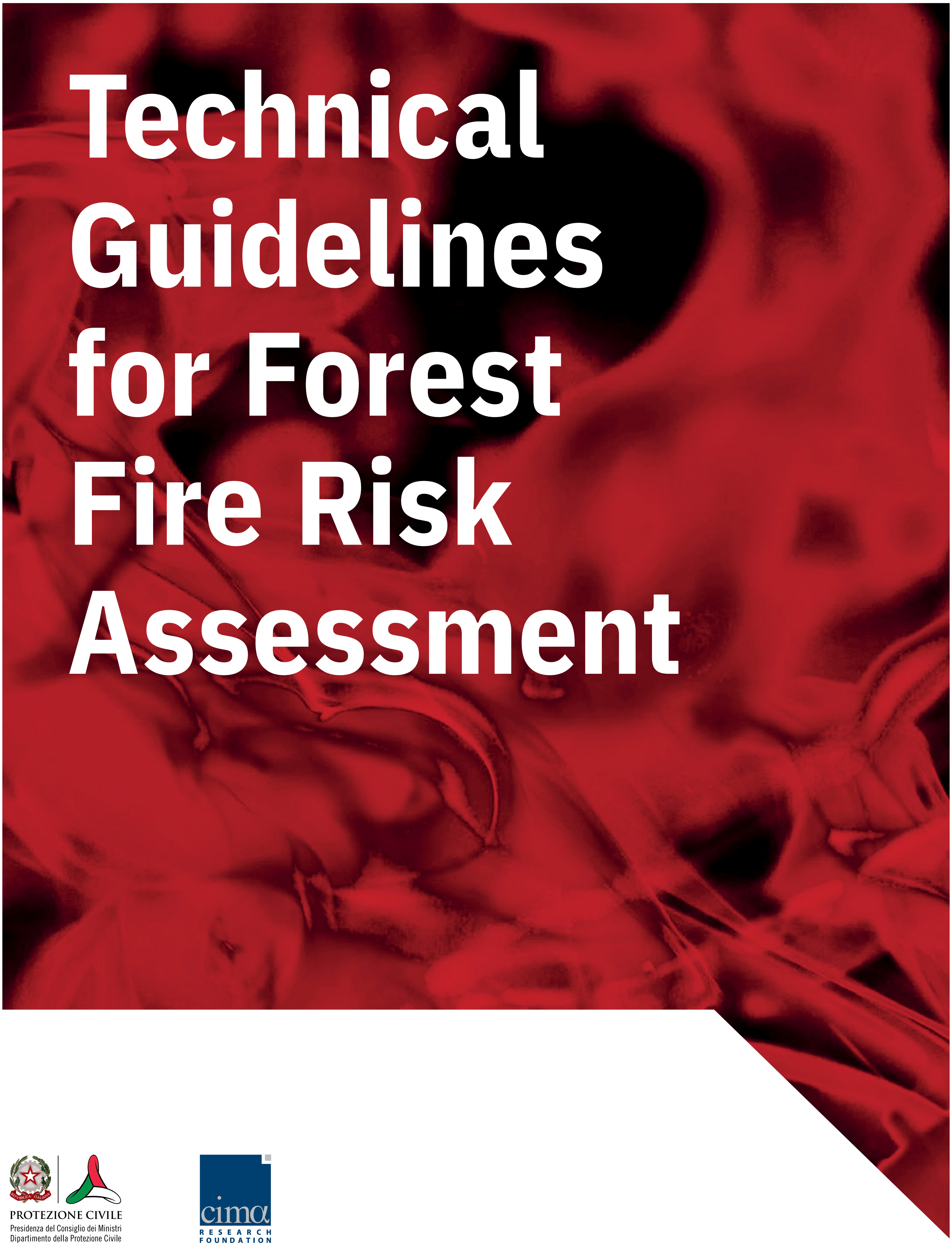
IPA Floods and Fires
EU Support to Flood Prevention and Forest Fires Risk Management in the Western Balkans and Turkey

Funded by the European Union

European Civil Protection

Technical Guidelines for Forest Fire Risk Assessment



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MSB Swedish Civil Contingencies Agency

APELL-RO

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Glossary

COPING CAPACITY
Ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks.[1]

EXTREME WILDFIRE EVENT (EWE)
High intensity fire events requiring control measures that may exceed even high coping capacities (fire-fighting resources). Although they represent a minority among wildfires, EWE can cause severe impact on any exposed asset, causing fatalities and damage to the environment, cultural heritage and landscapes, and economic activities.

FIRE BEHAVIOUR
Manner in which a fire reacts to the influences of fuel, weather and topography.

FIRE DANGER
Result of a combination of both constant and variable factors that affect the initiation, spread and difficulty of control of wildfires on an area.[2]

FIRE EXPOSURE
Situation of people, infrastructure, housing, production capacities and other tangible human assets located in fire-prone areas.[3] Fire exposure is simply the spatial juxtaposition of the likelihood and intensity metrics of wildfire with the location of Highly Valued Resources and Assets (HVRAs) found in a specific area.

FIRE HAZARD
Any situation, process, material or condition that can cause a wildfire or that can provide a ready fuel supply to augment the spread or intensity of a wildfire, all of which pose a threat to life, property or the environment. Fire hazard differs from fire danger as variable factors (meteorological variables) are not included in the assessment.[4] Fire hazard is the potential fire behaviour for a fuel type, regardless of the fuel type's weather-influenced fuel moisture content.

FIRE INTENSITY
General term relating to the heat energy released by a fire.

FIRE RISK
Calculation of the probability of a wildfire occurring and its potential impact on a particular location at a particular time. Wildfire risk is calculated using the following equation: Fire risk = Hazard (H) x potential impact, that is expressed by the product between the value of exposed elements (E) and their vulnerability to damage (V).

FIRE RISK ASSESSMENT
Scientific methodology to quantify risk levels, specifying acceptable and actual levels of risk posed to an individual, group, society or the environment, and allowing decision-makers to investigate the trade-offs of alternative actions.[5] The assessment incorporates evidence regarding the likelihood and magnitude of future forest fire events in respect to recent fire behaviour such as ignition, spread, suppression, and duration.[6] The process involves the identification of risk, assessment of probability and of potential impact. Without an accurate measure of probable fire risk, it is not possible to develop a plan to identify and prioritize fire-prone zones.[7]

FIRE RISK MAPPING
Builds upon fire hazard maps by adding exposed elements and their vulnerability to the assessment. The result is a map that displays varying degrees of fire risk ranging from very low to very high. These maps can be broken into two broad categories: long- and short-term. Long-term (seasonal) fire risk maps generally map risk using inputs that do not vary greatly over time such as vegetation type, human settlements and topography and therefore can be considered static. Short-term fire risk maps normally provide risk estimates that are only appropriate for a short period (days-weeks) after their creation. Short-term fire risk maps use many of the same inputs as long-term fire risk maps but also include variables that are continuously changing such as fuel moisture content, weather conditions and vegetation conditions.[8,9]

FIRE SEASON
period(s) of the year during which wildland fires are likely to occur, spread and affect resource values sufficient to warrant organized fire management activities.
A legally enacted time during which burning activities are regulated by the state or local authority.

FUEL
Combustible material, including vegetation, such as grass, leaves, ground litter, plants, shrubs and trees, that feed a fire.

FUEL MOISTURE CONTENT
Quantity of moisture in fuel expressed as a percentage of the weight when thoroughly dried at 212 degrees Fahrenheit.

FUEL TYPE
Identifiable association of fuel elements of a distinct plant species, form, size, arrangement or other characteristic that can cause a predictable rate of fire spread or render it difficult to control under specified weather conditions.

HOST NATION SUPPORT
Any action undertaken in the preparedness and response phases by the country receiving or sending assistance, or by the European Commission, to remove foreseeable obstacles to international assistance offered through the Union Mechanism. It includes support from Member States to facilitate the transiting of this assistance through their territory.[10]

INTEGRATED FIRE MANAGEMENT
Integration of science and wildfire risk management approaches with socio-economic elements at multiple levels for the planning and implementation of a balanced approach to managing fires. This approach places greater emphasis on integrating all phases of the wildfire risk management cycle, including prevention/ preparedness, detection/ response, restoration and adaptation to climate change, and thus overcoming any existing silos approach.

OPEN FIRE
Planned and controlled fire of vegetation ignited for different purposes (e.g. cooking, vegetation clearings, recreation).

RISK MANAGEMENT CAPABILITY
Ability of a Member State or its regions to reduce, adapt to or mitigate risks (impacts and likelihood of a disaster), identified in its risk assessments to levels that are acceptable for that Member State. Risk management capability is assessed in terms of their technical, financial and administrative capacity to carry out adequate: a) risk assessments; b) risk management planning for prevention and preparedness; and c) risk prevention and preparedness measures.[11]

RURAL FIRE
Uncontrolled fire affecting rural areas characterized by the presence of crops and wildland areas.

URBAN FIRE
Fire starting in an urbanized area where houses, surrounding infrastructure (e.g. fences, retaining walls, cars, sheds) and gardens become the dominant wildfire fuel and the main source of embers that ignite adjacent structures.[12]

VULNERABILITY
Conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, community, assets or systems to the impacts of hazards.[13]

WILDFIRE (UNDRR)
Any unplanned or uncontrolled fire affecting natural, cultural, industrial and residential landscapes.[14] It is an unusual or extraordinary free-burning vegetation fire that poses significant risk to social, economic or environmental values. It may be started maliciously, accidently or through natural means.[15] Wildfires should be distinguished from prescribed fires which involve the use of fire as a planned management practice and suppression / tactical fires which relate to the use of fire as a means of fighting wildfires. Effective forest fire management requires an integrated consideration of natural and human-induced wildfires and/ or planned application of fire in forestry and other land uses.

WILDLAND URBAN INTERFACE (WUI)
Zone of transition between wildland and human settlements and /or development.

WUI FIRE
Uncontrolled fire affecting WUI that may require specific fire management procedures.

