Spatial distribution of surface forest fuel in the Slovak Republic

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ABSTRACT
Forest fires represent a real danger not only for countries situated in the tropic and subtropic zones, but the fire danger is more and more actual also in moderate climate zones, particularly due to continuous climate change consequences. Forest fire prevention and fire mitigation measures were both developed in the Slovak Republic to cope with this problem. Some have been included in effective legislation. Fire behaviour modelling is a forest fire mitigation measure. Information on surface forest fuel spatial distribution, fuel height and volume are the necessary prerequisites for the fire behaviour modelling process. In this paper, we introduce the methodology and results of surface forest fuel spatial distribution mapping in the Slovak Republic. The results are introduced in both tabular and map form.

1. Introduction

Nowadays, the problem of forest fires is very common even in the conditions of the Slovak Republic. Every year, there are hundreds of forest fires that cause economic losses running into hundreds of thousands of euros. In addition to the direct economic loss for forest management, the fires often completely destroy natural ecosystems, thereby causing incalculable harm to the landscape.

For that reason, the Slovak Republic agreed to the adoption of a wide range of measures, involving both forest fire prevention and mitigation (Government SR Resolution no. 697/2015).

One such a measure is the implementation of tools, programme environments, allowing fire behaviour to be modelled in real time. The FARSITE environment is used, for this purpose in Slovakia since 2002 (Glasa, Halada, & Weisenpacher, 2011).

To model the forest fire behaviour in software environments, which are based on geographical data applications, such as the FARSITE, it is necessary to apply a raster representing the spatial distribution of the fuel (fuel bed), the particular fuel models, respectively, in the area, as one of the primary inputs.

Due to the surface fuel complexity and the key role that surface fuel plays in a fire, it is of the utmost importance in fire research (see Pyne, Andrews, and Laven (1996)). A strong emphasis is also placed on exploring fuel characteristics (Sandberg, Ottmar, & Cushon, 2001).

Surface forest fuel is found in the forest at a height of 0–0.5 metres above the ground surface (Stacey, Gibson, & Hedley, 2012).

A fuel model, in general, is a mathematical representation of fuel properties within a specified location, often used to predict and plot the spread and intensity of fire (Stacey et al., 2012).

The issues of forest fires, fuel model classification and mapping have engaged several experts.

Among the early works focusing on the issue of forest fuel determination and description belong the works of Rothermel (1972), Brown, Oberheu, and Johnston (1982), Anderson (1982), and Allgöwer et al. (2002). In these works, the study and classification of forest fuel to fuel models was based on field survey, in particular.

In the past, the issue of the classification and quantification of surface forest fuel in the territory of the Slovak Republic was performed by Majlingová and Vida (2008), Majlingová, Sedliak, and Tuček (2014), and Sedliak and Majlingová (2014). Those procedures were based on the field survey implementation, using the modified method of Brown et al. (1982).

There are currently often used new sophisticated methods for obtaining or processing the data. Development in science and technology has also resulted in progress in the area of forest fuel mapping and volume assessment. Here, we introduce the works of several experts dealing with applying the Geoinformatics tools to automate the process of forest fuel mapping.

Mutlu, Popescu, Stripling, and Spencer (2008) reported four different methods to identify fuel models,
taking into account the advantage of a combination of data generated by ground-based measurements, remote sensing (RS) methods and geographical information systems (GIS), and especially the combination of data acquired using LIDAR technology and multispectral QuickBird satellite images. In data processing, they used the methods of raster images overlapping, principal component analysis, the minimum noise fraction, maximum likelihood and the Mahalanobis distance. The results showed a significant increase in the accuracy of determining the surface fuel models, when using the data obtained by LIDAR technology.

A similar approach to the mapping of forest fuel was chosen by Wagendonk and Root (2003), who also used RS data to derive vegetation characteristics, particularly from Normalized difference vegetation index images acquired. Based on the analysis, they characterized 30 different classes associated with each fuel model. The result of the work was the classification of the area of the Yosemite National Park into six fuel models.

