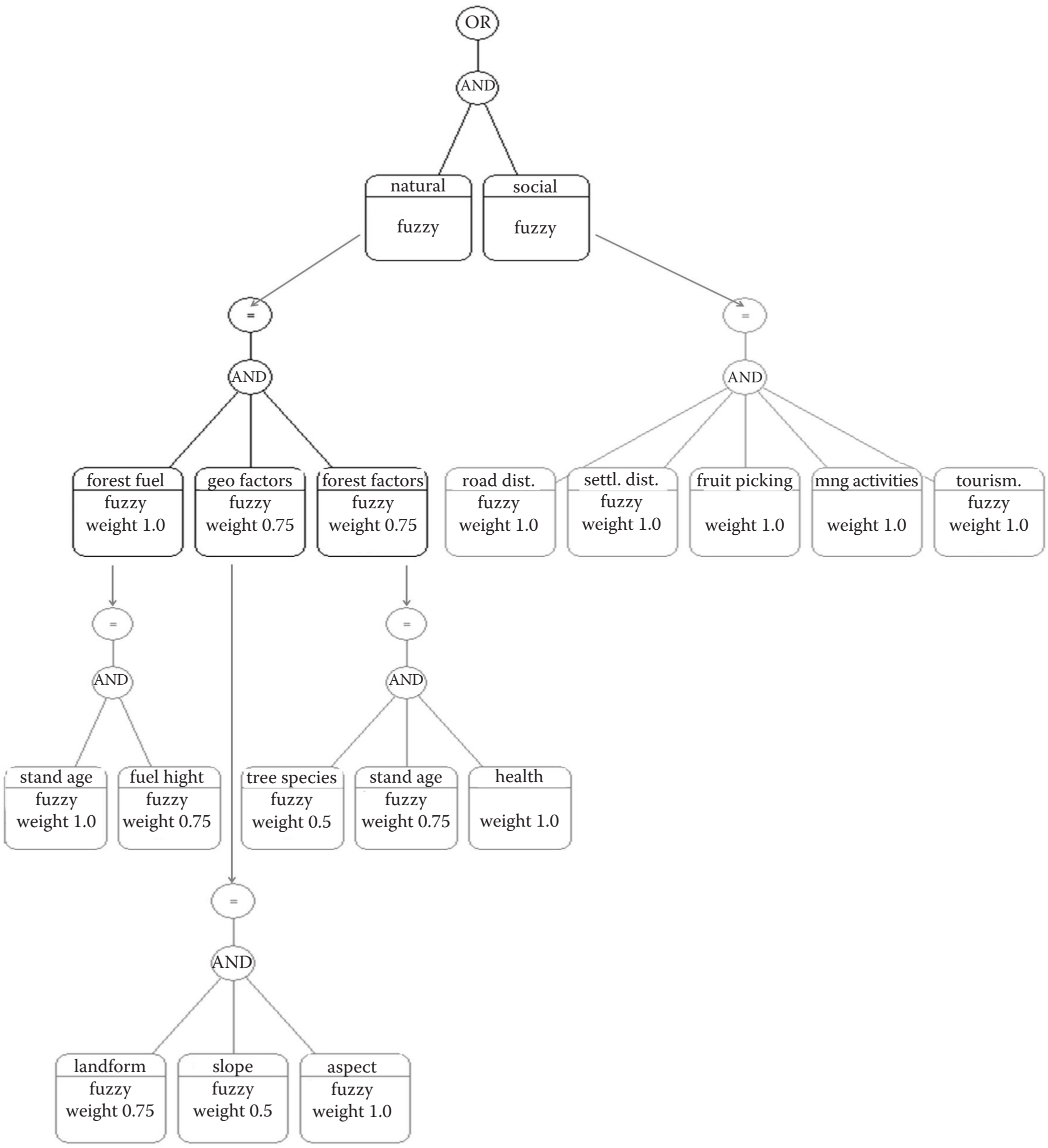

Fig. 3. Architecture of the decision model for automated assessment of susceptibility to forest fire

