ASSESSMENT AND MAPPING OF FOREST FIRE RISK USING GIS: A CASE STUDY OF BULGARIA

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Abstract
The aim of the study is to present methods for assessment and thematic mapping of forest fire risk of the forest territory of Bulgaria using GIS. Basic assessment parameters were determined to describe forest territories at risk of fires. A spatial GIS database was built according to the requirements of the National Methodology for Determining the Risk of Forest Fires in Bulgaria. GIS modules were used to analyze the forest fire risk, and to combine different forest fire-causing factors, and, as a result, to create a variety of thematic maps and to visualize graphic and non-graphic data of forest fire risk via GIS.

Keywords: forest fire risk, GIS, thematic mapping

INTRODUCTION
Since the middle of the last century the problem of forest fire activity globally has acquired new, dangerous, and in certain years critical dimensions. This problem has mostly affected large forest areas in the USA, Canada, Australia, and Europe countries. Forest fires significantly affect the forest ecosystems and ecological balance of the planet. This research discusses the methods for classifying of forest fire risk on the territory of Bulgaria into three categories – high, middle, and low. The methodology for mapping the risk of forest fires in the country includes a variety of cartographic methods and GIS applications, and numerous techniques to process and present the specialized information.

It should be noted that within the European Union there is a lack of a unified methodology for determining the class (level) of forest fire risk. National Methodology for Determining the Forest Fire Risk in Bulgaria defines terms used for this purpose [12]. This is the basis for correct analysis, comparisons and evaluations of forest fire situations in Bulgaria, other countries, and regions. Differences in terms and definitions related to forest fires and risk exist and possibly remain into the future, despite the efforts for unification, harmonization, and consolidation around common terms and definitions by the scientists, scientific organizations, and in accordance with recommendations by UNECE/FAO [7], Regulation (EEC) No. 2158/92 [9], European Forest Fire Information System (EFFIS) [4], recommendations in the European Court of Auditors (ECA) Report [19], and many others. The main reason for the enactment of Art 2 of the Commission Regulation [3] on protection of the Community’s forests against fire that “Member States shall classify their territory according to the forest fire risk level”. Therefore, each country should independently develop a methodology for determining the forest fire risk, which adequately takes into account its national and/or regional characteristics associated with the differences in climatic conditions, forest vegetation, topography, national forestry legislation, forestry practices and traditions and other specifications.

METHODOLOGY FOR DETERMINING FOREST FIRE RISK
The main objective of the methodology for determining the forest fire risk in the country requires [6, 11, and 12]:

- clarification of the general characteristics of the terms “fire danger” and “fire risk”;
- review of the fire activity in Bulgaria and in other countries for determining the forest fire risk character;
- analysis of the available concepts and methodical approaches in forest fire risk definition;
- suggestion of methodology for determining and mapping the forest fire risk in the country;
pilot testing and applying of the adopted methodology for determining and mapping the forest fire risk for the districts on the territory of Bulgaria.

**Concepts and definitions related to forest fires used in Bulgaria and other countries**

Forest areas can be categorized into three groups:

- forest land (area) – occupied with forest trees adopted according to the national definition of the term “forest”;
- other wooded land (area) – occupied with other (specific) vegetation other than the included in the term “forest”;
- non-wooded land (area) – these are other areas other than defined by terms “forest” and “other wooded area”, that are located in forest area or near it, but are not subject to agricultural use.

The sum of the three categories forest areas define the term “total forest area”. Notwithstanding the national and regional differences this term is used at the international and European level. It has also been adopted in Bulgaria. Forest land of Bulgaria covers 35.8% of the territory, as 92% is covered by forests and 8% are non-wooded (bare) land.