Acronyms

AFAD	Disaster and Emergency Management Authority of Türkiye
AHP	Analytical Hierarchy Process
ASIG	Autoriteti Shtetëror për Informacionin Gjeohapësinor (Albanian State Authority for Geospatial Information)
BA	Burnt Area
BAM	Bosnia-Herzegovina currency
CIMA	CIMA Research Foundation
CMC	Crisis Management Centre
DGF	Directorate General of Forestry
EaR	Element at Risk
EC	European Commission
ECPM	European Civil Protection Mechanism
ECPP	European Civil Protection Pool
EMA	Emergency Management Agency of Kosovo*
EFFIS	European Forest Fire Information System
EU	European Union
EWE	Extreme Wildfire Event
FAM	Forest Administration of Montenegro
FAO	United Nations Food and Agricultural Organisation
FBiH	Federation of Bosnia and Herzegovina
FFRM	Forest Fire Risk Mapping
GIS	Geographic Information Systems
IGEO	Institute of Geosciences of Albania
HVRA	Highly Valued Resources and Assets
IHMS	Institute of Hydrometeorology and Seismology of Montenegro
IPA	Instrument for Pre-Accession (EU co-funded programme)
IPA DRAM	IPA Disaster Risk Assessment and Management
IPAFF	IPA Floods and Fires
ISO	International Organisation for Standardization
IT	Information Technology
JRC	Joint Research Centre
KFOR	Kosovo* Force
KPA	Kosovo* Forest Agency
KSPD	Cantonal Forest Enterprises of Bosnia and Herzegovina
LGU	Local Government Unit
MERIT DEM	Multi-Error-Removed Improved-Terrain Digital Elevation Model
MESP	Ministry of Environment and Spatial Planning of Kosovo*
ML	Machine Learning
MoEPP	Minister of Environment and Physical Planning in North Macedonia
NCEP	National Civil Emergency Plan
NF	National Forest of North Macedonia
NFFIS	National Forest Fire Information System
NGO	Non-Governmental Organisation
NP	National Park
NRA	National Risk Assessment
OGM	General Directorate of Forestry of Türkiye
OSM	OpenStreetMap
PENF	Public Enterprise National Forests
PENPM	Public Enterprise National Parks of Montenegro
POI	Point(s) of Interest
PRAF	Peer Review Assessment Framework
PRD	Protection and Rescue Directorate of the Republic of Macedonia
RF	Random Forest
RS	Republika Srpska
RWG	Regional Working Group
UAV	Unmanned Aerial Vehicle
UCPM	Union Civil Protection Pool
UNDRR	United Nations Disaster Risk Reduction
UNEP	United Nations Environmental Programme
UNSCR	United Nations Security Council Resolutions
WRA	Wildfire Risk Assessment
WUI	Wildland Urban Interface
WWF	World Wildlife Fund

01

Scope of the technical guideline

1.1 Introduction

IPA Floods and Fires (IPAFF) is a 3-year EU-funded programme that aims at improving capacities for flood and forest fire risk management in Albania, Bosnia-Herzegovina, Kosovo*, Montenegro, North Macedonia, Serbia and Türkiye. In particular, the programme aims at improving wildfire risk assessment (WRA) and risk management capabilities of all actors engaged in forest fire management, and thereby improve all phases of the forest fire cycle: prevention and preparedness; detection and response; adaptation and restoration.

This document is an IPAFF WP2.1 deliverable: *"Technical guideline for forest fire risk mapping and associated implementation plans"*; more specifically it is the second outcome of Activity 2.1.1 *"Development of regional technical guidelines for forest fire risk mapping and associated implementation plans"*.

1.2 Rationale

WRA is fundamental for developing plans for prevention, mitigation and preparedness. Wildfires are a complex phenomenon with many factors contributing to an event's initiation (ignition) and subsequent development. As opposed to other phenomena, wildfires are not cyclical due to their intrinsic connection to human factors that are beyond current modelling capabilities. Thus, validating a wildfire risk is as complex as its computation. Because wildfires depend on different meteo-climatic, physical and human aspects, their risk assessment and mapping lack a consolidated science-based methodology, as in other natural hazards. This variance limits the adoption of risk assessment/ mapping by and across authorities involved in wildfire management, from local to national and regional governments. The lack of common approaches affects the proper handling of transboundary aspects as different authorities are involved. Many countries have their own customized approaches to assess wildfire risk[16] with variables and procedures that are often incompatible or poorly defined.

To address this gap, efforts are underway to develop the first pan-European WRA, engaging 43 countries in the European region, the EC Joint Research Centre (JRC) and other Commission services. This effort will facilitate the harmonization of terminology, data, variables, metrics and components of WRA among different organizations and governmental levels.

However, since the inception phase of the IPAFF programme, the lack of knowledge and tools to produce forest fire risk maps both at strategic and operational levels has been evident.

1.3 Aims of the technical guideline

Aligned with the EU effort to establish a Pan-European WRA, the IPAFF programme aims at strengthening capabilities for forest fire risk assessment. It will do this by providing tools, training and a capability assessment, as well as developing a technical guideline for wildfire risk mapping in the Western Balkans and Türkiye. The technical guideline aims at:

- empowering strategic and operational capacities on forest fire risk assessment and mapping
- understanding how variables and components of WRA are incorporated in the decision-making process of these organizations
- harmonizing existing methodologies to develop a common methodology for fire risk mapping
- facilitating risk mapping of transboundary fire events towards a regional approach to forest fire risk assessment and mapping
- contributing to reinforce territorial solidarity and synergies / cost-effectiveness in the use of resources for forest fire assessment and mapping in the region of Western Balkan and Türkiye

The guideline explains how WRA and mapping can be carried out bearing in mind the interactions between fire and landscape management under climate change conditions.

Furthermore, the guideline takes into consideration the knowledge and results of various European and international guidelines and recommendations, including:

- Wildfire Peer Review Assessment Framework[17]
- Pan-European Wildfire Risk Assessment, Technical report[18]
- Recommendations for National Risk Assessment for Disaster Risk Management in EU[19]
- Risk management - Risk assessment technique[20]
- Regional Disaster Risk Assessment Technical Guidelines for Eastern Partnership countries under development through the PPRD East 3 programme[21]
- National Disaster Risk Assessment[22]

1.4 Targets and stakeholders

This technical guideline targets stakeholders in charge of forest fire risk assessment and mapping, at all levels of government (e.g. politicians, decision-makers, planners, practitioners).

In particular distinctions are made between the following stakeholders:

- Civil Protection Authorities (national and local level)
- Governments (all levels, e.g. Ministers of Environment and of Agriculture; Environmental Agencies, Defence Departments, Law Enforcement agencies such as the police)
- Emergency and Fire Services (e.g. Forest Corps, Fire Brigade, Search & Rescue Teams, Disaster Relief, Medical Emergency Services)
- Fuel managers, land planners

Other stakeholders not directly involved in forest fire risk assessment and mapping, but potentially interested include:

- Insurance and Real Estate agencies
- Infrastructure, Transport and Utilities (e.g. railways, motorways, energy grids, oil & gas, water management authorities, hospitals)
- Forest and Agriculture industries
- Tourism and Travel industries
- Other industrial and commercial sectors
- International organizations and NGOs (e.g. WWF, FAO)

1.5 Approach for developing the guideline

The guideline includes indications and recommendations on the assessment of forest fire risk mapping capabilities conducted in the region of Western Balkans and Türkiye. It is the result of a collaborative effort among IPAFF beneficiaries who provided insight on current practices, methods and tools for forest fire risk assessment and mapping in their own territories. The guideline benefitted from a bottom-up and iterative approach, engaging panels of forest fire management experts from partner countries to constitute a Fire Risk Regional Working Group (RWG). The Fire Risk RWG comprises up to five experts on forest fire risk assessment and mapping and forest fire risk management from different institutions, government levels and areas/ sectors (e.g. civil protection/ disaster management, forestry sector and/or line ministries), including practitioners and academics, from each partner.

The RWG helped to:

- understand the institutional and legal context of each country in which wildfire risk mapping can be implemented
- position the role of risk assessment and mapping as key for the adoption of an integrated forest fire risk management approach, across all wildfire management phases, integrating fire management and landscape management
- stimulate cross-level/ cross-boundary cooperation in the region crucial for transboundary wildfire events


Meeting in Begrade, Serbia, 2021

The approach for developing the guideline involved multiple steps, including:

- preparing and delivering questionnaires (Annex 1) integrated with interviews, from previous CIMA Foundation experiences in the area through the IPA DRAM project (2016-2019)[23] which focused on improving disaster risk assessment capabilities in Western Balkans and Türkiye.
- conducting several iterative (face-to-face and online) meetings for in-depth feedback
- developing an open-source Forest Fire Risk Mapping (FFRM) tool and making it accessible to all partner countries
- deploying incremental training on FFRM, structured in five modules, aimed at enhancing capability and implemented through a set of hybrid (in presence and online participation) meetings
- organizing two workshops (intermediate and final) gathering all RWG experts to exchange knowledge on the cross-border application of the wildfire risk map in Western Balkans and Türkiye

1.6 How to read the guideline

Chapter 1 introduces the rationale, aims and targets of the guideline.

Chapter 2 discusses the terminology used regarding forest fire risk mapping and the role of WRA and mapping.

Chapter 3 describes the context surrounding forest fires in Western Balkans and Türkiye.

Chapter 4 presents: i) a literature review of the methodologies for forest fire risk mapping; ii) a brief illustration of the most common methodologies currently used by partners/ beneficiaries in Western Balkans and Türkiye; iii) a broad description of the FFRM machine learning based methodology; and iv) the process adopted to develop forest fire risk mapping.

Chapter 5 explains the use of forest fire risk mapping for different purposes/ activities in the forest fire management cycle[24] and procedures for adoption.

The final **Chapter 6** proposes recommendations for improving risk assessments based on data gaps identified in the capability assessment conducted with each partner as well as on feedback provided by the RWG.