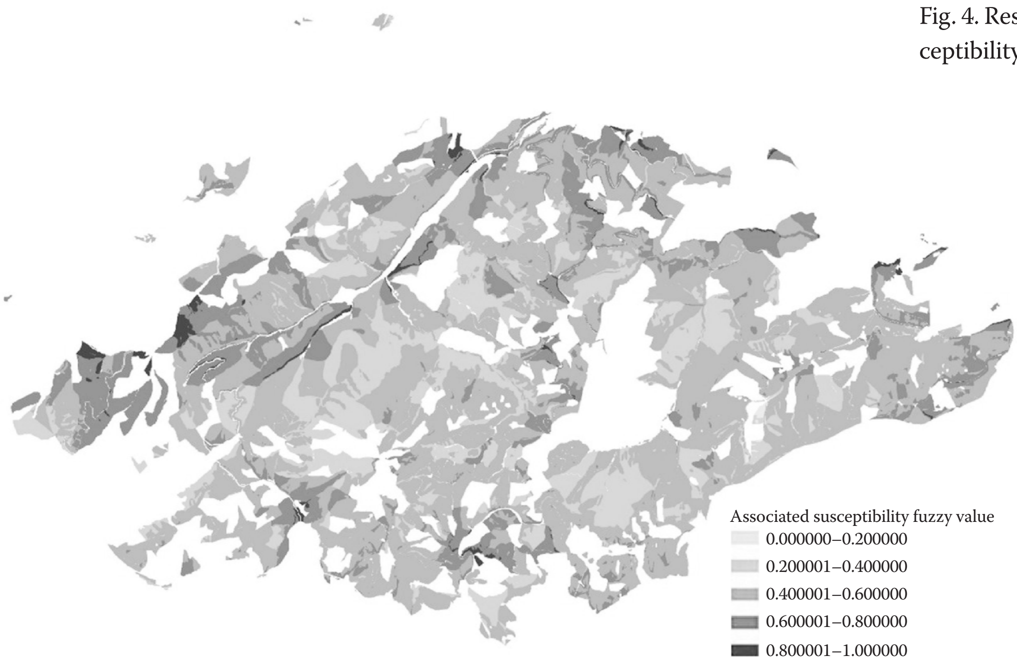

Fig. 4. Results of associated susceptibility assessment

In view of forest vegetation conditions the results showed that almost a half of the territory is located in a low degree of susceptibility to fire, and about 30% in a high degree of susceptibility to fire. It is mainly caused by the tree species composition of vegetation that is mostly mixed and by the age of forest stands. A higher degree of susceptibility is typical mainly of forests that have been affected by windbreaks and subsequently by an overabundance of bark beetles in the last 10 years.

As for the group of natural factors, the area mostly belongs to the high (55.86%) and medium (36.48%) degree of susceptibility to fire.

In view of the assessment of social factors, it can be stated that the majority of the area belongs to a low degree of susceptibility to fire (almost 63%). Maximum fuzzy values were recorded for the factors of distance from the nearest road and forest fruit collection.

As it was mentioned in the chapter above, the verification of associated fire susceptibility assessment was performed. The results are documented in Table 3.

The results of the verification showed that the stands affected by fire belong mostly to a medium de-

Table 1. Results of the assessment of associated susceptibility to fire

Degree	Fuzzy interval	Area (ha)	Representation (%)
1	0.0–0.2	9.24	0.10
2	0.2–0.4	1,700.09	18.19
3	0.4–0.6	5,734.88	61.36
4	0.6–0.8	1,777.40	19.02
5	0.8–1.0	124.19	1.33
Σ		9,345.79	100.00

Table 2. Results of the assessment of susceptibility to fire according to groups of particular factors

Factors	Degree	Fuzzy interval	Area (ha)	Representation (%)
Forest fuel	1	0.0–0.2	30.65	0.33
	2	0.2–0.4	84.54	0.90
	3	0.4–0.6	0.00	0.00
	4	0.6–0.8	2,859.44	30.60
	5	0.8–1.0	6,371.16	68.17
	Σ		9,345.79	100.00
Geographical	1	0.0–0.2	375.24	4.02
	2	0.2–0.4	3,107.70	33.25
	3	0.4–0.6	4,501.56	48.17
	4	0.6–0.8	949.71	10.16
	5	0.8–1.0	411.58	4.40
	Σ		9,345.79	100.00
Forest	1	0.0–0.2	13.60	0.15
	2	0.2–0.4	4,612.19	49.35
	3	0.4–0.6	575.29	6.16
	4	0.6–0.8	2,961.48	31.69
	5	0.8–1.0	1,183.23	12.66
	Σ		9,345.79	100.00
Natural	1	0.0–0.2	1.79	0.02
	2	0.2–0.4	102.71	1.10
	3	0.4–0.6	3,409.18	36.48
	4	0.6–0.8	5,220.14	55.86
	5	0.8–1.0	611.98	6.55
	Σ		9,345.79	100.00
Social	1	0.0–0.2	1,005.31	10.76
	2	0.2–0.4	5,872.59	62.84
	3	0.4–0.6	1,828.30	19.56
	4	0.6–0.8	604.55	6.47
	5	0.8–1.0	35.05	0.37
	Σ		9,345.79	100.00

Table 3. Verification of the results of fire susceptibility assessment

Degree	Fire area (m^2)	Rate (%)
1	60	0
2	292,440	13
3	1,520,744	69
4	389,700	18
5	23,108	1
Total	2,202,944	

gree of susceptibility to fire. However, after the susceptibility degree is related to the actual meteorological situation, the resulting fire danger will increase to high or very high degree. Therefore, in relation to the meteorological situation during the fire days and the degree of susceptibility of the areas, there is a real precondition for the stands to be affected by fire.

CONCLUSIONS

The paper deals with the problem of assessment of susceptibility to fire applying the multicriteria analysis method. For assessment a decision-making model was built. The assessment was performed in a selected area situated in the Slovensky raj Mts. territory and was based on mutual evaluation of factors with an influence on fire occurrence or its behaviour. The results showed that the most important factors are the factors of forest fuel and geographical factors when considering the natural factors. In some cases they are more important than the social factors.

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