The term “forest fire” shall mean fire that is spreading in a forest area thus burning forest vegetation. Given the national differences in the terms “forest area” and “forest vegetation”, the difference in the meaning of the term “forest fire” is also logical in different countries and regions. In the specialized books in USA, Australia, Russia and also in other countries forest fires are presented as vegetation fire, part of the group of so called “landscape fires”, which includes burning of grasslands, pastures, agricultural areas, etc., but not forest areas. Recently, with respect to the analysis of the causes leading to global climate change so-called natural fire or wild land fire are also added as a factor. The so defined fires also burn vegetation, without specifying its nature, without specifying the functional use of the territory which covers. Thus the area covered by the fire includes parks, urban areas, orchards, vineyards, agricultural plantations and other areas covered with vegetation. Using the general terms in forest fire statistics leads to considerable variation in data and incorrectness in comparison and evaluations. Therefore data produced by different sources (forest administrations, fire departments, municipalities, NGOs, etc.) diverge 2 to 4 and more times. The European Forest Fire Information System (EFFIS) notes that such data are compiled, i.e. they are specified based on the so-called compilation protocol. For clarity this work shall use the classic term “forest fire” with the following definition: uncontrolled burning of forest vegetation, that is spread in forest areas and inflicts (causes) direct and/or indirect damage to forests and forestry.

“Burnt area” is a part of the forest area, which is ablazed by the forest fire. In the literature and statistics of different countries, this term has a different content, mostly related to the degree of damage to forest vegetation, i.e. the damage caused by the fire. Therefore terms such as “burnt area”, “destroyed area”, “affected area” or swept by fire, damaged by fire, etc. may be noted. For the purposes of this work burnt area shall mean forest area or part thereof covered by the fire which has left visible scars on forest plants and/or components thereof. Areas burnt by forest fire are divided into two categories according to the forestry signs – “wooded” and “non-wooded” areas.

In literature and practice in different countries’ and regions’ practices the terms “forest fire danger” and “forest fire risk” are commonly used as equal terms. Notwithstanding the fact that there is certain link between both terms they have different meaning and origin [1, 4, and 10]. The common term “danger” is defined as a “phenomenon, action or circumstances that jeopardize the normal state of functioning of a certain system or site” [12]. The so-defined common term is not directly applicable to the assessment of fire danger in forests because of the diversity of the characteristics of the fire site – forest vegetation and the impact on this danger by weather, topography, socio-economic, and other factors. Therefore the meaning of the term forest fire danger is not unambiguous and is not finally clarified. For that reason multiple systems for fire-danger evaluation exist in Europe and worldwide: The USA, Canada, Russia, Spain, France, Italy, Germany, Poland, etc., use their own national or adapted other forest fire evaluation systems, including various and numerous factors [12]. The large number of different national systems and methodologies for identification and classification of forest areas by fire danger level results particularly results from the geographical differences of territories and the great inequality in the forest fires distribution in space and time.

Theoretically forest fire danger must include two elements: the probability of fires in a particular territory and magnitude of the potential damage caused thereby.

Depending on the purpose that it is used for, the definition of forest fire danger” may be reasonably divided into three separate elements, depending on the origin, character, and parameters of the determinants:

- fire risk that is determined based by the quantity and activity of sources of ignition leading to the occurrence of forest fires;
permanent natural fire danger that is determined by the type, quantity and combustible characteristics of forest vegetation. Fire-danger classes of different sections of the forest area are defined based on this evaluation. These classes serve as a basis for designing forest fire prevention infrastructure components and parameters thereof (barrier and sylvicultural hedges, belts, mineralized strips, roads, ponds) and other forestry activities increasing fire resistance of forests;

dynamic (ongoing) fire danger that is determined by meteorological conditions for a certain time period, defining the so called “fire danger weather”. The dynamic fire danger assessment is used to determine the level of preparedness of forest and fire services for active fire combating activities and compliance with the forest fire preventive measures.

The forest fire risk level is a separate, conditionally accepted term, aimed to eliminate differences in the various national and regional systems for forest fire danger assessment. This term, with reasonable accuracy and consistency, brings together the aforementioned components of forest fire danger. This generalized fire danger characteristic is used for evaluations, analyses, comparisons, and for the classification of forest areas by forest fire risk level.

Essentially, the classification of forest areas by forest fire risk level is also a measure and specification of fire activity therein. Fire activity in forests worldwide is estimated by two clearly defined criteria: the number of fires in a forest area occurring within for a certain period of the time, and quantity of burnt area therein for the same time period.

