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Implementation of Wildfire Risk Evaluation Elements into the Hungarian Forest Fire Prevention System

Nowadays, wildfires are an increasing challenge for the defence sector. The fire risk of a given area depends only in part on human factors and the number of registered fires. A fire occurs when the moisture content of dead biomass drops to a level, where the fire can already spread between the individual pieces of fuel. Daily fire danger forecast examines the constant and changing components of the fire environment. This determines the flammability of the biomass; the rate of fire spread makes firefighting more difficult. The fire danger forecast identifies the fire hazard periods when fires can occur. Fire Risk Assessment Systems have been developed in many countries around the world. In addition to the daily fire risk, these include parameters describing the vulnerability of the areas affected by the fire. National risk assessments are available in many countries around the world using several methodologies. The Joint Research Centre of the European Commission has developed a community-wide approach to forest fire risk assessment, using scientific results and studying good practices. In this approach, the risk of a forest fire is made up of the effects of daily fire hazards and vulnerabilities. The risk of fire due to weather conditions is associated with ignition and the spread of fire. The authors examine in the paper the basic criteria to assess wildfire risk at the pan-European level. The authors analyse external and internal risk factors in an observation plot and examine how international recommendations can be utilised in Hungary.

Keywords: *wildfire risk evaluation, fire risk assessment, observation plot*

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1. Introduction

Wildfires have always been a part of our lives. The cavemen had already used fire, and during this time, humanity also recognised the harmful effects of fire. So wildfires have always been present in our lives, but climate change will pose an even greater challenge in some parts of the world, including Europe, in the future. Climate change is aggravating the situation, making countries more prone to wildfires and increasing the intensity of such events.[3] Year after year the fire seasons start earlier and end later, so it gives a greater opportunity to ignite the biomass.[4] Legislators have enacted legislation in order to prevent fires and fight against forest fires. In Hungary, the main legislation in connection with fires is Act CXXVIII of 2011 concerning disaster management and amending certain related acts (hereinafter referred to as Act on Disaster Management) and Act XXXI of 1996 on Fire Protection, Technical Rescue and Fire Services (hereinafter referred to as Fire Protection Act). The Act on Disaster Management is a comprehensive and complex legislation that includes the management of disaster management as well as the general order in the fields of industrial safety, civil protection and fire protection. It gives more importance to prevention activities compared to previous legislation. The Fire Protection Act specifically regulates the operation of fire departments. This legislation sets out in detail the procedures for the management and execution of firefighting, technical rescue and authority tasks in connection with fire protection. The importance of protection against wildfires is reflected in this law, but the relevant firefighting tasks are already set out in an implementing decree. At the international level, countries have different fire and forest fire regulations, so some organisations have already made recommendations to solve this problem.

National risk assessments are available in many countries around the world using several methodologies. The Joint Research Centre of the European Commission has developed a community-wide approach to forest fire risk assessment, using scientific results and studying good practices. In this approach, the risk of a forest fire is made up of the effects of daily fire hazards and vulnerabilities. The risk of fire due to weather conditions is associated with ignition and the spread of fire. Vulnerability can be characterised by ecological and socio-economic parameters. Socio-economic parameters are the environmental services and the human infrastructure. According to the European model, the factors influencing the occurrence and spread of wildfires can be interpreted as components of an internal and external system. Internal factors include biomass structure, forest health status and topographic parameters. External factors, such as climate change, land use, weather and human activity are not related to the parameters that describe the forest. The paper aims to examine how the elements of the European model can be adapted to the Hungarian fire risk assessment, and how the elements involved in the forest fire risk assessment can be reflected in the national and county-level Fire Protection Plans in Hungary. During

[3] European Commission 2021; Restás 2020

[4] Teknős 2019

our research, we study the elements of the model with the help of relevant literature and examine the possible operation of the model in a selected observation plot with high forest fire risk based on the fires that occurred between 2011 and 2020. As a result of the research, we make findings about the extension of the model and the limitations of the application.

2. Forest fire risk trends in Hungary and the European Union

One of the key elements of forest fire prevention activities is the registration of wildfire events that occur under natural conditions in Hungary, knowledge of the characteristics of wildfires and the course of the fire season. To achieve these goals, the forestry authority and disaster management have been working together for the past two decades to develop methodologies for data collection and analysis. They have also developed the professional and legal regulations and the development and operation of IT systems needed for daily operations. The Forest Fire Information System contains data on forest fires in Hungary. During data gathering, fires that typically damage property on the outlying property, grass vegetation and wooded areas, or affect crops, are registered as vegetation fires. This category also includes undergrowth burning in forests or wooded areas, as well as reed and peat fires or grass burning in pastures. A forest fire is defined as a fire in an open area that did not necessarily start in a forest and did not exclusively, but completely or partially, affect a forest or a wooded area. A fire is therefore considered to be a forest fire that affected a forest or other area covered with trees.[5]

In the last two decades, the risk of forest fire has increased significantly in the central and southern regions of Europe, but the number and extent of forest fires must also be expected to increase in the northern countries. Currently, 85% of burned areas in Europe are located in Southern Europe (Portugal, Spain, France, Italy and Greece) due to the higher risk of weather conditions typical of the Mediterranean region. In these five Mediterranean countries, an average of almost half a million hectares of land has burned annually over the past 20 years. In addition to the increase in the annual number of high and extreme fire-risk days, the impact of extreme fires will likely increase in large areas, with long-term effects. The forest fire season starts earlier and ends later, which puts an additional burden on disaster management agencies.

Based on the temporal distribution of forest fires in Hungary, there are two high-risk periods each year. Spring forest fires (February–May) accounted for 56.3% of all forest fire cases. In the last decade, only in the spring of 2013, so much precipitation fell that the spring fire season was practically missed. In the other years, March and the first half of April proved to be extremely high risk. Between 2011 and 2021, six springs had more than 50% of fires in these two months compared to the annual number of cases. At the beginning of the decade, the number of forest fires began to

[5] Camia et al. 2014

rise at the end of February, and, depending on the spring rainfall, we registered high numbers of fire cases until the middle or end of April. This trend seems to change by the end of the decade. In 2019 and 2020, the number of forest fires started to increase from the second week of February and we registered high numbers of fire cases until the end of April. In May and the first half of June, depending on the distribution of precipitation, the risk of fire decreases and we do not experience any outliers in the number of fire incidents.