02

Defining risk assessment and mapping

2.1 Notes on definitions and terms for forest fire risk assessment and mapping

The IPAFF analysis of the legal and institutional framework conducted in Western Balkans and Türkiye revealed how definitions of forest fires often vary from country to country, or are not properly defined within the legal framework.

Table 1: Definition of forest fires provided by IPAFF Partners

PARTNER	DEFINITION OF FOREST FIRE
Albania Kosovo*	Forest fire is not defined in the legal framework
Bosnia and Herzegovina	A forest fire is an uncontrolled, spontaneous movement of fire on a forest surface. It is a natural disaster that differs in type, manner of origin and damage. A certain temperature, fuel and oxygen are needed for a fire to start, if one of them is removed, the fire stops
Montenegro	Fire is an uncontrolled combustion process, the occurrence of which (flames, heat and combustion products) often endangers human life and can cause great material damage
North Macedonia	The term fire means uncontrolled burning that causes material damage or poses a danger to human and animal lives, property and natural resources. Forest fire is any uncontrolled burning of forest, forest land regardless of the affected area, intensity and causes of its occurrence (article 12)
Serbia	There is no definition of forest fires in the Forest Act. Article 16 instead defines the obligation to rehabilitate forests, and regards forest fire as a natural disaster
Türkiye	The fire that has a tendency to spread freely and destroy all living and non-living beings in the forest by burning

Moreover, where the definition of forest fires explicitly refers to forests, such as in North Macedonia, a definition of the meaning of forest is required. In particular, the following definition from the Law on Forests (“Official Gazette of the Republic of Macedonia”, No. 160 of October 31, 2014)[25] states:

Article 6, comma (1) *“Forest, in the sense of this Law, is an ecosystem that exists on forest land overgrown with trees and shrubs of different species. It includes areas that are adjacent to the forest, meadows within the forest, nurseries, roads, seed plantations, windbreaks, as well as forests in protected areas. Furthermore, a forest consists of young plantations and crops covering an area of over two acres, as well as areas that are an integral part of the forest and are temporarily deforested as a result of human impact or natural disasters on which natural regeneration has begun”*.

Article 6, comma (2) *“Forest does not comprise separate groups of trees, an area of less than two acres, trees bordering agricultural land, plantations of fast-growing tree species, coastal vegetation outside the forest, tree lines or parks in settlements”*.

On the contrary, the term “outdoor fire” in North Macedonia refers to *“any uncontrolled burning of forest and forest land, regardless of the affected area, intensity, and reason for its occurrence, which includes burning of agricultural land and pasture, closer than 200 m to the edge of the forest”* (Article 12, comma 27).

In accordance with the FAO Guidelines, “fire” is any fire burning living or dead vegetation outside the urban environment.

Italy defines forest fire as an unplanned and uncontrolled fire of combustible vegetation (trees, grass, peat) that tends to expand in forests, bushes, rural areas, infrastructures and built-up environments located in the same burned areas (from the Italian Law 353/2000).

Legislators should be aware that while forest fires may be identified as fires in forests (whether these are administratively or scientifically defined), forest fire experts refer more generally to “wildland fires” as fires concerning all types of burnable vegetation (forests, other wooded land, rangelands, grasslands, bush lands and agricultural lands).[26] In order to define more efficient procedures for fire management it is crucial to expand the definition towards wildfires.

2.2 Role of wildfire risk assessment and mapping

WRA and mapping are central components of a more general process that identifies the capacities and resources available to reduce the recognised levels of risk or the possible effects of wildfires (capacity analysis), as well as considering the planning of appropriate risk mitigation measures (capability planning), and the monitoring and review of hazards, risks and vulnerabilities.[27]

WRA and mapping, conducted at any level (e.g. regional, national, local) can provide key inputs for informed capacity building and decisions in all wildfire management phases. In particular, WRA plays a key role in each phase of the wildfire cycle, enabling the shift from fire suppression to prevention activities while improving decisions for response and restoration (recovery) activities. Furthermore, it facilitates synergies between fire and landscape management thereby enabling the development of an integrated fire management approach.

When carried out at national level, WRAs and risk management can become essential inputs for planning public and private activities. By improving the awareness and understanding of wildfire risk, decision makers and stakeholders can agree on preventative measures to be taken and thereby avoid the most severe consequences of wildfire events and potential cascading effects (e.g. increasing flood risk, erosion, landslides).

Furthermore, producing WRAs enables public authorities, businesses, NGOs and the general public to reach a common understanding of wildfire risk as a community and contemplate possible prevention and mitigation measures. Awareness-raising and dissemination develop and integrate a risk prevention culture within sectoral policies. The latter are complex and involve numerous stakeholders, such as WUI and landscape management, where fires affect both public and private property as well as the population at large.

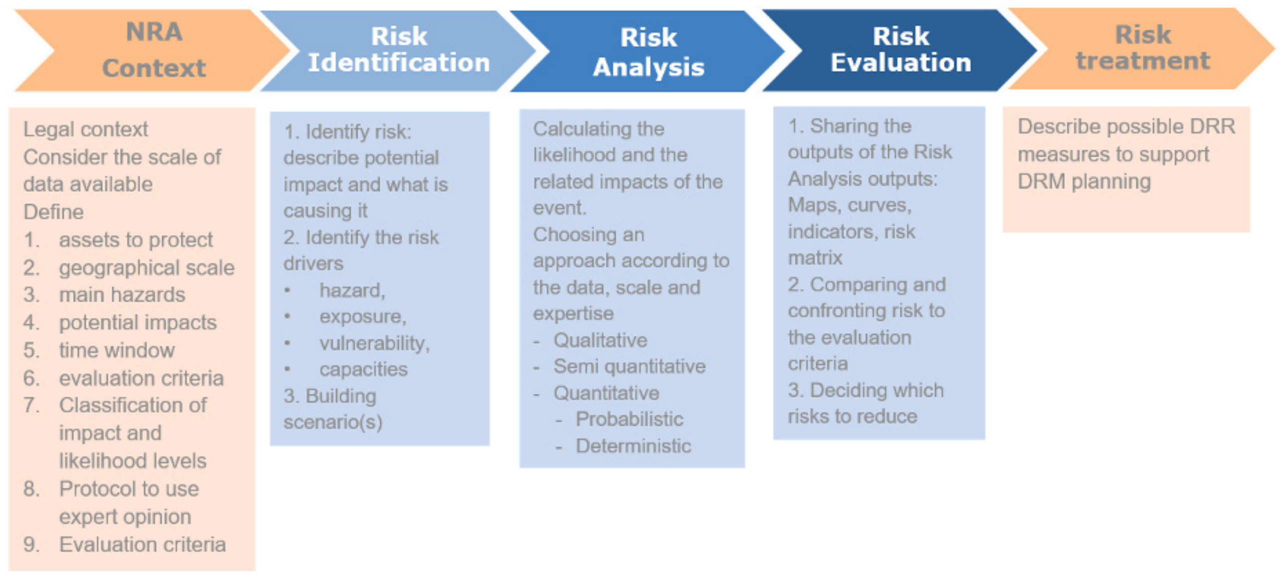
Risk maps generate a level of objectiveness and transparency enabling interested actors to prioritise decisions on plans, strategies and tactics so as to address the most severe risk areas with appropriate prevention and preparedness measures. Risk assessments deal with uncertainty and probabilities since wildfires depend on diverse factors (fuel distribution, local meteorology, forest management practices, coping capacity, etc).

In the case of wildfires it is necessary to consider human caused fires, such as arson, negligence and accidents. Furthermore, in the Western Balkans and Türkiye rural areas and agricultural activities are being abandoned leading to an accumulation of fuels. These are subjects of debate concerning the level of risk that governments find acceptable vis-a-vis the cost of prevention and mitigation measures, and call for a cost-benefit analysis.

2.2.1 Risk management capabilities assessment

According to the Risk Management Capability Assessment Guidelines,[28] the assessment of capability covers the whole risk management cycle: 1) risk assessment, 2) risk management planning for prevention and preparedness, and 3) implementation of risk prevention and preparedness.

Figure 1: Stages of Risk Assessment process according to ISO 31010



1. risk assessment: in undertaking a WRA, the aim should be to find a common understanding, among stakeholders, of the risks faced and their relative priority. The risks identified, assessed and prioritized in the assessment are the basis for the management planning and successive implementation of risk prevention and preparedness measures
2. risk management planning: defines how wildfire risk can be reduced, adapted to or mitigated in terms of impacts and likelihood by implementing selected suitable and concrete prevention and preparedness measures. The planning needs to indicate the required resources and timelines, and assign responsibilities, as appropriate
3. implementation of wildfire risk prevention and preparedness measures: includes the allocation of responsibilities and resources, monitoring of duties, and evaluation and recognition of lessons learned

This technical guideline focuses on the risk assessment process as described in (Figure 1). ISO 31030[29] provides a common approach to managing any type of risk, including wildfires. It divides the risk assessment process into three stages: identification, analysis and evaluation.

2.2.2 Role of risk assessment in the Union Civil Protection Mechanism

The Union Civil Protection Mechanism (UCPM) is a framework established by the EU to facilitate cooperation among its member states in the field of civil protection. The UCPM aims to improve the EU's ability to respond to natural and man-made disasters, including those that occur within its own borders or in other parts of the world. To be part of the UCPM, a country must be a EU member state or a participating country in the European Civil Protection Pool (ECPP). The ECPP is a voluntary pool of assets and resources that can be mobilized by the EU and its member states in the event of a disaster.