In cited literature [10, 13] the forest fire risk level is defined also as “real” or “realized fire danger”. The last note makes it clear that both terms have the same content, as both cases deal with the same statistically defined indicators derived that are derived from real fire activity in a forest area.

This study shall use the conditional term “forest fire risk level” taking into account fires occurring in a forest area and burnt areas thereby for a certain time period. This term complies with the general objective of [3] for the reduction of the number of fires and the size of burnt areas thereby.

**Review of fire activity in Bulgarian forests**

European Fire Database (EFD) is maintained and managed by the Joint Research Centre (JRC) with the EC. As of 2013, data from 39 countries are collected and analyzed in the forest fire database through the EFFIS from 25 EU Member States, 10 other European states and 4 countries of Middle East and North Africa. JRC publishes annual consolidated reports with forest fires database for different countries and regions which are members of the information network. Review of fire activity in Bulgarian forests is based on the official published data from EFD [8]. This specification is mandatory for comparisons between fire activities in other countries, and is based on data from the same source. The analysis of forest fire activity in Bulgarian forests include data for the period 1990-2013 – total of 12905 fires occurred, or 538 average per year [10, 11, 12, 13]. A general analysis of the level of overall national forest area, the parameters of fire activity in Bulgarian forests and comparisons with the situation in other countries leads to the following general conclusion. Fire activity in forest areas of Bulgaria is significantly lower than that of traditionally high fire-risk countries of Southern Europe (Portugal, Spain, Italy and Greece), is close to level of activity in France, but is higher than in Turkey, Romania, and Germany.

**National methodology for determining the forest fire risk**

The methodology for determining the forest fire risk in Bulgaria is developed on the basis of the requirements of the Ordinance on the terms, conditions and bodies for performing analysis, evaluation and mapping of disaster risk [17] and in conjunction with the implementation of Measure 8.3 from the Rural Development Program 2014-2020 [14]. The concept of forest fire risk is introduced as fire activity assessment in the forests of an administrative unit of the country, taking into account the average number of fires and burnt average size thereby. This study use the term “forest fire risk level” as a function of number of fires and area burnt therein for a given time period. The methodology is based on the following rules:

- any administrative unit, that risk assessment is assigned to, is referred to as “district” (NUTS3) in accordance to Nomenclature of territorial units for statistics (NUTS), applied in Bulgaria and Europe Union [2];
- the length of historical review of data for risk assessment is 10 years (2006-2015);
- the number of fires is reported regardless of the size of the area burnt thereby;
- an area (wooded or non-wooded) is considered burnt if signs of fire are visible on combustible matter in the living or dead forest;
- number of classes by risk level – 1, 2 or 3 (Table 1).
Table 1. Forest fire risk level look-up table [11, 12]

<table>
<thead>
<tr>
<th>N</th>
<th>Values of the integral indicator $R_{f.risk}$</th>
<th>Forest-fire risk level</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$R_{f.risk} \leq 0.1$</td>
<td>low</td>
<td>green</td>
</tr>
<tr>
<td>2</td>
<td>$R_{f.risk} &gt; 0.1$ and $\leq 0.3$</td>
<td>medium</td>
<td>yellow</td>
</tr>
<tr>
<td>3</td>
<td>$R_{f.risk} &gt; 0.3$</td>
<td>high</td>
<td>red</td>
</tr>
</tbody>
</table>

### Stages and algorithm for assessing forest fire risk [11, 12]

- general socio-economic characteristics of the district [16];
- forester specification of the forest areas of the district;
- assessment of the dynamics in the number of forest fires occurred and burnt areas thereby in the district over 10 years;
- determining % distribution of forest areas of the district by high fire danger level (1 class) according to Forest management plans [1, 18];
- determining the fire density $R_{dens.}$ (Formula 1);
- determining of real combustibility of the forest area (real burnt area) $R_{f.comb.}$ (Formula 2);
- forest fire risk is determined by the indicator $R_{f.risk}$, including the numerical values of forest fire density $R_{dens.}$, and real combustibility of forest area $R_{f.comb.}$, according to the formula (Formula 3). The integrated forest fire risk indicator simultaneously records the number of fires occurring and the size of the area they burnt;
- forest fire risk level is obtained from the level look-up table (Table 1).