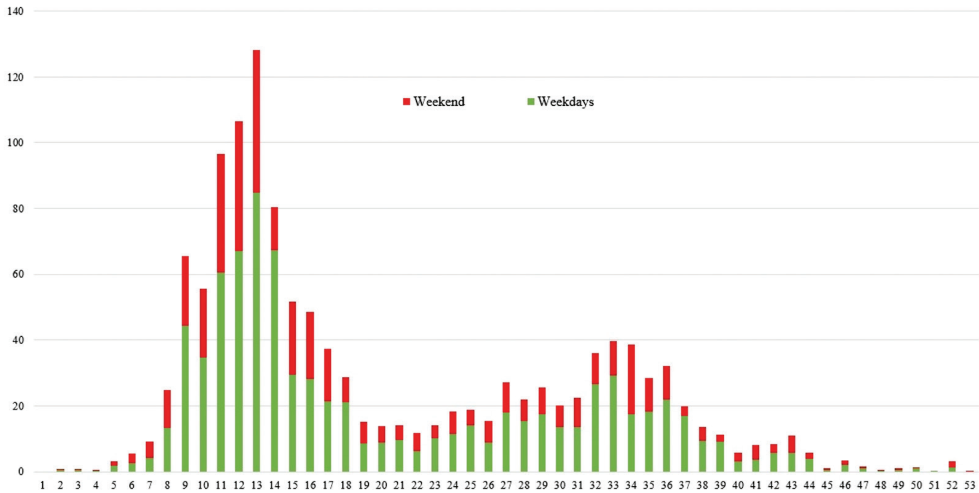

Figure 1: Average number of forest fires per week (2011–2021)
Source: Forest Fire Information System of Hungary.

Based on the number of fire events, the other fire-risk period of the year is in the month of July–September. In the second half of the decade, during periods without precipitation, forest fires also occurred in October. During the summer, when there is an increased risk of fire during heat waves, the number of fires does not reach the number of fires that occur in the spring, but the proportion of the area burned in one fire can be much higher. In recent years, during the increased risk of fire caused by the summer drought, many large-scale crown fires have occurred in the pine forests of the Great Plain and the wooded and shrubby areas of the northern part of the country. In the last decade, 35% of all forest fires started on weekends or holidays.

Between 2013–2021 a total of 9,789 forest fires occurred. Looking at the last 9 years, an increasing trend of fire incidents can be shown in Hungary, as shown in Figure 2.

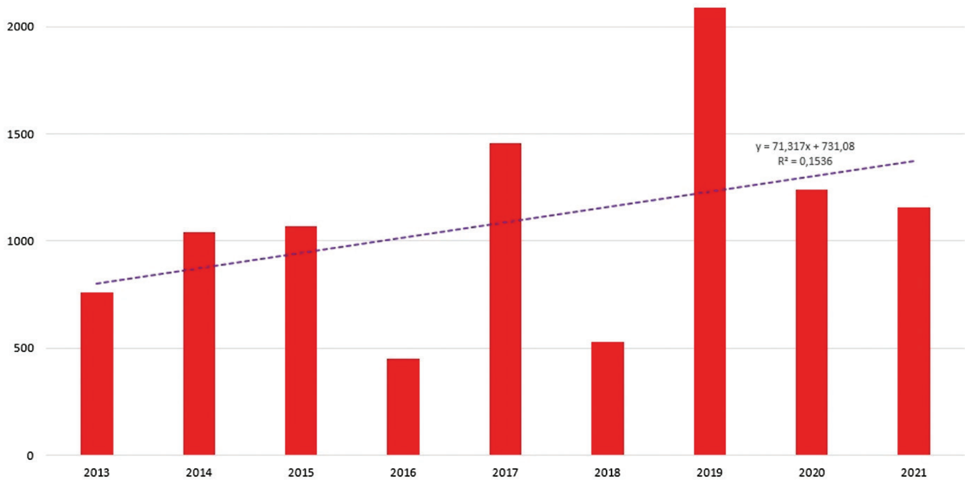

Figure 2: The number of forest fires in Hungary (2013–2021)
Source: Forest Fire Information System of Hungary.

From the data on forest fires that occurred between 2011 and 2021, a trend can be identified in the number of fires under 0.5 hectares, which shows a continuous increase in the last decade. These small fires require the intervention of the fire department at all times of the year, even in cases where the burning could be carried out safely by following the rules for lighting fires. In addition, a fire can become uncontrollable in the case of topography, biomass and meteorological conditions favourable to the spread of fire.

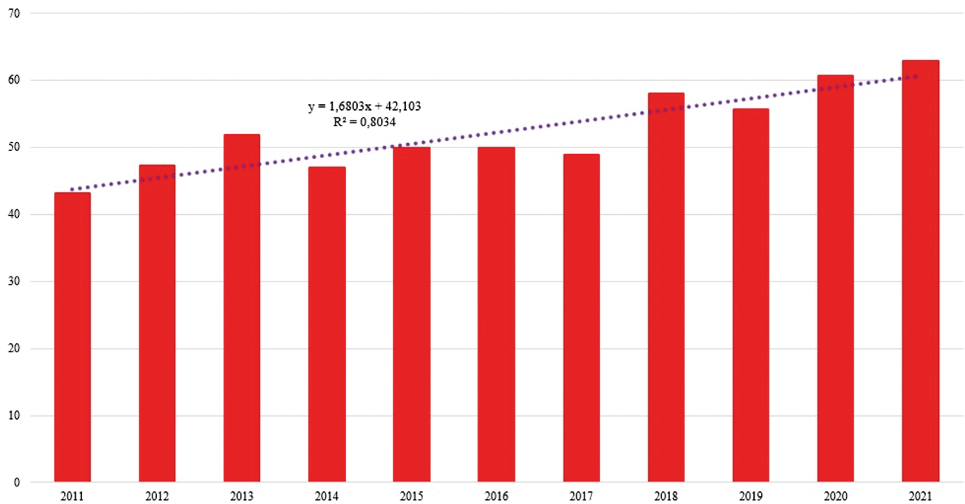

Figure 3: Proportion of forest fires under 0.5 hectares (2011–2021)
Source: Forest Fire Information System of Hungary.

The analysis of the fire incident data points out that a large number of smaller forest and vegetation fires separate in space and time occur every year. As a result of changing weather conditions, fires can have a significant impact on protected natural values, the maintenance of agricultural areas that provide livelihoods, and, in some cases, the condition of infrastructure. In periods of increased fire risk, several fires occurred at the same time in many cases, which can pose a great challenge to the personnel of the disaster management organisation and the forest managers and land users, and the use of their tools and resources. In the coming decade, more attention must be paid to the preparation, compliance with fire regulations and increasing the resilience of forest stands. Forest fire risk assessment is essential for the development of forest fire protection plans, for a better understanding of the factors that play a role in the origin of the fire, and for establishing the basis for official decisions that implement protection measures.

3. Forest fire risk evaluation in Hungary

Due to the mosaic landscape structure in Hungary, wildfires affect not only forest areas but also another wooded and agricultural land. The prevention of forest and vegetation fires, therefore, requires the continuous, well-thought-out, integrated cooperation of several specialist areas, economic organisations and authorities. Forecasting fire risk periods, early detection of fire, forest fire risk assessment, support of firefighting activities with IT systems, preparing and continuously updating of protection plans, public information, a support system for rural development, and education programs are the framework of modern forest and vegetation fire prevention activity. Forest fire prevention measures can be effective if they are planned by organisations with appropriate authority, infrastructure, and a team of professionals coordinate the activities and implement them according to plan. A scientific background is therefore essential for continuous development, the effective transfer of knowledge, and the development of new tools and methods. Domestic forest fire prevention tasks are included in the Forest Act and its executive decree, as well as in the ministerial decree on forest fire protection.