The key legal instrument that establishes the UCPM is Decision No 1313/2013/EU[30] of the European Parliament and of the Council of 17 December 2013. This decision sets out the legal framework for the UCPM, including the objectives, scope and governance of the mechanism. As part of the UCPM, member states and participating countries are required to conduct risk assessments. This is important for several reasons, as follows:

- to ensure that member states are adequately prepared to respond to disasters: by conducting risk assessments, member states can identify the potential risks and hazards they may face and develop appropriate response plans and procedures to mitigate the impact of disasters
- to enable effective cooperation among member states: risk assessments allow member states to share information about potential risks and hazards, which can help facilitate effective cooperation and coordination in the event of a disaster
- to ensure that resources are allocated effectively: risk assessments can help member states to identify the areas and populations that are most at risk, thereby ensuring that resources are allocated effectively

In order to participate in the UCPM, member states and participating countries must meet certain requirements and obligations, including:

- designating a national contact point for civil protection
- developing and maintaining a national civil protection system
- contributing to the ECPP
- cooperating with other member states and participating countries in the field of civil protection, including sharing information, coordinating response efforts and providing mutual assistance

According to article 5 of Decision No 1313/2013/EU[31], in order to promote an effective and coherent approach for the prevention of and preparedness for disasters by sharing non-sensitive information - namely information whose disclosure are not contrary to the essential interests of Member States' security, and best practices within the Union Mechanism - Member States shall perform several activities. These include providing the Commission with an assessment of their risk management capability at national or sub- national level every three years following the finalization of the relevant guidelines referred to in point (f) of Article 5(1) and whenever there are important changes. The latter article states that countries are requested to "compile and disseminate the information made available by Member States; organise an exchange of experiences about the assessment of risk management capability; develop, together with the Member States and by 22 December 2014, guidelines on the content, methodology and structure of those assessments; and facilitate the sharing of good practices in prevention and preparedness planning, including through voluntary peer reviews".

In line with the Decision's recommendations, the FFRM guideline aims to facilitate the accomplishment of these activities, thus improving overall risk management capabilities.

Finally, risk mapping is key for host nation support in the preparedness and response phases by allowing recipients to anticipate their request for assistance and thereby optimize the allocation of resources, thus reducing response time and improving the effectiveness of fire-fighting.

03

Context of forest fires in Western Balkans and Türkiye

This chapter introduces the context of WRA in Western Balkans and Türkiye. It explores territorial and climate information; statistics and impacts; fire types, causes and effects; institutional and legal frameworks; and the individual country's coping capacity to handle wildfires.

3.1 Territorial and climate context

IPAFF's focus covers: Western Balkans (Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Kosovo* and Serbia), and Türkiye. Collectively they comprise a vast area (circa 1,612,500 km2), characterised by different bio-geographical regions: Mediterranean, Continental, Alpine, Anatolian, Nannonian, and Black Sea.[32] According to the Koppen-Geiger climate classification,[33] the area is characterised as a) hot-summer Mediterranean climate (Csa) especially along the coast, b) semi-arid climate (BSk) in internal continental areas, and c) Mediterranean-influenced warm-summer humid continental climate (Dsa, Dsb, Dfb) in mountainous areas and the interior regions of Eastern Europe and Türkiye. Given the diversity of environments, vegetation typically ranges from maquis, pines forests and evergreen broadleaves typical of the Mediterranean to deciduous and fir forests especially in the high-elevation areas, as well as large expanses of grasslands. Most of the area is characterised by heavy anthropic impact on the distribution of vegetation species, mainly for agro-forestry purposes. Over the last decades, the abandonment of traditional agricultural and forestry activities has led to reforestation with impacts on biodiversity[34] along with potentially positive effects on carbon sequestration.[35]

The Western Balkans is largely mountainous, with the Dinaric Alps running throughout the region. The mountains are interspersed with river valleys and plains, particularly along the coast and in the northern part of the region. The area is vulnerable to the impacts of climate change, including increased frequency and intensity of extreme weather events such as heat waves and droughts, which further impact wildland fires and floods. Climate change is also expected to impact the region's agriculture, water resources and biodiversity.

Türkiye spans the geographic regions of the Mediterranean, Aegean, Black Sea, and the Anatolian plateau, each with its own climate. Along the Mediterranean and Aegean coasts, the climate is generally Mediterranean, with hot summers and mild winters. In the Black Sea, the climate is humid subtropical, with warm summers and cool winters. In the central and eastern parts of the country, including the Anatolian plateau, the climate is continental, with hot summers and cold winters. Türkiye is also prone to natural hazards: located in a seismic zone, earthquakes are common, with several major events having occurred

Meeting in Sarajevo, Bosnia and Herzegovina, 2022

Meeting in Skopje, North Macedonia, 2022

over the past century; landslides are frequent, particularly in mountainous regions; flooding is common in the Black Sea region, where heavy rainfall can cause flash floods and landslides; wildfires are particularly risky in the summer months due to the dry conditions and high temperatures. Türkiye has a large population, with many people living in urban areas along the coast and in the major cities.

Overall, the territorial conditions and climate of the Western Balkans and Türkiye present a range of challenges and opportunities, requiring a coordinated and proactive approach to disaster risk reduction and climate adaptation.

3.2 Fire events in Western Balkans and Türkiye

This section provides an overview of wildfire events and their impacts in each country.

Forest fires in Albania have increased in number and intensity over the past decades.[36] The most destructive fire seasons of 2007, 2011, 2012 and 2017 were characterized by their number and total area burnt. Climate change is a principal contributor to this phenomenon with rising temperatures and decreasing precipitation leading to heat waves and droughts that dry out vegetation. Several UN reports have concluded that Albania's current civil protection system is inadequate to stem the risks and impacts of forest fires. Despite efforts, such as the National Civil Emergency Plan (NCEP) in 2004,[37] to improve the division of responsibilities and resource allocation in respect to civil emergencies, reports highlight the divide between government ministries and disaster risk reduction units.

Fires in Bosnia and Herzegovina represent a serious danger for forests and forest cultures, especially in the Herzegovina karst region and similar areas with warmer days and less precipitation during the summer months. Humans are the main cause of fires, highlighting citizens' lack of awareness of the dangers and harmful effects of wildfires. The Public Forestry Company runs frequent campaigns to inform the community, encouraging the adoption of preventive and repressive measures to eliminate this hazard. Between 2010 and 2022, each year there was an average of 198 fires, affecting 7,733 hectares, which is close to 0.63% of the total forested area. These were primarily caused by humans, and amounted to an average loss of forest cover of 46,000 m^3, with the direct annual damage estimated at around two million BAM.

In Kosovo*, the frequency of landscape fires[38] has increased since 2007, mirroring global trends attributed to climate change and forest degradation. These wildfires represent a significant ecological problem, resulting in severe environmental, ecological, social and economic damage. The total burnt area for the period 2000 - 2022 is 34,992 hectares resulting from 2,318 forest fires. It is imperative that responsible institutions take immediate action to enhance the wildfire management system. Warning signals for the protection of forests from fire need to be updated; preventive and punitive measures need to be strengthened; and the cartography of risk from forest

fires needs to be improved including forecast systems. This requires commitment and coordination among all actors engaged in forest fire risk management.

In Montenegro the largest number of forest fires occurs in coastal areas, while the greatest damage is found in the northern part of the country. The lack of communication between institutions (HMZ, Directorate, Protection and Rescue Services, etc.) hinders efforts to localize and extinguish fires. This is further confounded by a shortage of adequately trained personnel, organised as teams with the appropriate fire-fighting equipment.

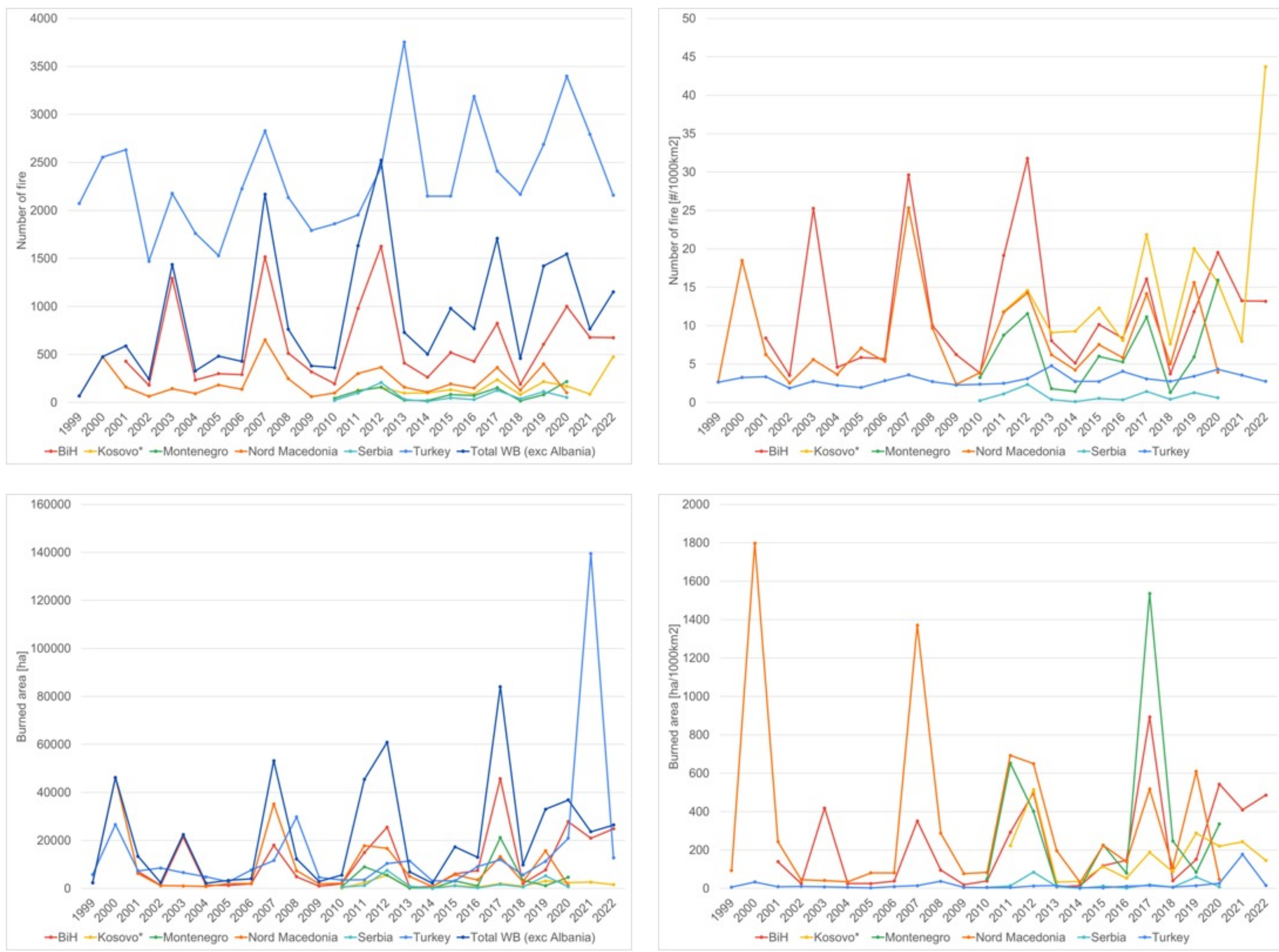
Over the past two decades, the impact of forest fires in North Macedonia has been fluctuating, with peaks in 2007, 2011-2012, 2019 and 2021 alternating with quieter seasons, such as the summer of 2023. However, indicators predict that the risk of fires is increasing, with fire firmly listed among the top environmental threats to the country. In addition to depopulation, the determining factor is the climate crisis with longer hot seasons and more frequent extreme phenomena. Debilitated by neglect and the planting of unsuitable species, forests are vulnerable to insect and fungal infestations. This is further hampered by the unplanned expansion of urban areas such as Skopje, which creates an inflammable transition belt between cities and forests. Most North Macedonian parks and reserves are located along the border, or are cross-border. North Macedonia has joined the European Civil Protection Mechanism (ECPM) and is aligning its system for fire prevention and response with that of its neighbours, with whom it increasingly cooperates during major fires. Still to come is a comprehensive commitment to the coordinated management of protected areas, which should be managed as single ecosystems regardless of borders.