#### Stages and algorithm for assessing forest fire risk

1. **General socio-economic characteristics of the district** [16];
2. **Forester specification of the forest areas of the district**;
3. **Assessment of the dynamics in the number of forest fires occurred and burnt areas thereby in the district over 10 years**;
4. **Determination of % distribution of forest areas of the district by high fire danger level (1 class) according to Forest management plans** [1, 18];
5. **Determination of the fire density** $R_{dens.}$ (Formula 1);
6. **Determination of real combustibility of the forest area** (real burnt area) $R_{f.comb.}$ (Formula 2);
7. **Forest fire risk is determined by the indicator** $R_{f.risk}$, including the numerical values of forest fire density $R_{dens.}$, and real combustibility of forest area $R_{f.comb.}$, according to the formula (Formula 3). The integrated forest fire risk indicator simultaneously records the number of fires occurring and the size of the area they burnt;
8. **Forest fire risk level is obtained from the level look-up table** (Table 1).

#### Stages and algorithm for assessing forest fire risk [11, 12]

- Determine the fire density $R_{dens.}$ (Formula 1);
- Determine the real combustibility of the forest area (real burnt area) $R_{f.comb.}$ (Formula 2);
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### Stages and algorithm for assessing forest fire risk

1. **Determination of the fire density** $R_{dens.}$ (Formula 1);
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4. **Forest fire risk level is obtained from the level look-up table** (Table 1).

### Stages and algorithm for assessing forest fire risk [11, 12]

#### Formula 1

$$R_{dens.} = \frac{1000 \sum_{i}^{n} N_i}{n \times F_{for.area}}, \quad (1)$$

Where:
- $R_{dens.}$ is the average annual numerical value of fire density per 1000 ha (10 km$^2$) forest area, number/years/1000 ha;
- $N_i$ – annual number of fires occurred in the forest area, number/years;
- $n$ – number of years for the period (10 years);
- $F_{for.area}$ – total forest area of the district, ha.

#### Formula 2

$$R_{f.comb.} = \frac{1000 \sum_{i}^{n} F_{burnt.area}}{n \times F_{for.area}}, \quad (2)$$

Where:
- $R_{f.comb.}$ is the average annual numerical value of real combustibility of forest area, ha/year/1000 ha;
- $F_{burnt.area}$ – annual burnt area in the forest area of the district, ha/years;
- $n$ – number of years for the period (10 years);
- $F_{for.area}$ – total forest area of the district, ha.

#### Formula 3

$$R_{f.risk} = R_{dens.} \times R_{f.comb.}, \quad (3)$$

Where:
- $R_{dens.}$ is the average annual numerical value of fire density per 1000 ha forest area, number/years/1000 ha (Formula 1);
- $R_{f.comb.}$ – the average annual numerical value of real combustibility of forest area, ha/year/1000 ha (Formula 2).

### THEMATIC MAPPING AND ANALYSIS OF FOREST FIRE RISK USING GIS

#### Subject and data

The subject is the territory of Bulgaria (28 districts). A spatial GIS database was built according to the requirements of National Methodology for Determining the Risk of Forest Fires in Bulgaria [4, 17]. Database includes a base map with boundaries of the districts (coordinate system WGS 84, UTM 35N) and geocoded general and special forest attribute data of the level “district”.

Existing data for the risk level assessment of the district level were provided by the National Statistical Institute (NSI) [16], Executive Forest Agency (EFG) to the Ministry of Agriculture and Food and Regional Directorates of Forestry [15]. Attribute data include general socio-economic characteristics of the district (current up to end of March 2011) [16]; forester specification of the forest areas of the district (current up to 31.12.2014) [5]; assessment of the dynamics in the number of forest fires occurred and burnt areas thereby in the district over 10 years (2006-2015) [15];
determining % distribution of forest areas of the district by high fire danger level (1-st class) according to Forest management plans [1, 18].