The fire hazard classification of forest areas is prepared by the forestry authority and updated every year. The classification is based on tree species data recorded in the forestry register. The classification is carried out at the forest section level. After the classification, each forest section will have its fire hazard indicator, on a three-level scale. The indicator expresses the quantity and combustibility of the combustible biomass in the forest section. The classification is based on the data registered by the forestry authority, and with its help, professional expectations can also be properly enforced.

Based on the classification at the forest section level, the forest manager must prepare a forest fire protection plan and is obliged to keep specific tools and work groups ready in case of a forest fire. Farmers with between 10 and 100 ha of fire-prone forest must prepare a simplified protection plan. Farmers in fire-prone areas larger than 100 hectares must prepare a complex forest fire protection plan. The forest fire protection plan includes the risky forest areas in the farmer's territory and the prevention activities. The plan also includes a map system, which the forestry authority provides free of charge to forest managers. The classification is also available on the public forest map operated by the forestry authority on the World Wide Web. Hungary provides the use of forest maps as part of a web map service for the GIS system of disaster management.

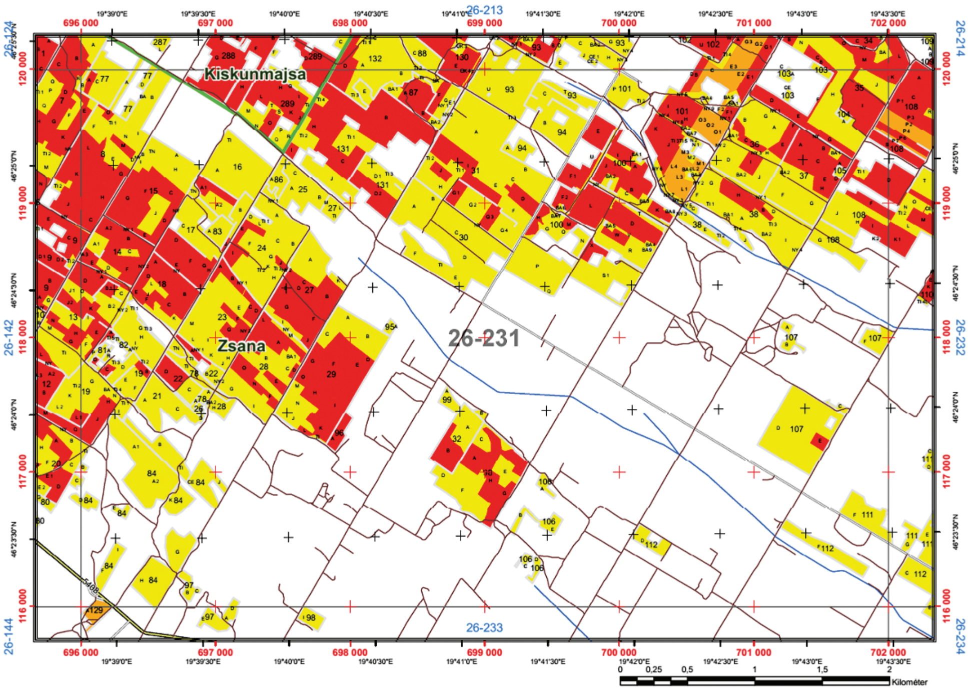

Figure 4: Fire hazard classification of forest land area
Source: Forest Fire Information System of Hungary.

In high-risk periods, the forest authority can order a fire ban in consultation with the fire service. The risk periods and the delimitation of the areas affected by fire risk must be displayed on the website of the forestry authority. The map is continuously available during the fire season on the websites of the relevant authorities[6] and cooperating organisations. The decision depends on three main parameters: meteorological conditions, the daily value of the Fire Weather Index (FWI) published by the JRC, and the frequency of fires. The assessment and analysis of forest fire risk are carried out every year from 1 February to 31 October. The forestry authority and the fire service will announce the increased risk of fire.

6 Fire bans (http://erdotuz.hu/kezdolap/); BM Directorate General for Disaster Management (www.katasztrofavedelem.hu/).

The domestic forest fire risk assessment is based on the hazard classification of forest areas and the use of the FWI published by the JRC. In the next section, we will examine the approach the European Commission recommends for the Member States at the community level.

4. Forest fire risk evaluation in the European approach

In the Member States of the European Union, many approaches and methodologies are used to assess forest fire risk. Each method has been defined on a scale that varies from country to country (national, regional, local). In many cases, systems were created for different purposes. This has also caused some concepts related to fire risk to be used in different ways in some Member States. For this reason, it is difficult or impossible to compare the fire risk management measures of the member countries.[7] Different approaches not only take into account the frequency and effects of fires but also consider the level and to what extent each risk factor should be taken into account in decision-making processes (landscape management).

The Joint Research Centre of the European Union (JRC) wanted to create an approach that is simplified at the community level but can remain flexible to satisfy multiple needs and integrate new factors into the model later on. Of course, bearing in mind the limitation of the approach, the national and local fire risk assessment can be more accurate than the community-level model. The community approach defines wildfire risk as the product of the probability of a wildfire occurring and the damage it causes. Consequently, it examines three areas: fire ignition factors, fire behaviour, and the effect of fire on human life and equipment. In the following, we present the data sets that can be considered the basic criteria of the European forest fire risk assessment, which are illustrated in more detail in Figure 5.

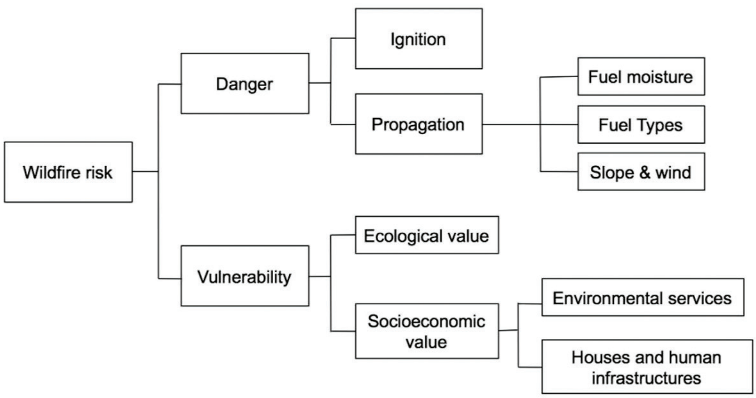

Figure 5: Basic components of wildfire risk assessment
Source: European Commission 2021: 10

[7] Hardy 2005

According to Figure 5, we can see that the two main components of wildfire risk are wildfire danger and vulnerability. Wildfire danger includes elements such as ignition, which is a natural chemical process, and propagation, which depends on fuel moisture, fuel types and other factors (slope, wind). So the fire propagation depends on several components, which is described in Richard Rothermel's surface fire spread model.[8]

$$R= I r \zeta(1+\Phi w+\Phi s)/\rho b\ \varepsilon Q i g$$

R = rate of spread
Ir = reaction intensity
ξ = propagating flux ratio
Q_w = wind factor
Q_s = slope factor
P_b = bulk density
ε = effective heating number
Q_{ig} = heat of pre-ignition

The essence of this is that if one factor of fire propagation is smaller but another factor is higher, we can get a similar fire propagation value.