Forest fires are a common occurrence in Serbia with direct and indirect economic and environmental consequences. According to Sekulić et al.[39] fires pose a serious threat to certain ecosystems and species, with the size of the area affected hampering the sustainable management of forest resources.[40,41] The most favourable conditions for forest fires in Serbia are high air temperatures, low relative humidity, wind and lack of precipitation.[42,43] Malinovic-Milicevic et al.[44] state that the longer the duration of extreme temperatures and low precipitation levels the greater the risk of forest fires.

As in other countries, environmental conditions are rapidly changing the wildfire situation in Türkiye. After the unprecedented megafires of 2021, Türkiye increased its fire-fighting capacity, particularly with the acquisition of aircraft. But the dramatic effects of climate change demand a new more integrated approach to fire management with a focus on prevention rather than suppression, along with a greater number of wildfire experts. Projects are currently ongoing to build a fire management and decision support system that makes use of weather data, surveillance, early warning and detection, optimal resource allocation and other tools. The General Directorate of Forestry (OGM), the agency responsible for fighting wildfires, is now working with institutions in and outside the country, with a protocol between themselves and the Disaster and Emergency Management Authority (AFAD) for better emergency response and coordination among agencies in case of an extreme wildfire danger. The World Bank has initiated a project with OGM that focuses on new methods for prevention and suppression of wildfires, while IPAFF programme activities are also contributing to new approaches and collaborations to address the issue.

Throughout the Western Balkan region and Türkiye, the data collection processes vary due to different circumstances including geopolitical instability in the area. It is possible to rely on a harmonized national dataset on fire events and burnt areas from 2010 - 2020, with the exception of Albania that lacks data, as shown in Figure 2.

Figure 2: Shows the number of fires and burnt areas in the Western Balkans and Türkiye. On the top left, the total number of fires is reported while on bottom left the total burnt area is shown. On the top right, the number of fires over 1,000 km^2 is shown, while the bottom right indicates the burnt area over 1,000 km^2.



On average, throughout the Western Balkans (excluding Albania) there are approximately 1,000 fire events per year with a total burnt area of 22,000 hectares; while in Türkiye there are approximately 2,500 fire events over the same period with a total burnt area of 15,000 hectares.

Furthermore, Serbia and Türkiye have fewer fire events and less burnt areas relative to their national geographical coverage due to their better wildfire management, while the other countries with lower capacities suffer greater inter-annual variability (e.g. 2007, 2012 and 2017). Bosnia and Herzegovina, North Macedonia and Türkiye have collected data for the longest period, including data on the total damage in terms of wood biomass destroyed by fires, as shown below.

Meeting in Konjic, Bosnia and Herzegovina, 2022

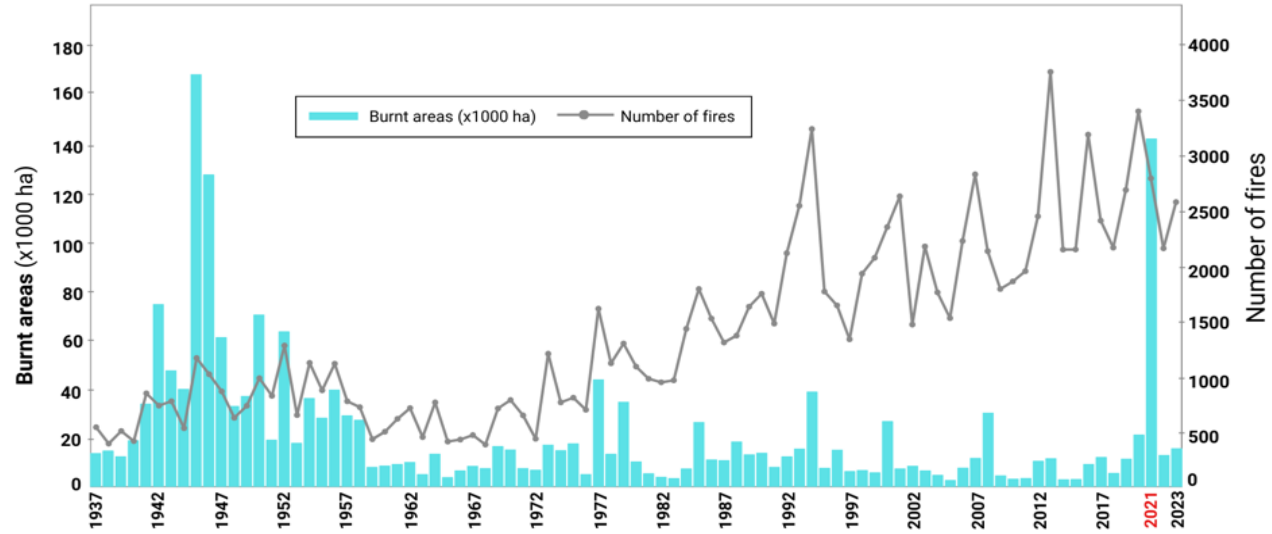
Figure 3: Wildfire direct damage and fire-fighting costs in Republic of Srpska (BiH)

In the Republic of Srpska, the total damage cost over 5 million euro in 2001 and some 4 million euro in 2012. Fire-fighting costs are limited to 75,000 euro per year on average with the maximum cost of 379,000 euro sustained in 2012 due to the extreme fire season.

Figure 4: Total damage from wildfires in North Macedonia

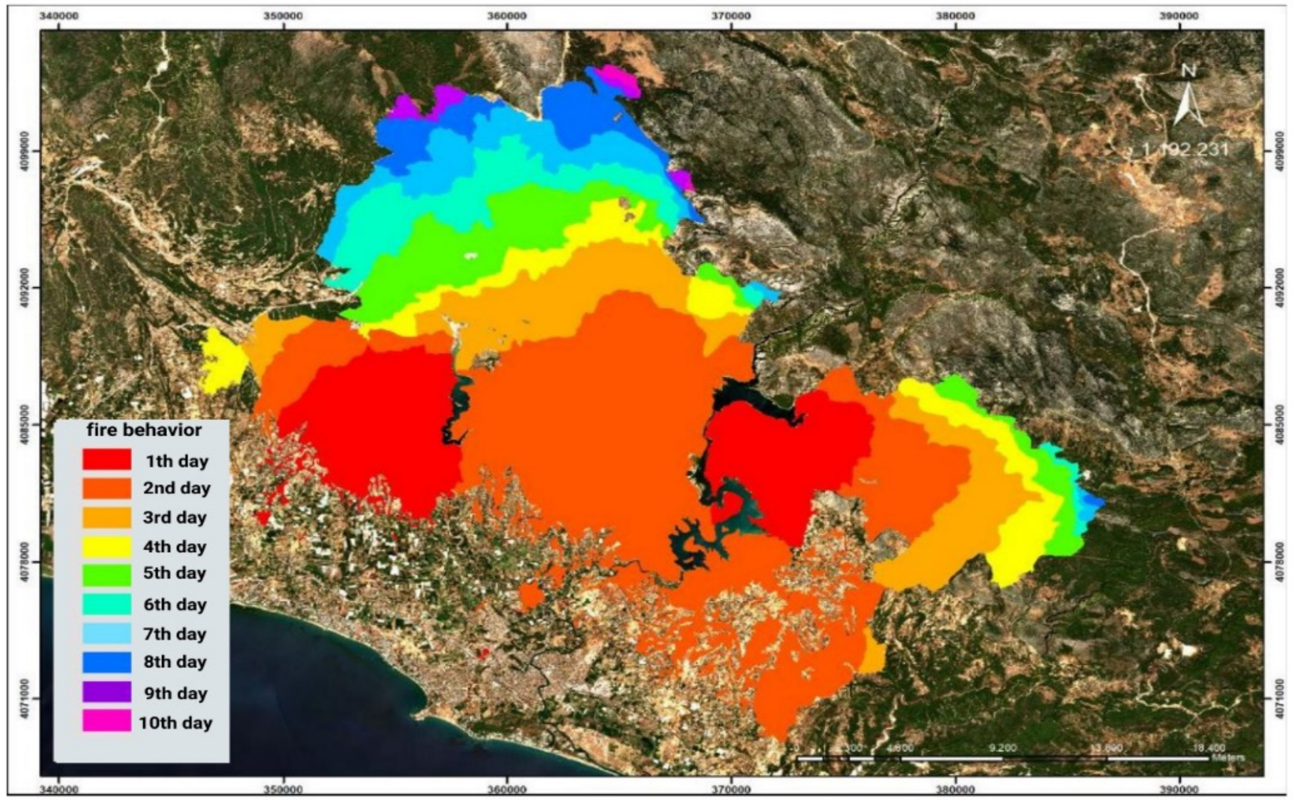
In North Macedonia the total damage costs accounted for 7.5 million euro, surpassing 20 million euro in 2007 and 2015, and reaching the maximum value of more than 30 million euro during the 2017 extreme fire season.