Data from the forest information system to the EAG (SYSTEM.IAG.BG) [15] were used for the analysis of the fire activity in the forest territories by districts (Table 2). The assessment of aggregated data and was made for the period 2006-2015, during which a total of 5500 fires occurred on the territory of Bulgaria, burning a total of 88786 ha of forest area. An assessment was made of the dynamics of the number of forest fires and their burned areas in the area over the 10 year period. Forest fires risk is calculated by formulas (1), (2) and (3) for each district based on fire density, real burned area, and integrated forest fire risk indicator. Determination of the level of forest fire risk by districts is in accordance to the adopted 3-step scale.

Table 2. Specialized attribute data of the forest fire risk [11]

<table>
<thead>
<tr>
<th>N</th>
<th>Districts</th>
<th>Average burnt area per year as percentage of the total forest area, %</th>
<th>Forest fire density $R_{max}$</th>
<th>Real combustibility of forest area $R_{comb}$</th>
<th>Integral risk indicator $R_{int}$</th>
<th>Forest areas classified as 1-st class fire risk, %</th>
<th>Risk level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blagoevgrad</td>
<td>0,05</td>
<td>0,09</td>
<td>0,50</td>
<td>0,045</td>
<td>58,0</td>
<td>medium</td>
</tr>
<tr>
<td>2</td>
<td>Burgas</td>
<td>0,17</td>
<td>0,09</td>
<td>1,66</td>
<td>0,149</td>
<td>22,0</td>
<td>medium</td>
</tr>
<tr>
<td>3</td>
<td>Varna</td>
<td>0,17</td>
<td>0,22</td>
<td>1,10</td>
<td>0,242</td>
<td>3,9</td>
<td>medium</td>
</tr>
<tr>
<td>4</td>
<td>Veliko Tarnovo</td>
<td>0,11</td>
<td>0,10</td>
<td>1,14</td>
<td>0,114</td>
<td>7,46</td>
<td>medium</td>
</tr>
<tr>
<td>5</td>
<td>Vidin</td>
<td>1,19</td>
<td>0,17</td>
<td>11,92</td>
<td>2,030</td>
<td>6,7</td>
<td>high</td>
</tr>
<tr>
<td>6</td>
<td>Vratsa</td>
<td>0,46</td>
<td>0,27</td>
<td>4,64</td>
<td>1,233</td>
<td>5,6</td>
<td>high</td>
</tr>
<tr>
<td>7</td>
<td>Gabrovo</td>
<td>0,12</td>
<td>0,09</td>
<td>1,23</td>
<td>0,111</td>
<td>32,4</td>
<td>medium</td>
</tr>
<tr>
<td>8</td>
<td>Dobrich</td>
<td>0,06</td>
<td>0,25</td>
<td>0,64</td>
<td>0,160</td>
<td>18,2</td>
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</tr>
<tr>
<td>9</td>
<td>Kardzhali</td>
<td>0,01</td>
<td>0,12</td>
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<td>0,012</td>
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<td>0,297</td>
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<tr>
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<td>Lovech</td>
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<td>0,22</td>
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<td>1,674</td>
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<tr>
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<td>Montana</td>
<td>0,26</td>
<td>0,09</td>
<td>2,58</td>
<td>0,232</td>
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<td>medium</td>
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<tr>
<td>13</td>
<td>Pazardzhik</td>
<td>0,13</td>
<td>0,15</td>
<td>1,27</td>
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<tr>
<td>14</td>
<td>Pernik</td>
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<td>0,16</td>
<td>1,14</td>
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<tr>
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<td>0,22</td>
<td>4,71</td>
<td>1,036</td>
<td>8,4</td>
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</tr>
<tr>
<td>16</td>
<td>Plovdiv</td>
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<td>0,17</td>
<td>1,17</td>
<td>0,199</td>
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<tr>
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<td>Razgrad</td>
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<td>0,14</td>
<td>0,59</td>
<td>0,083</td>
<td>9,1</td>
<td>low</td>
</tr>
<tr>
<td>18</td>
<td>Ruse</td>
<td>0,01</td>
<td>0,08</td>
<td>0,12</td>
<td>0,010</td>
<td>6,1</td>
<td>low</td>
</tr>
<tr>
<td>19</td>
<td>Sliven</td>
<td>0,07</td>
<td>0,08</td>
<td>0,75</td>
<td>0,060</td>
<td>8,3</td>
<td>low</td>
</tr>
<tr>
<td>20</td>
<td>Silistra</td>
<td>0,09</td>
<td>0,11</td>
<td>0,92</td>
<td>0,101</td>
<td>16,5</td>
<td>medium</td>
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<tr>
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<td>Smolyan</td>
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<td>0,09</td>
<td>0,23</td>
<td>0,021</td>
<td>41,9</td>
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</tr>
<tr>
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<td>Sofia</td>
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<td>0,301</td>
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<td>high</td>
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<tr>
<td>23</td>
<td>Sofia - grad</td>
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<td>0,15</td>
<td>0,49</td>
<td>0,073</td>
<td>31,9</td>
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</tr>
<tr>
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<td>Stara Zagora</td>
<td>0,36</td>
<td>0,10</td>
<td>3,55</td>
<td>0,355</td>
<td>25,3</td>
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</tr>
<tr>
<td>25</td>
<td>Targoviste</td>
<td>0,02</td>
<td>0,05</td>
<td>0,17</td>
<td>0,008</td>
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<td>low</td>
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<tr>
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<td>Haskovo</td>
<td>0,12</td>
<td>0,17</td>
<td>1,17</td>
<td>1,004</td>
<td>22,0</td>
<td>high</td>
</tr>
<tr>
<td>27</td>
<td>Shumen</td>
<td>0,04</td>
<td>0,09</td>
<td>0,39</td>
<td>0,035</td>
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<tr>
<td>28</td>
<td>Yambol</td>
<td>0,70</td>
<td>0,10</td>
<td>6,98</td>
<td>0,698</td>
<td>14,5</td>
<td>high</td>
</tr>
</tbody>
</table>