The other element of wildfire danger is vulnerability. This includes ecological values and socio-economic values, such as environmental services and houses and human infrastructures.

In many cases, wildfire danger means the conditions under which a fire occurs or spreads. There are indicators such as the FWI that give a direct assessment of fire hazards due to weather conditions.[9] Wildfire danger includes factors such as wildfire ignition and wildfire propagation.

In connection with wildfire ignition, it can be determined that an increase in fire ignitions results in the occurrence of many fires at the same time. It allows a heavy fire spread and contributes to the development of large forest fires, which cause significant environmental damage. Biomass and weather conditions also affect the development and behaviour of fire.[10] It is also important to mention that the primary cause of fires in Europe is human negligence or intent.[11] It is 95% in the Mediterranean region and roughly 99% in Central Europe. The natural occurrence of fires is very small on the continent.

Wildfire propagation is another factor influencing wildfire danger. This includes the fuel moisture content, the types of fuel, and the slope and wind factors. Fuel moisture content is a basic element for wildfire spread because dry fuels burn easily and result in more intense wildfire propagation. Fuel moisture can be modelled via fuel moisture indexes derived from weather data. It was developed in Canada but

8 Rothermel 1972
9 Lee 2003
10 Finney 2005
11 Ganteaume et al. 2013

can also be used in European conditions.[12] The possibility of using indexes has already been analysed in Hungary.[13]

The fuel type is also a factor influencing the fire spread. In the case of fuel type, it is important how quickly the vegetation dries out, and the horizontal and vertical structure of the fuel. As a result of a European dataset, fuel types can be classified into 9 classes.

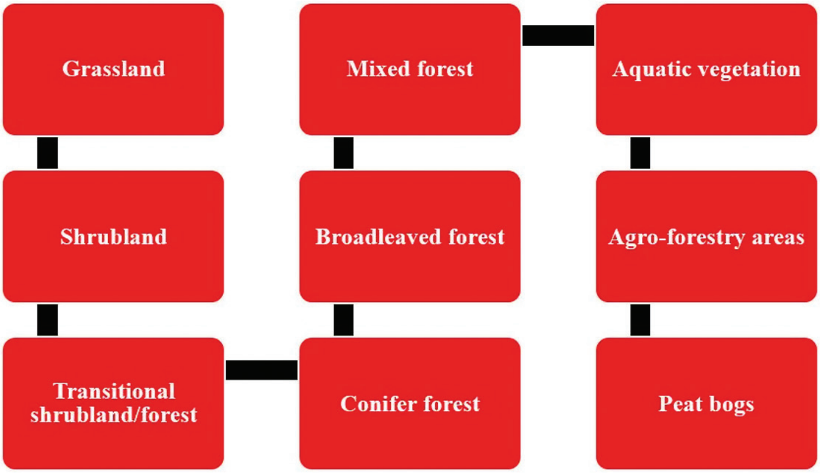

Figure 6: Fuel types in Europe organised into 9 groups
Source: Compiled by the authors based on European Commission 2021.

These 9 groups characterise the flammable fuel of the European continent. Fuel types have different combustion properties, which also affect the fire spread.[14] In this research, we do not examine it, due to space limitations.

In case of wildfire risk assessment analysis, the slope and wind factors are also essential. These affect the generation of wildfires, the fire spread, and the size of the burned areas, and these can be considered the abiotic factors of forest fires (non-living factors in the ecosystem). So the spread of wildfires also depends significantly on topographic conditions. The precipitation (rain) flows from the upper part of the hill towards the lower parts, so the moisture content of the flammable fuel and soil layer is potentially always higher in the valley. The lower part of the hill is also more windproof, and the effect of solar radiation is not as effective as on the hilltop, therefore, the precipitation cannot dry out quickly. The water conditions on the southern slopes are unfavourable, so the moisture content of the fuel is lower in this part. This provides better conditions for fire generation. Another significant factor is where the fire occurs on the terrain. Fires at the bottom of the slope develop faster than at the top of the slope. In these conditions flames bend, just as they do on plains in

12 Van Wagner 1987
13 Debreceni 2021
14 MPI Feuerökologie und Biomassverbrennung AG 1994

case of wind. In this case, the pre-drying effect of convection and radiation increases towards the fuel in front of the frontline of fire. In contrast, fires occurred at the top of a slope move downhill slowly and slip slowly through the mountain ridge due to flame deflection.[15]

Wildfire vulnerability means ecological and socio-economic values. However, ecological values are difficult to measure, because they are often elusive, but their protection is essential for everybody. The Natura 2000 site network emphasises the special ecological values of a territory. National Designated Protected Areas must also be considered when assessing wildfire risk. The European Environment Agency (EEA) groups the designation types into three main categories such as:

a) designation types used to protect fauna, flora, habitats and landscapes
b) statutes under sectoral, particularly forestry, legislative and administrative acts providing adequate protection relevant for fauna, flora and habitat conservation
c) private statute providing durable protection for fauna, flora, or habitats[16]

Forest fires can have not only ecological but also socio-economic values that affect people's livelihoods, safety and health.[17] Socio-economic value is a practical approach to estimating the cost of damage caused by wildfires. There are a lot of costs involved during firefighting, but these include mainly the costs of fuel, mechanical depreciation, manpower and burnt areas. Most of the damage caused by forest fires is the burned areas.[18] Areas, in particular where houses meet or intermingle with the undeveloped wildland vegetation can also be considered a socio-economic value. It is referred to as the Wildland-Urban Interface (WUI) in international literature.[19] Research on WUI and the identification of areas have already begun in Hungary.[20] Socio-economic factors also include critical infrastructure elements. The JRC has collected European data on critical infrastructures from a range of sources and harmonised and stored them in a geographical database.[21]

The above-mentioned points set out the basic criteria for the European assessment of wildfire risk. The next step in the process is to implement the basic criteria and to test and validate the wildfire risk map at the European level.

In addition to the risk assessment dimension, it is also worthwhile to qualitatively examine the factors (hereinafter referred to as drivers) that play a role in the occurrence of forest fires and the increase in the number of fire incidents. In this approach, external and internal drivers play a role in the development of fire risk.

At the European level, cooperation in forest fire prevention is implemented by the Expert Group on Forest Fires of the Joint Research Centre. Its main role is to provide advice for the implementation and further development of the European Forest Fire

15 Nagy 2013
16 Nationally designated protected areas (www.eea.europa.eu/data-and-maps/indicators/nationally-designated-protected-areas).
17 Vhiriri et al. 2021
18 Bodnár 2017
19 Radeloff et al. 2005
20 Bodnár 2020; Bányai–Pántya 2020
21 European Commission 2021: 10.