Krasnow, Schoennagel, and Veblen (2009) used a terrain survey of the type and the volume of fuel, in which they applied the methodological approach published by Brown et al. (1982). Data obtained from the survey were used to derive data for the entire model area, using GIS tools, and finally applied for modelling fire behaviour in the FARSITE environment.

He et al. (2011) chose a different approach, applying regression analysis and the principle of the backpropagation neural network to data defining the forest stand characteristics in order to derive the characteristics of forest fuel. The results showed the appropriateness of the backpropagation neural network method, which provides more accurate results.

A similar approach was chosen by Dimitrakopoulos (2002), who published a method for identifying the characteristics of the fuel and fuel models based on a field survey of conditions in southern Europe. In his work, the measurements were taken at 181 research plots, reflecting the different fuel characteristics. He used the statistical methods to evaluate the data. In this way, he identified seven fuel models, which were subsequently used for the simulation of fire behaviour in the BEHAVE environment.

Another approach to mapping forest fuel is through vegetation phenology. This approach was tested and described by Bajocco et al. (2015).

In present time, the LIDAR technology itself, but also in combination with satellite time series data, seems to be the most effective tool to map as surface as canopy fuel. It is confirmed in the work of more experts, e.g. Bright et al. (2017); Crespo-Peremarch, Ruiz, and Balaguer-Beser (2016), and Chen, Zhu, Yebra, Harris, and Tapper (2016).

2. Methods

The fundamental principle for the mapping of surface forest fuel in the conditions of the Slovak Republic is based on the geobiocoenological classification of the forests of the Slovak Republic. This is the most detailed classification of forest biocoenosis, which results from the evolution, vegetation indicative and differentiating principles, and the properties of the environment (Križová, 1995). In both the Slovak Republic and the Czech Republic, the classification scheme developed by Zlatník (1956) was applied.

The nature of a forest ecosystem is significantly affected and determined by the trees. Trees significantly affect the nature of the undergrowth, and as a result it is possible to differentiate forest ecosystems based on their tree species composition.

The nature of other types of land cover is based on ecological conditions, which reflect the existence of the characteristics and dominant plant species in a particular territory, and the characteristics of a site, which are specific and thus allow the fuel model to be identified and distinguished.

The basic typological unit is a forest that essentially represents a permanent ecological condition. This is a unit with a limited range for the growth of trees, their production and restoration, and consequently, for the desired tree species and the desired stand structure. The forest type is characteristic with more or less sustainable production conditions, which means that the forest type is also the productive type (Križová, 1995).

The supervening geobiocoenological unit of a forest type is a ‘group of forest types’, collecting the forest types based on the similarity of their biocoenosis and ecological conditions. In managed forests, the association of forest types is based on similarities in the undergrowth synusia. It is not a unique production unit, but it is the unit of natural distribution of trees in their natural range in the Slovak Republic (Križová, 1995).

In hierarchical sequences, the supervening geobiocoenological units, in terms of Zlatník classification (Zlatník, 1956), are the forest vegetation zones. These are, in the framework of the ecological network of the Slovak Republic typology, vertically divided, based on the relationship between climate and biota (Križová, 1995). This is a rough division, which only takes into account variability due to differences in elevation.

The ‘group of forest types’ (FTG) was selected for the classification of fuel models in the Slovak Republic, for the following reasons:

- Using FTG instead of forest types simplifies the subsequent forest fuel quantification process (volume assessment);
• It is available in a database containing a detailed description of forest. These data are produced and made available by the National Forest Centre and is updated for all types of forests in the Slovak Republic on a regular basis;
• It is commonly used in forestry practice as a characteristic describing the forest phytocenose (plant community);
• It makes provision not only for biotic but also for abiotic site conditions.

The aim of the work was to classify each FTG into the classes, based on the dominant herbal species, their physiognomy and partly also based on their degree of cover, tree species composition and moisture content parameters. Classified FTG is thus the initial fuel model representing the areas with similar surface fuel and herbal synusia, as well as similar natural tree species composition.