Database and visualization

The integrated database (vector, raster, and attribute data) is created in GIS environment (Figure 1). The database is processed, mapped and analyzed spatially with MapInfo, Google Earth Pro and QGIS (Figures 2). GIS modules were used to analyze the risk of forest fires, to combine different forest fire-causing factors, and, as a result, to create a variety of thematic maps and visualize graphic and non-graphic data of forest fire risk.

The data base (Figure 1) include vector layers – a base map with administrative units (districts as polygon area objects); country boundary; hydrography; district names; the raster data – open-source satellite data from Bing, Digital Globe, and Google Earth Pro; and attribute data, organized in four parts (Figure 2):

- general socio-economic data - number, district name, district name EU, code NUTS, total area of the district, % of the territory of Bulgaria, population, density; total count of settlements, municipalities, mayoralities;
- forester specification – total forest area of the district; % of Bulgarian forest land; afforested land, afforestation of the district as %; coniferous forests, deciduous forests, and non-wooded areas;
- forest fire activity for the period 2006-2015 – average count of fires per year of the district; average burnt area per year; average size of a medium fired area; top tree fires of burnt areas %, base tree fires %; average burnt area per year as percentage of the total forest area;
• forest fire risk – forest fire density; real combustibility of forest area; integral risk indicator; forest areas classified as 1-st class fire risk; forest fire risk level.