Information System and recommendations for improved forest fire prevention in the European and Mediterranean regions.[22]

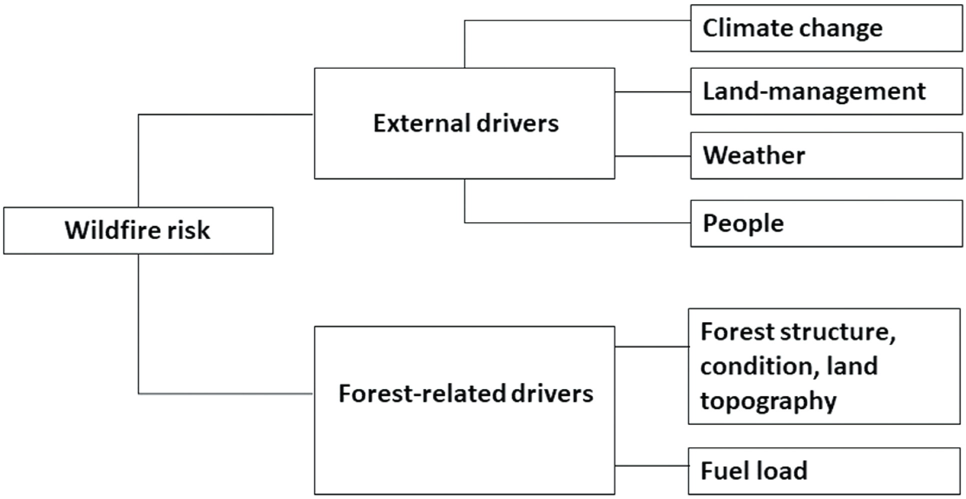

Figure 7: Forest fire drivers in risk evaluation
Source: Compiled by the authors based on European Commission 2021.

External factors such as climate change, land management, land use, weather and people affect wildfire risk. Rising temperatures and increased droughts are responsible for the higher risk of wildfires, as they make biomass more susceptible to ignition. Higher temperatures and more frequent droughts lead to more days with high fire danger, which partly explains the impact of climate change on wildfire risk. Rising temperatures and droughts also affect vegetation types, because changing environmental conditions stress existing vegetation types, thereby increasing their desiccation and susceptibility to forest fires.

At the same time, the changed climatic conditions extend the growing season, which in turn can lead to a change in species composition and an increase in combustible biomass, and thus to the risk of fire. Additionally, changing environmental conditions can affect species distribution, potentially making ecosystems more vulnerable to fire. Weather changes are of course closely related to climate. Decreasing rainfall and more frequent droughts are affecting areas of Europe that historically have rarely experienced forest fires.

Human actions often contribute to wildfires. Although fires can also be caused by natural causes (lightning, spontaneous combustion), European Forest Fire Information System[23] (EFFIS) data shows that the majority of fires in Europe are caused by humans, either accidentally, carelessly, or intentionally.

[22] For more information see https://effis.jrc.ec.europa.eu/
[23] For more information see https://effis.jrc.ec.europa.eu/

Land management and planning are the main links between forest-related factors and external activities. Fire management is also a form of land use. While the decline of rural areas can contribute to wildfires in some areas, in other cases urban sprawl has resulted that people are moving to fire-risk areas. On abandoned or only intermittently managed farmland, biomass also contributes to the increase of fire risk and the spread of fire in the absence of a human operator. Factors related to the forest and its biomass, such as its species composition, horizontal and vertical composition, as well as topography, all affect forest fire risk. Management decisions also affect the composition and quantity of combustible biomass. The risk of fire increases with the lack of cultivation work and improperly selected tree species in forest plantations. At the same time, forest fire risk is reduced by forest thinning and the creation and maintenance of the fire protection system, as well as the choice of resistant species suitable for the growing area for planting. Forest fire risk can be further reduced by forest fire prevention measures carried out during farming.

After reviewing the individual factors, in the next section, we will examine how the individual components can be transferred to the domestic system.

5. Investigating the possibility of implementation in the Hungarian forest fire risk assessment system

Risk modelling systems should be the result of an integrated framework of interconnected components associated with the firing process [24] [25] to provide an integrated view of fire likelihood and the consequences caused by them. Wildfire risk can be identified as the joint effect of:

- wildfire danger (also known as a fire hazard)
- wildfire vulnerability of people, ecosystems and goods exposed to wildfires

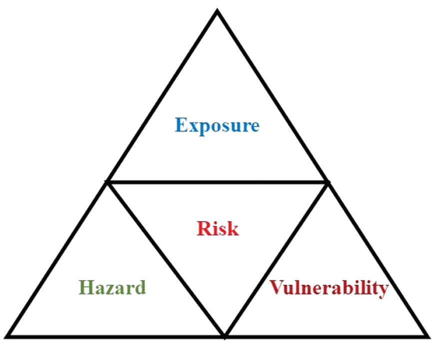

Figure 8: Forest fire risk scheme in European approach
Source: Compiled by the authors based on San-Miguel-Ayanz 2019.

[24] Chuvieco 2012
[25] Xi et al. 2019

This scheme is designed to be scale-independent and easily applicable to local, regional and global scales. The three main components are defined below.

Hazard: A dangerous phenomenon, substance, human activity, or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Exposure: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

Vulnerability: The characteristics and circumstances of a community, system, or asset that make it vulnerable to the adverse effects of a hazard.

The scheme was based on the quantitative analysis of "risk", based on the probability or possibility (P) of negative outcomes (damage, D):

Risk = Probability × Damage

The probability for a fire to start at a given location and time (P: fire danger/fire hazard) depends on the likelihood of ignition sources and local conditions to start and spread a fire (fire behaviour); namely, it depends on the fuel availability, type and pre-conditions of the fuel, the prevalent meteorological conditions, and on the presence of an event triggering the initial ignition. In Europe, the vast majority of wildfires are linked to human causes either deliberate or due to accident or negligence.[26] Therefore, P is not only a function of fuel and weather but prominently also of human behaviour P (fuel, weather, human).

Wildfire risk is assessed by considering the vulnerable areas where people, ecological and socio-economic values are exposed to fire danger. An aggregated wildfire risk index is proposed, which prioritises the risk for human lives, while also considering ecological and socio-economic aspects. This is done by ranking as high-risk areas those where people may be exposed to wildfires, and secondarily other areas where ecological and socio-economic aspects are at stake.

Figure 5 shows the main components of the pan-European forest fire risk assessment system. Appropriate basic data is required for the calculation and risk ranking of the individual components. In the European system, freely accessible databases produced by the JRC are used. The resolution of the data lines also corresponds to this. 250 m for components affecting fire behaviour, 0.25 degrees for FWI for fire ignition.