Figure 5: Long term data for burnt areas and number of forest fires from 1937 to 2023. Data from OGM Strategic Plan (2019-2023)



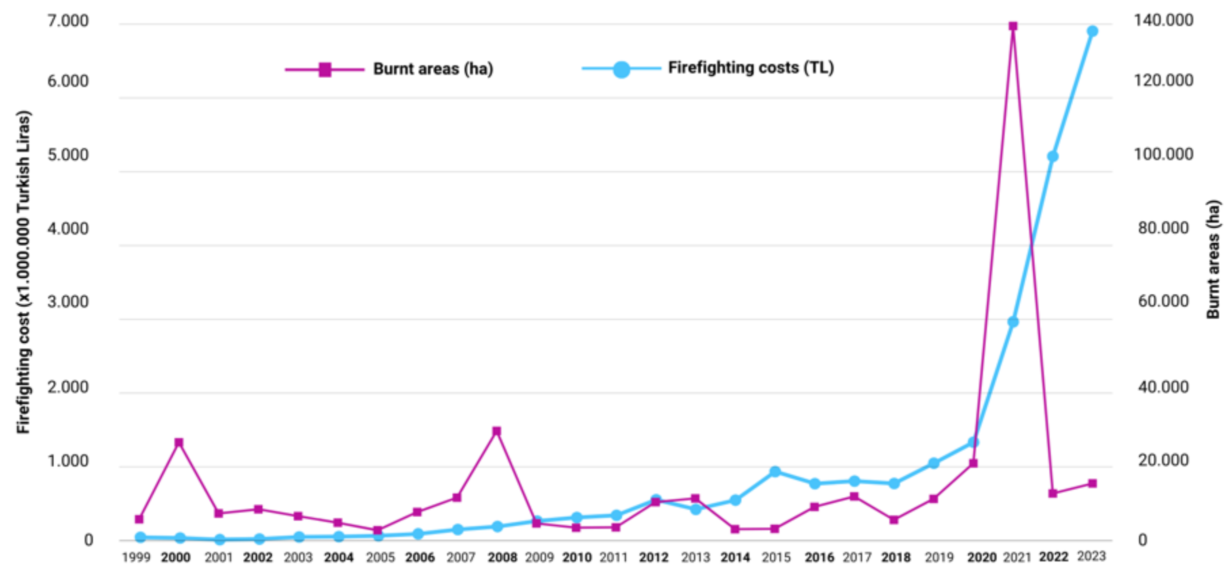
In Türkiye, the recording of fires started in 1937, with annual updates. The total number of fires recorded up to 2023 was 122,473, with a long-term average of 1,407 fires per year. However, in the last decade (2014-2023), the annual average number of fires was 2,568. The rising trend in the number of fires is evident in Figure 5, starting from the 1970s, although this increase is not reflected in the extent of areas burnt. In the period 1937 - 1958, an average of around 60,000 hectares was burnt per year, but this decreased significantly thereafter to an average of 10,000 hectares per year. The amount of areas burnt varied due to the severity of the fire season, but was always limited to a maximum of 40,000 hectares with the exception of 2021. In this year, most of the burnt areas were registered in less than one month. Almost half of the total burnt area was related to the major Manavgat fire that lasted for 10 days, burning a total area of 54,662 hectares (Figure 6).

Figure 6: Manavgat fire evolution from 29th July - 6th August 2021



In this period persistent dry winds blew across the western and southern coasts, which were partially covered by highly flammable forests and shrubs, thus explaining the extent of the impact. This experience proves that even when coping capacity is high - following the extensive investment made in Türkiye over the last 20 years (Figure 7) on prevention, firefighting and restoration - under extreme weather conditions, the entire system can collapse especially when there are concurrent active fires spreading over large areas of the country.

Figure 7: The cost of firefighting and total burnt areas by year in Türkiye



3.3 Type, causes, effects and parameters of forest fires

An analysis of the types of fires occurring in Western Balkans and Türkiye was conducted through specific questions (see Annex 1). The first classification distinguishes among three main typologies: ground, surface and crown fires (Figure 8).

For example, in the Republika of Sprska, the distribution of forest fires per typology from 2003 - 2020 is shown below.

Table 2: Distribution of forest fires per typology (2003-2020) for Republika of Sprska

YEAR	CROWN	SURFACE	UNDER-GROUND
2003	39	434	3
2004	2	88	0
2005	3	102	0
2006	1	82	1
2007	24	558	2
2008	4	152	2
2009	2	128	0
2010	1	78	0
2011	4	293	1
2012	23	517	6
2013	1	89	4
2014	0	83	0
2015	6	170	3
2016	1	116	0
2017	12	247	1
2018	3	42	0
2019	2	203	1
2020	9	317	0
∑	137	3699	24

Figure 8: Types of fires

It is evident that surface fires are the most frequent types of fires experienced. However, ground and crown fires, although less common, require large fire suppression efforts and are responsible for the highest impacts.

Another classification considers the environment in which the fire occurred, distinguishing among:

- wildfires and forest fire
- wildland urban interface (WUI) fire
- rural fire
- urban fire

For these fire types, the analysis conducted in Western Balkans and Türkiye tried to identify the main causes, effects and relevant parameters to use for fire risk assessment and mapping. Urban fires do not fall within the scope of this guideline.

Meeting in Begrade, Serbia, 2021

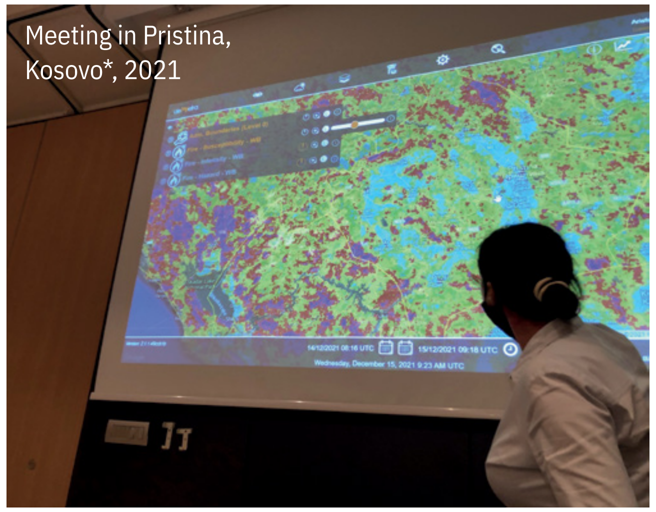
Table 3: Type of fires, causes, effects and parameters

TYPE OF FIRES	CAUSES OF FIRES	EFFECTS OF FIRES	RELEVANT PARAMETERS
Wildfire and Forest fire	Natural Deliberate/Arson Negligence • open fire • agricultural / pastoral Accident: • railroad • electric power	Damage to exposed elements (vegetation, ecosystem services) Plume emissions impacting health Loss of carbon sequestration Cascading effects: • soil erosion • flooding	Total burnt area Fire severity Fire intensity Rate of spread Probability of occurrence of crown fires Flammability Ecosystem services of vegetation
WUI	Natural Deliberate/Arson Negligence • open fire • agricultural / pastoral Accident: • railroad • electric power	Damage to exposed elements (population, infrastructures, buildings, vegetation, ecosystem services) Plume emissions impacting health	Fire severity Fire intensity Rate of spread Flammability Structural vulnerability of buildings Population density Traffic flows Tourism flows
Rural fire	Deliberate/Arson Negligence • open fire • agricultural / pastoral	Damage to exposed elements (crop and income from agriculture, vegetation, ecosystem services)	Total burnt area Fire severity Fire intensity Rate of spread Probability of occurrence of crown fires Flammability Ecosystem services of vegetation Agricultural production

For Kosovo* it is interesting to note how among the causes of fires, there are also technical-technological fires, caused during the development of technological processes/breakdowns, or from hazardous materials, landfills, etc.

Moreover, the problem of wildfire is exacerbated by the presence of landmines readily found throughout the Western Balkans, due to recent wars. This is a serious limitation for managing ground fire-fighting interventions that needs to be considered in WRA and mapping.

3.4 Authorities engaged in forest fire risk assessment Western Balkans and Türkiye


Meeting in Pristina, Kosovo*, 2021

The IPAFF programme commenced with a context analysis that helped identify the legal and institutional bodies responsible for forest fire risk assessment and mapping in Western Balkans and Türkiye. The table below shows how this managerial responsibility varies among the countries.