The geographical vector layer containing the objects representing the spatial distribution of forest types in the Slovak Republic was applied in the analyses. The layer was produced and provided by the National Forest Centre. The scale of input data was 1:10,000 and the S-JTSK reference system (national grid) was used.

The expected height assigned to each fuel model was derived from the representation of grasses and herbs specified for each group of forest types and the maximum height of those species. This maximum height was adopted from the general description published in the ‘Atlas of Plants’ (Križová, Križo, & Benčatová, 2012).

The spatial analyses were performed in the ArcGIS for Desktop version 10.2 environment.

3. Results

The forest landscape of the Slovak Republic was classified into 10 fuel model classes:

• FM 1 Mosses and lichens;
• FM 2 Grasses up to a height of 30 cm;
• FM 3 Grasses and herbs (also shrubs) up to a height of 30 cm;
• FM 4 Herbs, grasses, mosses up to a height of 30 cm;
• FM 5 Herbs up to a height of 15 cm;
• FM 6 Herbs up to a height of 30 cm;
• FM 7 Tall grasses up to a height of 100 cm;
• FM 8 Without dominance of herbal synusia (cover) – lat. ‘Pauper’ (e.g. Fagetum);
• FM 9 Grasses, herbs up to the height of 30 cm of drier groups of forest types in the D series;
• FM 10 Grasses, herbs up to the height of 30 cm of wetter groups of forest types in the D series.

The outcome of the analyses is a map (Main Map) of the spatial distribution of surface forest fuel (fuel bed) in the Slovak Republic territory and a table, introducing the extent (ha) of the area of the Slovak Republic belonging to each fuel model.

The map representing the assignment of the fuel bed in the Slovak Republic to particular fuel models was produced based on the results of the geobiocoenological classification of the forest (fuel complex) and its assignment into the FTG classes, whose results were further used for assignment of the fuel bed to the relevant fuel model classes. The results obtained represent the primary input data for forest fire behaviour modelling and simulation in all available fire behaviour modelling software environments, which are based on GIS data applications (FARSITE, FlamMap).

In Table 1, we introduce the results of the analysis related to the areas of individual surface forest fuel classes.

According to the results shown in Table 1, the most common fuel model is FM 2 Grasses up to the height of 30 cm, followed by FM 3 Grasses and herbs (also shrubs) up to the height of 30 cm, but also FM 7 Tall grasses up to the height of 100 cm and FM 8 Without dominance of herbal synusia. The least represented are FM 1 Mosses and lichens and FM 9 Grasses, herbs up to height of 30 cm of drier groups of forest types of the D series.

4. Conclusions

In the paper, an approach is introduced to classify and assess the volume of surface forest fuel (fuel bed) that was developed for the Slovak Republic territory. The approach introduced is based on application of geobiocoenological classification of fuel bed to fuel models which was completed by the field survey to precise the classification results and assess the volume of the fuel models existing in the territory of the Slovak Republic.

To prepare the complete dataset of fuel parameters to be applied in the fire behaviour modelling, those data need to be further completed with laboratory testing results. Laboratory testing is focused mostly on determination of fuel moisture content using the hot-air oven and weighting method, gross calorific value and heat capacity using the oxygen calorimeter.
However, those data are research objects of further studies and will be published separately.

The primary output of research introduced in this paper is a map representing the identified fuel models distribution on the area of the Slovak Republic. It represents the primary input data layer to the fire behaviour modelling software environments including the GIS tools (e.g. FARSITE, FlamMap).

Software

For processing the reclassification of forest types to forest type groups and then to the specified fuel models, the ArcGIS for Desktop ver. 10.2 software environment was used, and specifically the Spatial Analyst tools. This software environment was also applied to produce the map, representing the spatial distribution of surface forest fuel, the fuel models, across the forest landscape of the Slovak Republic.

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