Table 1 shows which components must be included in the forest fire risk assessment model and which data sources are available in Hungary.

We have selected an observation area in which we can examine how certain parameters of the forest fire risk assessment behave under conditions in Hungary, and from which data source they can be obtained.

Our main observation plot is in South Hungary, in Bács-Kiskun County nearby the town Kiskőrös. The area belongs to the professional fire department of Kiskőrös, where a lot of wildfires occur each year. Approximately 20% more fires occur here each year than in other counties of the country, and several of these are large-scale wildfires, which are the biggest challenge for firefighters.[27]

[26] De Rigo et al. 2017
[27] Ronchi et al. 2021

Table 1: Datasets for the components of the wildfire risk assessment system

Wildfire risk component		**Subcomponent**	**Values**	**Source**
Fire danger or hazard	Ignition	Human cause	Historical fire data	Forest Fire Information System of Hungary
	Fire behaviour	Fuel moisture content	Dead fuel moisture content	Fire weather index
		Fuel types	Vegetation types	Corine Land Cover
		Climatic conditions	Wind, humidity, precipitation, temperature	Hungarian Meteorological Service
		Terrain	Slope, aspect	Topographical maps of Hungary
Vulnerability	People	People in WUI	Wildland-urban interface	OSM
	Ecological value	Ecological indicators	Irreplaceability score10 Protected area Potential burnable land	Protected area Natura2000 sites
	Socio-economic value	The monetary value of land cover and vegetation	Forest fire damage restoration costs	Corine Land Cover, restoration costs
		House, infrastructure	House, infrastructure	Local maps

Source: Compiled by the authors based on San-Miguel-Ayanz 2019

5.1. Wildfire danger

Wildfire danger is influenced by factors related to the probability of ignition and those affecting fire behaviour. It is therefore composed of the likelihood/possibility of having a fire ignition, and the behaviour (propagation and intensity) of a fire once it is ignited.

5.1.1. Wildfire ignitions

In Europe, the vast majority of ignitions are due to human causes (either deliberate, or accidental), exposing the critical role of the human factor in fire occurrence and fire conditions, either by increasing ignitions or by suppressing activities. Naturally caused fires are normally a very small fraction of the total number of fires in Europe. The distribution of fire causes shows a similar picture in Hungary.

Based on the information obtained from the EFFIS, the most common cause of the fire is carelessness (96%). Cigarette butts thrown from a car, train, or bicycle, carelessly left campfires, carelessly done small garden and stubble burning, poorly organised barbecues and potlucks, or poorly executed slaughterhouse waste burning in forest areas are acts that can be categorised as careless negligence. The annual burning of lawns and shrubbery areas adjacent to forest areas to renew the vegetation can be classified as conscious carelessness (luxury). A natural cause or intentionality was indicated in 2–2% of the cases. For natural reasons, summer lightning can cause forest fires. In some cases, the origin of the fire can be traced back to some technical error (a broken electrical wire or a spark falling from the machine on the stubble).

Studying the high number of fire incidents and the cause of fire recorded on the data sheets, it is also necessary to draw attention to the fact that the fires were caused by breaking the fire lighting and fire use rules. According to the regulations in force, open burning of standing vegetation, stubble and waste generated in connection with plant cultivation is prohibited.

5.1.2. Fire behaviour

The fire behaviour is conceptually influenced by the fuel moisture content of both dead and live fuels, the different fuel types, slopes and wind patterns that will determine the propagation (rate of spread and spread direction) of a wildfire.

5.1.3. Fuel moisture

Fuel moisture content is a fundamental element for the availability of fuel for combustion, and as dry fuels burn easily, it is a fundamental element in providing favourable conditions for wildfire propagation.[28] The fuel moisture content, defined as the proportion of water contained in the vegetation about dry, fluctuates in time and space and is highly dependent on weather conditions. Fine fuel components may show a fast response to changing weather so that a windy, dry day might easily trigger a noticeable drop in their moisture content. On the other hand, thicker parts of the vegetation define quite a different fuel component: if thicker fuel requires more time (even several days or weeks) to dry under weather conditions facilitating the process, it conversely may preserve this dryness for a longer period, with higher latency to fast-changing weather. Even (not major) precipitation events may be unable to significantly increase a low fuel moisture content in thicker fuels, while a minor rainfall could easily saturate the moisture of finer fuels. Therefore, the behaviour of a wildfire is not only linked with the very recent weather conditions but also with the cumulative effect of the past weather.

[28] Yebra 2013

Common indices used for assessing vegetation moisture content of dead fuels are the three moisture indices which are components of the Canadian FWI system, Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), and Drought Code (DC), focusing respectively on fine, intermediate and thicker components of fuel. The dynamic nature of these indices, and their ability to keep the memory of past weather conditions, have been associated with their partial ability (especially for the components with longer time inertia) to correlate even with live fuel moisture.

For the risk assessment, we used the FWI which is a combination of the ISI index and the Buildup Index (BUI) which by combining DMC with DC, models the total amount of fuel available for consumption, providing a uniform numerical rating of the relative fire potential, by dynamically combining the information from four local meteorological variables such as temperature, wind speed, relative humidity and precipitation. The higher the FWI is, the more favourable the meteorological conditions would be to start a wildfire. The FWI uses information on the moisture content of dead fuels, as estimated from meteorological variables, and wind speed to determine the level of "fire danger" in different areas.[29] Long-term series of FWI data can be used as an explanatory variable in the assessment of wildfire danger at the pan-European level. The FWI has been proven suitable for European conditions[30] and is currently used in the EFFIS and widely adopted by many European countries as a best-harmonised approach to assess wildfire danger.[31] As detailed in the presentation of the domestic forest fire risk assessment system, the forestry authority also uses FWI in its daily work. We download the raster data for Hungary from the JRC database daily and evaluate the daily fire weather situation.

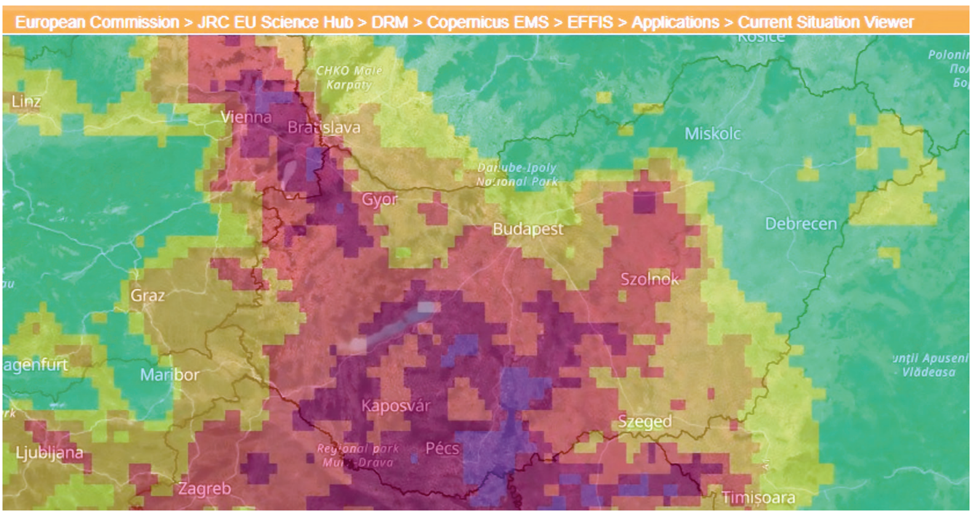

Figure 9: Fire Danger Forecast for Hungary
***Source:** European Commission s. a.*