Table 4: Authorities engaged in forest fires risk assessment in Western Balkans and Türkiye

AUTHORITY TYPE	ALBANIA	BOSNIA-HERZE-GOVINA	KOSOVO*	MONTE-NEGRO	NORTH MACEDONIA	SERBIA	TÜRKIYE
Ministry of Interior, Civil Protection Authorities	AKMC		Emergency Management Agency			Sector for Emergency Management	AFAD
Ministry of Environment	PAKs						
Ministry of Agriculture, Forestry		Ministry of Agriculture, Forestry, Water				Department of Forestry	Directorate General of Forestry (DGF)
Forest Agencies and Companies		Public forest companies (R Srpska)	Kosovo* Forest Agency	Forest Administration of Montenegro	Public Enterprise National Forests (PENF)	State Enterprise “Srbijasume” Private	
State bodies					Crisis Management Centre (CMC)		
Natural Parks		National Parks (R Srpska)	Directorates of National Parks	Public Enterprise National Parks			
Regions, Provinces, Cantons	Prefectures	KSPD					Regional Directorates
Municipalities	Forest institutions		Directorates of Municipalities		Local self-governance units	Departments for Civil Protection	

3.5 Coping capacity to respond to forest fires

Forest fire vulnerability is influenced by the capacity of the authorities responsible for its suppression. To ascertain this capacity, an investigation was conducted measuring the availability of specific assets, using national sources provided by the partner countries. The following considerations were made:

1. availability of adequate numbers of fire-fighters: the number required is determined by the size of the territory, extension of WUI, extension of high hazard areas, available equipment, experience, training, fire-fighting protocols and procedures
2. capacity of early detection, mainly performed through watch towers. This can be improved by increasing the numbers of automatic thermal cameras that require advanced knowledge and infrastructure for effective data processing/ elaboration. The use of drones for early detection is still under exploited
3. availability of relevant information from partner countries: this is necessary to enable the formulation of specific considerations

Table 5: Coping capacity on forest fire management from each Partner

COPING CAPACITY ASSETS	AL [28,748 KM2]	FBIH [51.209 KM 2]	KOS [10,887 KM2]	ME [13,812KM2]	NM [25713KM2]	SER [88,500K2]	TK [783562KM2]
No. of fire-fighters	1295	1429 professional and volunteers (25 per unit extinguish 70% of fires in public forests)	802 serving in MPUs in state institutions	660	870 and 100 volunteers (fire-fighting ratio 1/1500 citizens)	3508	14586 plus 4110 technical staff 6435 officers 113000 volunteers
Surveillance points for early detection	24 hydro-meteorological monitoring stations	2 watch towers with cameras (which is insufficient as at least 50 more towers are needed)	In process through NFFIS in cooperation with Japan	During summer FAM engages additional staff to monitor the situation in forests	N/A	Enhanced monitoring in fire-prone areas	776 watchtowers and 162 thermal cameras
Available ground suppression resources	N/A	N/A	Fire-fighters in 34 locations Vehicles: 24 Commanders, 78 attackers, 21 technicians, 54 escorts, 40 mountain, 34 vehicles and 10 scale auto vehicles	46 specialized vehicles for extinguishing fires and for rescue operations and 62 other vehicles (command, transportation etc)	N/A	160 Fire and Rescue Units with 1318 vehicles of which: 1068 special fire-fighting vehicles, 118 other vehicles and 132 cargo trailers	1050 fire trucks 323 water supply vehicles 2285 first vehicles 188 bulldozers 501 other tools
Available aerial suppression resources	2 airports: Nene Tereza and Kukes	N/A	No capacity for own air intervention but assisted by KFOR	2 airports: Podgorica and Tivat	Recharging at airport and in artificial lakes	2 H-215 Super Puma helicopters 2 AB-212 helicopters 3 H-145 helicopters 2 Ka-32 helicopters	28 amphibian airplanes 55 water drop helicopters 8 UAV
Nr. of water supply points for aircraft operations	Lakes and reservoirs for helicopters	N/A	No supply points but 7 artificial lakes	Lakes and rivers	N/A	Depending on the location of the fire, different positions are utilized	4580 pools/ water reservoirs

04

Methodologies for forest fire risk mapping

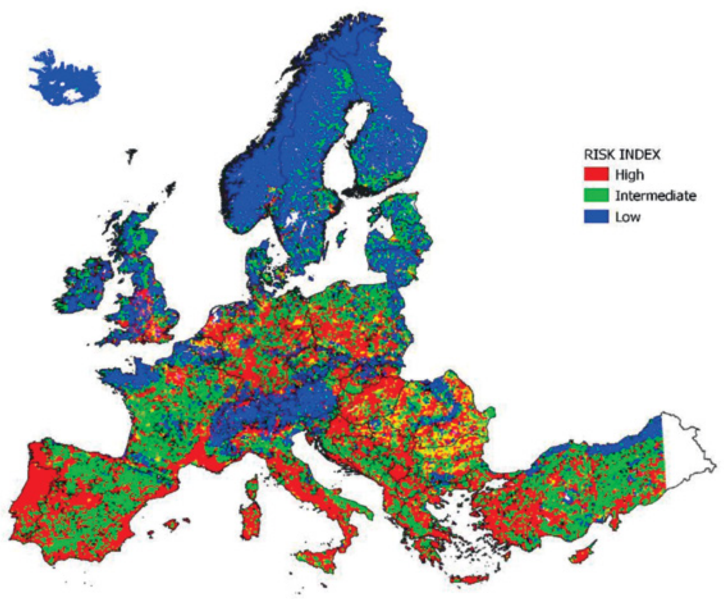
4.1 Different methodologies for forest fire risk mapping

Fire risk modelling is a tool to support forest protection plans and to address fuel management strategies to reduce the consequences of fire.[45] Risk and susceptibility analyses are mandatory for land use planning, civil protection and risk reduction programmes. Several techniques were recently developed using physically-based GIS integrated models. These rely on expert knowledge or include statistical analyses/ modelling to assess the importance of underlying factors.[46] Physical/ statistical and stochastic/ random approaches have been used, highlighting the benefits of data driven methods.[47]

The EC JRC in cooperation with other Commission services, and the Commission Expert Group on Forest Fires is developing the first pan-European prototype European WRA. The conceptualization of a European WRA as the combined impact of wildfires on people, ecosystems and goods illustrates the multiplicity of risk dimensions and sources of uncertainty. It already serves as an integrated framework for gathering Europe-wide experiences on fire management and risk, added to which will be the inter-comparison of WRA among countries. This will complement existing national WRA with a simpler but shared methodology.

The first wildfire risk map was generated as an index to summarize the combined effect of wildfire danger and vulnerability. An aggregated wildfire risk index is proposed, which prioritizes the risk for human lives, while also considering ecological and socioeconomic aspects. This is done by ranking as high-risk those areas where people may be exposed to wildfires, and secondarily where ecological and socioeconomic aspects are at stake. The format of the risk map identifies risk classes (from low to high) with a simple score ranging from 0 - 100 %, which are subsequently aggregated in three levels of risk: low, intermediate and high (Figure 9).

Figure 9: Final aggregated wildfire risk by pixel level indicates the prevalence of the (a) lower-risk class, (b) intermediate-risk class and (c) higher-risk class in each EURO-CORDEX spatial cell. The percentage based on the risk classification in each EURO- CORDEX cell of 100 equi-possible model aims to integrate the uncertainty sources. The map shows the RGB composition of risk classes (Red-High, Green-intermediate, Blue-Low) that is merely qualitatively illustrative of the main patterns in Europe (as the information in the three classes of risk a, b and c cannot be fully represented in a single aggregated view).



4.2 Forest fire risk methodologies currently used in Western Balkans and Türkiye

For each partner country, the following issues were explored:

- existing methodologies and processes for producing hazard and risk maps (emphasizing the difference among hazard, risk and damage assessment)
- available data from different sources (e.g. satellite, UAV, in-situ, cartographic, meteo)

Table 6: Type of methodology on forest fire risk assessment by Partner

METHODOLOGY	ALBANIA	BOSNIA-HERZEGOVINA	KOSOVO*	MONTENEGRO	NORTH MACEDONIA	SERBIA	TÜRKIYE
Type of methodology	Statistics (# fires, total BA)	AHP and GIS analysis	AHP and GIS analysis	AHP and GIS analysis	Statistics (# fires, total BA)	3508	14586 plus 4110 technical staff 6435 officers 113000 volunteers
AHP and GIS analysis	AHP and GIS analysis	2 watch towers with cameras (which is insufficient as at least 50 more towers are needed)	In process through NFFIS in cooperation with Japan	During summer FAM engages additional staff to monitor the situation in forests	N/A	Enhanced monitoring in fire-prone areas	776 watchtowers and 162 thermal cameras

The analysis revealed that most partners make use of GIS analysis, based on expert knowledge, in order to produce fire risk maps. In particular, it emerged that concepts pertaining to hazard, vulnerability and value of exposed assets are often unclear or overlapped.

Table 7: Details on forest fire risk maps from each Partner

PARTNER	ALBANIA	BOSNIA-HERZEGOVINA	KOSOVO*	MONTENEGRO	NORTH MACEDONIA	SERBIA	TÜRKIYE
Who makes the maps	National Civil Protection Agency	Public Company (RS) Part of a study (FBiH)	EMA and KFA	PENPM. IHMS (Drought vulnerability map)	Crisis Management. Centre (CMC)	Company in charge of forest management	- Forest management - General Directorate of Meteorology
Uses/ Purposes	Land management Fire danger and fire-risk forecasts Civil protection early warnings Prioritization of intervention and support to fire-fighting strategies Climate change impact scenarios	Land management strategies Support to fire-fighting strategies Activity planning	Fire danger and fire-risk forecasts Civil protection early warnings Prioritization of intervention Risk scenarios simulation Support to fire-fighting strategies	Land management strategies Fire danger and fire-risk forecasts Prioritization of intervention Risk scenarios simulation Shift of vegetation species	Land management strategies Fire danger and fire-risk forecasts For the Cadaster's needs, but if requested, for central agencies/ state and for LGUs. Prioritization of intervention Support to fire-fighting strategies Shift of vegetation species	Fire danger and fire-risk forecasts Support to fire-fighting strategies Shift of vegetation species	Land management strategies Fire danger and fire-risk forecasts Civil protection early warnings Activation of restrictions by laws Prioritization of intervention Risk scenarios simulation Support to fire-fighting strategies Climate change impact scenarios
Coverage	Total territory	Total territory	Total territory	Total territory	Total territory	Total territory (except private forests)	Total territory
Level/ Scale	National	Cadastral National 1:10,000 - 1:25000	National Local 1:10,000-1:25,000 1:250,000 in digital format	1:25.000 1:50.000 Drought 1: 300 000.	1:100,000 – CMC 1:10,000 CMC 1:5,000 Cadastre	National Regional Local	National Regional
Users/ Stake-holders	Municipalities and prefectures ASIG (defines standards/ rules for GIS) IGEO (issues the bulletin for Wildfire Risk on a daily basis)	Council of ministers Local, cantonal and entity Civil protection, Universities in Sarajevo, Mostar, Banja Luka	Kosovo* Cadastral Agency Municipality/ Cadastre directorate "Emergency Management Agency for disaster risk maps, KJA / Kosovo* Seismological Institute MESP for environment and water, Kosovo* Agency of Statistics"	PENPM	PRD and NF LGUs and local branches of PRD and CMC Faculty of forestry (analysis/ research and planning activities), MoEPP (development)	Company in charge of forest management	Forest management General Directorate of Meteorology