Thematic maps

Various cartographic methods of presentation are used to analyze and illustrate the forest risk fire-causing factors. The fundamental methods applied in this research are the scale sign method, the line symbols method, and the qualitative and quantitative background method. Collation and choropleth maps are used for a graphic spatial representation forest fire risk, statistical data, forester data, which is processed and applied to administrative territorial units (districts). Collation maps show the distribution of a phenomenon by means of diagrams that are located within the units of the territorial grid and express the total magnitude of the phenomenon within the borders of each territorial unit (districts). The choropleth map is a method of showing the average intensity of a particular indicator (average population density, percentage of forest land, or others) within administrative units. In this case each territorial unit is colored or/and hachured so that the intensity of the color or hachure indicates the intensity of the risk fire parameter. A set of thematic maps and diagrams were created (Figures 3f) with GIS tools of the following indicators' distribution across Bulgarian districts: % forest areas of the district (Figure 3a); % woodiness (Figure 3b); forest fire density (Figure 3c); real combustibility of forest area of the district (Figure 3d); integral indicator of forest fire risk (Figure 3e), and forest fire risk level (Figure 4).
Figure 4. Map of forest fire risk level by districts

A variety of combined thematic maps were created by 2, 3, or 4 indicators with a 5-level legends:

- population density of the districts (number/1 km²), number of settlements and municipalities (Figure 5a);
- % average burnt area per year as percentage of the total forest area, number of settlements and municipalities, and forest fire risk level (Figure 5b);
- forest wooded area (ha) and woodiness (%) (Figure 5c);
- category of forest area (broad leaved forest, coniferous forest, or non-wooded area) and forest areas classified as 1-st fire risk, % of forest territory (Figure d);
- fire activity – % forest areas of high fire danger level (1-st class), and type of forest fire (surface, crown) (Figure 5e);
- number of fires per year and % average burnt area per year(Figure 5f);
- real combustibility and fire density of forest area of the district (Figure 5g);
- wooded area (ha), % forest areas of high fire danger, % average burnt area per year, and average burnt area (ha) (Figure 5h).

Figure 5. Combined thematic maps
RESULTS

A specialized database was planned with the appropriate graphical and attribute data for determining and analyzing the forest fire risk level on the territory of Bulgaria. The database was designed for use in a GIS environment.

A database was implemented in GIS to analyze forest first risk. A forest fire risk assessment was completed using criteria applicable to Bulgaria. Data from all Bulgarian districts was visualized by district and by general, forester and specialized characteristics necessary for the analysis of forest fire risk. The forest fire risk level was mapped by district. Specialized attribute data were analyzed and diagrams and other user interactive products were created. Various cartographic methods were employed in the analysis and presentation of the specialized data via the use of combined thematic maps describing the forestry characteristics, fire activity, and assessment of forest fire risk.

CONCLUSIONS

In the methodology we analyze the relationships between the various indicators that play a role in determining forest fire risk in Bulgaria. When processing data in GIS environment, the relationships are analyzed and confirmed objectively and with substantial proof. New relationships are also discovered in the process. As a result of the GIS analysis of the forest fires aftermath and forest fire risk in Bulgaria, we can make some general and some specific conclusions:

- GIS is an effective technology for assessing forest fire risk; digital processing and spatial analysis of data provide speedy results and convenience to end users.
- Forest stands that are categorized as first-class fire danger determine to a great degree the overall forest fire risk. The average size of burnt forest areas is a more significant indicator for fire risk than the number of forest fires in a given district.
- Forestry GIS databases need to be extended to be able to store registered forest fires by location, time/date, and other criteria that correspond to the reports specification of the National information system SYSTEM.IAG.BG. Current/short-term and long-term meteorological forecast data could also be included into the latter GIS databases and used in the assessment of forest fire risk. Forest fire assessment and protection of forest areas from fires will be more effective if they also make use of forest roads' GIS database data on the density and location of forest roads and roads for fire-fighter vehicles.
- Mapping of forest fire risk in a GIS environment should include thematic maps of the four aspects of forest fires database – socio-economic conditions, forester specifications, forest fire activity, and criteria for forest fire risk assessment. These thematic maps will improve the analysis and assessment of forest fire conditions and risk.
- For each thematic map, there could be a corresponding interactive map (by type of forest areas, by afforested and non-forested areas, by deciduous and coniferous forest stands, and by first-class fire hazard stands, and more), which are adapted for use on mobile devices by forestry specialists working on the field. Thus, the results of thematic mapping will be benefit directly the work of authorized units and volunteers in the event of fires in forest areas.

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