[29] Van Wagner 1987
[30] Viegas 1999
[31] San Miguel et al. 2017

5.1.4. Fuel–vegetation types

The type of fuel available to burn, which may include trees, shrubs, grasslands, etc., will directly influence wildfire propagation and is key to fire propagation risk assessment as it considers the changes and dynamics of vegetation due to fire.[32] Each type of vegetation fuel, with its physical and chemical-specific attributes and its phenology, affects wildfire behaviour (rate of spread, fire intensity and propagation) and the impacts of wildfires. Moreover, wildfire behaviour is highly dependent on the horizontal and vertical structure of the fuels and the interconnection among them, which may determine the horizontal and vertical progression of the firefront.

In Hungary, we use the Corine Land Cover (CLC) collections (2000, 2006, 2020, 2018) in the fire risk assessment. Based on the literature data, it is necessary to refine the resolution of the Corine database to make the estimation of the combustible material in the model more accurate. We prepared the CLC map for the sample area (Figure 8). Areas marked in red are high-risk areas based on the land cover map.

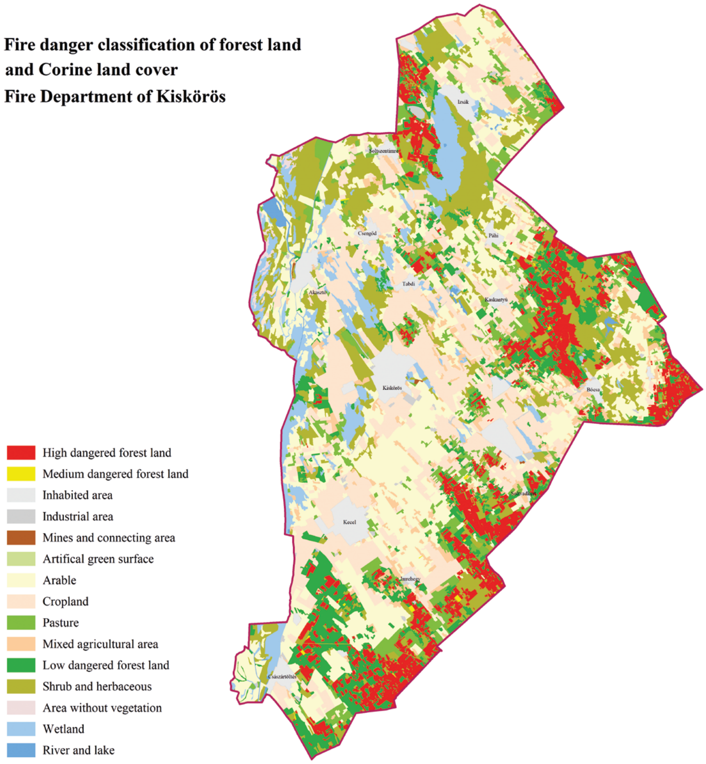

Figure 8: Fire danger classification of forest land and Corine Land Cover in the area of the Fire Department of Kiskőrös

Source: Compiled by the authors based on Corine Land Cover and Hungarian Forest GIS Database.

[32] Aragoneses–Chuvieco 2021

5.1.5. Slopes–Wind

The slope is the rate of change of elevation in the direction of the water flow line and it is especially important for the quantification of soil erosion, water flow velocity, or agricultural suitability. Angle, aspect and elevation is relevant for fire behaviour and wildfire propagation. For example, steep slopes (15°–20°) may affect wind direction and speed facilitating fire spread. In areas subject to frequent fire occurrence, even the local soil and vegetation composition may differ depending on the orography.[33] Associated with terrain characteristics, local wind conditions (direction, speed) could also affect wildfire propagation and intensity. Information on topography can be obtained from contour maps. Contour maps are available in Hungary from several sources. Contour maps made by digitising military maps can be obtained from the Lechner Knowledge Center. A land surface model created by the NASA space program using the radar interferometric process can be downloaded free of charge from the website of the U.S. Geological Survey (Shuttle Radar Topography Mission).[34] The model is also available for the Carpathian basin. Considering that the sample area is located on flat terrain, we did not examine the role of the slope separately in this research.

5.2. Vulnerability

The term "vulnerability" is intended to encompass people, ecosystems and goods exposed in vulnerable areas. This concise term includes the presence of assets within hazard zones,[35] and their susceptibility to suffering damage,[36] and within the risk framework, it is intended to be evaluated before the fire occurs. Defined as "the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" by UNISDR, it has been recently included in fire risk systems, referring to the condition of assets that are exposed and subject to being damaged by wildfires. As anticipated, we consider three categories of vulnerability:

- people (focusing on the population exposed in the WUI by ecological indicators beyond economy and market)
- assets at the interface between nature and human activity (for example, forests, another woodland, and agricultural land) whose market value (e.g. timber, agriculture products) can be quantified monetarily

5.2.1. People

Populated areas are often close to wildlands, generating a human–nature interface. This may be observed where abandoned agricultural areas lead to an expanding wildland, or

[33] De Rigo et al. 2017
[34] For more information see www.usgs.gov
[35] United Nations 2009
[36] San Miguel et al. 2017

conversely where settlements enlarge over areas previously dominated by wildland. The evaluation of the 'social vulnerability'[37] is often focused on this interface, designated as the WUI. This interconnected patch interface enhances the potential ignition agents and with a lack of fuel management can easily increase the wildfire risk, especially in a fire-prone landscape, posing a major threat to the population living in the WUI. Ignitions are more frequent because of the accessibility of fuels to people, threatening also neighbouring locations in the WUI, because fires may spread in fuel-rich areas within or adjacent to the WUI. Consequently, the risk of fire near these areas may be especially high for the population.[38] Particular attention is given to the topic all over the world.[39]

We examined the fire statistics on wildfires from the last 10 years, especially in the observation plot. We distinguished the fires according to their distance from the residential area. The location of fires in residential areas is also very important, so we examined it in Table 1. The resilience of buildings is also important,[40] but we will not analyse it in this research. Using TopoXmap, we have created buffer zones around the boundary line of populated areas. We put fires in the WUI-1 zone that occurred 500 meters from the residential area. Additional zones were as follows: WUI-2 zone – 1,000 m; WUI-3 zone 1,500 m; – WUI-4 zone 2,000 m; and WUI-5 zone 2,500 m. After creating the buffer zones, a GIS topological test was performed to determine which WUI zone the starting point of each fire falls into. In Table 2, fires in WUI-1 and WUI-2 zones (red and orange hoops) are important for the analysis, because these fires pose a threat to the residential areas.

Table 2: Number of wildfires in the WUI zones in the observation plot

Year	Number of wildfires	WUI-1	WUI-2	WUI-3	WUI-4	WUI-5
2011	103	42	17	9	9	26
2012	278	114	42	25	21	76
2013	66	23	11	8	6	18
2014	78	35	5	5	9	24
2015	50	18	6	2	5	19
2016	69	24	10	12	4	19
2017	145	32	30	21	22	40
2018	45	8	9	10	5	13
2019	180	41	25	22	34	58
2020	85	26	11	8	15	25
	123	29	23	20	16	35

Source: Compiled by the authors based on the Forest Fire Information System of Hungary.

37 Wigtil et al. 2016
38 Pastor et al. 2020
39 Kaim et al. 2018
40 Érces–Ambrusz 2022

We performed GIS Spatial analyses with topoXmap in Figure 3, which presents fires that occurred in wildland areas of the settlements in the observation plot. The red colour indicates fires that occur within 500 meters from the residential area (WUI-1 zone) and the orange those that occur within 1 km (WUI-2 zone).

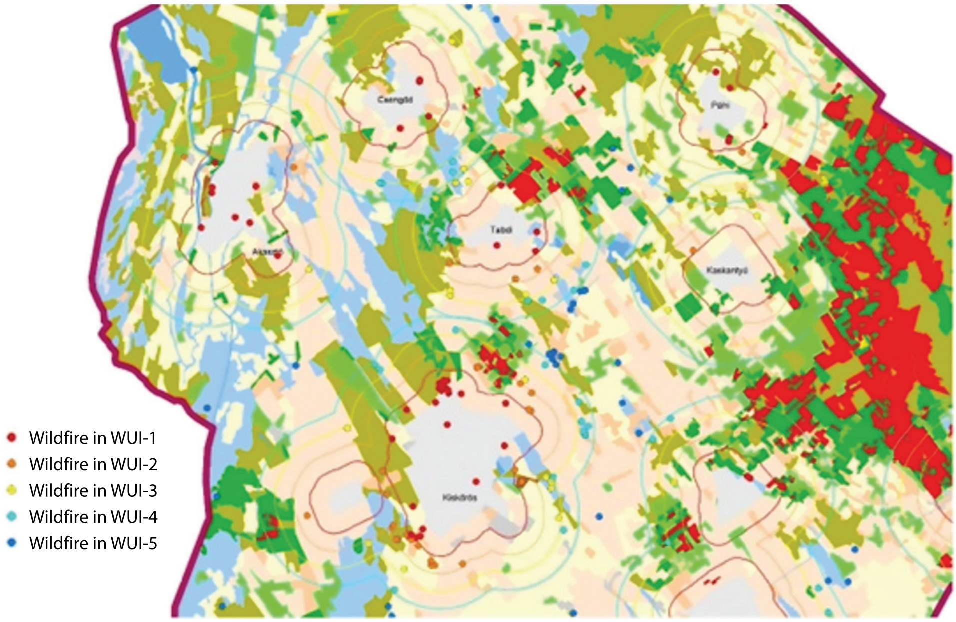

Figure 9: Wildfires (2011–2021) and WUI zones nearby Kiskőrös
Source: Compiled by the authors based on Corine Land Cover and Forest GIS Database.

5.2.2. Ecological value

Generally, the ecological impacts from a wildfire are mainly focused on the non-monetary values of ecosystem services, such as the negative impacts of fires on two major components: soils (soil loss, decreasing soil fertility, erosion) and vegetation cover. The protection of ecological assets is essential for all forms of life, including humans.

The vulnerability of an ecosystem's environmental value could be assessed through ecological indicators related to these three aspects at several temporal scales, such as short (immediately after the fire) and long-term (changes in vegetation structure and composition after a few decades including the vegetation response-ability). Ecological indicators may include the distribution of protected natural areas, and of areas of those ecosystems in which the recovery after wildfires may be compromised by weather conditions. Considering that ecological values are difficult to measure as they are often intangible, we suggest a qualitative approach to assess the ecological vulnerability within the wildfire risk framework. Therefore, to emphasise the special ecological values of the territory we use the Natura 2000 network.

Details of Hungarian Natura2000 are available on the website of the nature conservation authority (https://natura.2000.hu/).

5.2.3. Socio-economic value

Socio-economic damage caused by wildfires affects people's livelihood, safety and health. Vulnerable areas may be identified considering the presence and value of houses and infrastructure, the monetary value of the vegetation and wildlife that may burn, as well as the value of ecosystem services that would be lost after wildfires. Properties, infrastructures, economic services provided by the vegetation (wood, non-wood products, hunting revenues, fungi, etc.), agricultural products, carbon stocks, or recreational and tourist services can be associated with economic and social factors and be a part of the "tangible" values at stake (vulnerability) in the wildfire risk assessment.

In recent research, it was not possible to conduct a full-scale survey regarding socio-economic value. The built environment and infrastructure can currently be mapped based on the public Open Street Map data file. Methodology still needs to be developed to examine this factor in the domestic forest fire risk assessment.

6. Conclusions

A wildfire risk map was generated by JRC as a prototype index to summarise the combined effect of wildfire danger and vulnerability. An aggregated wildfire risk index is proposed, which prioritises the risk for human lives, while also considering ecological and socio-economic aspects. This is done by ranking as high-risk areas those where people may be exposed to wildfires, and secondarily other areas where ecological and socio-economic aspects are at stake. High risk may be expected where high wildfire danger affects the most critical areas for people, and secondarily for the other ecological and socio-economic aspects.

The method is also suitable for recalculating the fire risk for the entire country at certain intervals, even every year. In this way, changes due to sociological and economic reasons can also be followed. The fire risk assessment prepared by the JRC specifies the classification of a given area on a 12 km resolution raster map. Local data is required to prepare a higher-resolution fire risk assessment that also takes local specialties into account. Before preparing the assessment, it is necessary to define the goal that we want to achieve by preparing the risk maps. A forecasted risk estimate for the fire season helps the fire department and the forestry authority control. By increasing inspections, the public's attention can be drawn to the dangers that arise during the fire season. With targeted inspections, the authority can gather the areas that are particularly at risk. The maps based on the individual components can be used during firefighting. The land cover map and the relief map show important information about the possible spread of the fire. The component representing ecological values provides information on the damage caused and the difficulties of restoration.

The risk assessment prepared by the JRC classifies the regions of Hungary affected by forest fires (Northern Hungary, Great Plains) as high-risk areas. This fact shows that forest fire risk assessment and its usability should be considered an important issue shortly. By adapting the methodology, we can facilitate the clarification of the risk assessment prepared by the JRC, and we can give a new direction to the domestic risk assessment by incorporating new components.

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