The investigation concluded that the methodology from ex-Yugoslavia provides the general framework for what is used in the Western Balkans. It was adopted almost in its entirety by Bosnia and Herzegovina, with the following gaps:

1. lack of up-to-date and reliable data at various geographical scales for several wildfire risk components that cannot be covered when using open data
2. methodology is mainly focused on forests as exposed elements without due consideration to anthropic elements and their vulnerability to fires
3. process for prioritizing risk is not based on evidence from past burnt areas

These gaps pose limitations to the application of the methodology to the entire Western Balkan region.

Concerning Türkiye, the methodology for wildfire risk mapping focuses on a statistical analysis of the number of fires and burnt areas at administrative level (e.g. municipalities, provinces). While this can support strategic planning for enhancing fire-fighting capacities at national or regional level, it does not permit the identification of local scale priorities, such as vulnerable exposed elements in proximity to higher hazard areas.

4.2.1 Forest fire risk mapping methodology in Bosnia and Herzegovina

Forest fire risk is defined on a regular grid (through cells) or at cadastral level (through parcels), where each cell or parcel is considered homogeneous in terms of several pre-defined parameters. For each parameter a different value is assigned, considering a priori knowledge of the phenomena.

The following parameters are considered:

1. vegetation: forest vegetation is grouped as conifers, deciduous and mixed trees. To evaluate a proxy of potential damages for each group, the following measures are examined: origin and age of the forest, status of management, cultivation form, and purpose. Shrubs, maquis and garigue, are considered as additional classes characterized as very susceptible to forest fires but low value in terms of potential damage. Vegetation grown as plantations, artificially raised, with agro-technic applications were singled out as special categories regardless of age
2. anthropogenic factors: most forest fires are directly or indirectly related to human activity (anthropogenic factors), so this parameter represents a proxy of the cause of ignition adopting three categories, each with a different score
3. climate: average annual air temperature, total precipitation and average relative humidity are examined
4. soil type: special parameter that affects the degree of forest fire danger, as it depends on the dead fuel moisture content (needles, leaves, branches, stumps, etc.) and the live fuel moisture content which is also related to the type of soil
5. topography: intensity and duration of insulation affects fuel moisture dynamics and differs according to the exposure and slope. Altitude is also considered
6. forest management: directly affects the degree of risk of forest fire, as forests with no management contain a greater amount of fuel, and thus are an increased fire hazard

The risk class is determined by the sum of partial scores versus the parameter under consideration. The whole territory, based on the sum of the partial scores, can be classified into four (Federation of Bosnia and Herzegovina) or five (Republika of Sprska) risk classes, as follows:

Table 8: Tabular representation of the risk classes showing the total score P_i for both the Federation of Bosnia and Herzegovina (FBiH) and the Republika Srpska (RS)

RISK CLASSES	DESCRIPTION	TOTAL SCORE
I	very high	> 480
II	high	381 – 480
III	medium-moderate	281 – 380
IV	low	< 280

(a) Federation of Bosnia and Herzegovina

RISK CLASSES	DESCRIPTION	TOTAL SCORE
I	very high	>480
II	high	381-480
III	medium-moderate	281-380
IV	low	150-280
V	very low	<150

(b) Republika Srpska (RS)

This approach can be summarized as follows:
Let "i" be the i-th pixel of the raster (regular grid), or the i-th homogeneous parcel, where the risk is computed. For each i-th element, all the different parameters, which characterize a location, contribute to the computation of a total risk score P_i. In particular, each of these partial scores is computed via ad-hoc tables expressed as follows:

P_i= P_veg (veg_i)+ P_an (an_i)+P_c (c_i) +P_so (so_i) +P_oro (oro_i) + P_man (man_i)

Where P_i is the risk score (positive integer value) assigned to each pixel; P_veg is the function that assigns a risk score estimation (integer and positive number) to the vegetation cover of the "i-th" pixel vegi; Pan is the function which assigns a risk score estimate to the anthropogenic factors ani evaluated on the I; Pc is the function which assigns a risk score estimate to the climatic factors ciman_i evaluated in the pixel; Pso is the function which assigns a risk score estimate to the soil variables soi; Poro is the function which assigns a risk score estimate to the orographic variables oroi; Pman is the function which assigns a risk score estimate given the different forest management situation in the selected pixel man i. Finally, the risk class on the pixel is a function of the cumulated value P_i expressed by Table 9 and Table 10 (a-e), which assign the obtained value of P_i to a certain degree of forest fire risk. It is an integer value that may range from 1 - 4 or from 1 - 5 depending on the selected thresholds and subdivisions of the cumulated risk points.

This approach clearly considers a comprehensive set of factors that infringe on the risk of forest fire in a specific area. Many of these factors are the exposed assets (plantations); others refer to contributions to the hazard, such as the main drivers of forest fire propagation (aspect, slope and forest type) and factors related to ignition (tourism, power lines, roads). However, they all contribute to the overall risk estimation, regardless of the subdivision among hazard, exposure and risk.

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The following table illustrates the score for each parameter.

Table 9: Score for each parameter considered in the risk index

VEGETATION CLASS	VEGETATION TYPE	ORIGIN	AGE [YEARS]	SCORE
Coniferous	Heliophilous	Plantation		200
		Natural	<30	200
			31-60	180
			>60	160
	Shade tolerant	Natural	<30	160
			31-60	
			>60	120
Mixed forests	Heliophilous	Plantation		180
		Natural	<30	180
			31-60	160
			>60	140
	Shade tolerant	Natural	<30	120
			31-60	100
			>60	80
Deciduous	Heliophilous	Plantation		120
		Natural	Degraded	80a
			31-60	100
			>60	80
	Shade tolerant	Natural	Degraded	80
			<30	80
			31-60	60
			>60	
Maquis and Garrigue		Natural		200
Shrubs		Natural		160
Unforested forest land		Natural		80

Below the vegetation classes and types are described:

- crops and plantations are artificially grown forests and, regardless of their age, are subject to high risk
- coniferous forests are characterised by a minimum of 90% of coniferous tree species
- heliophilous coniferous forests are dominated by pine, cypress, larch and other coniferous species
- shade tolerant coniferous forests are dominated by fir, spruce, yew and other shade tolerant species
- mixed forests are characterised by a minimum of 10% of each coniferous and deciduous tree species
- heliophilous mixed forests are predominantly composed of heliophilous coniferous and deciduous forests
- shade tolerant mixed forests are populated by predominantly coniferous and deciduous shade tolerant tree species
- deciduous forests are characterised by a minimum of 90% of deciduous tree species
- heliophilous deciduous forests are dominated by oak, alder, birch and other types of heliophilous species
- shade tolerant deciduous forests are dominated by beech, hornbeam, elm and other shade tolerant species
- perennial forests are classified by the age class 31 - 60 years - according to the type of forest
- macchia are areas covered by evergreen tree species in which stump trees predominate;
- garigue is a degraded maquis or maquis without trees
- shrub is considered a forest area in which there are over 50% of bushy remnants of forest trees and shrubs

Table 10: Factors used in the risk assessment methodology

	CATEGORY	PURPOSE OF THE FOREST	SCORE
2.1.	1	Tourist recreation, national parks and reserves, forests located near landfill and agricultural land	60
2.2.	2	Containing public roads or transmission lines or grazing land	40
2.3.	3	Used for forest by-products, hunting, fishing, land reclamation and breeding works	20

(a) Anthropogenic factors

		SCORE
3.1 Average annual air temperature		
3.1.1	Above 11oC	30
3.1.2	7.1 - 11 o C	20
3.1.3	Up to 7.0 o C	10
3.2 Average annual rainfall		
3.2.1	Up to 700 mm	30
3.2.2	701 - 1200 mm	20
3.2.3	Above 1200 mm	10
3.3 Average annual relative humidity		
3.3.1	Up to 70%	30
3.3.2	71 - 80%	20
3.3.3	Above 80%	10

(b) Climate parameters

	CATEGORY		SCORE
4.1	I	Moving sands	80
4.2			
4.2.1	II	Dolomite and sailing limestone	60
4.2.2		Acid eruptive rocks (granite, syenite, trachyte, rhyolite, etc.)	
4.2.3		Basic eruptive rocks (gabor, basalite, periodite, senpentinite, etc.)	
4.2.4		Wood (flag)	40
4.2.5		Lake sediments	
4.3			
4.3.1	III	Dolomite and limestone	40
4.3.2		Acidic eruptive rocks	
4.3.3		Basic eruptive rocks	
4.3.4		Wood and lake sediments	
4.4			
4.4.1	IV	Acid silicate rocks (gneiss, phyllites, shales, etc.)	20
4.4.2		Clays and clay materials (pleistocene and pliocene)	20
4.4.3		Fluvial and fluviglicial materials, partly aeolian material (wetland)	20

(c) Habitat (parent substrate and soil type)

	OROGRAPHIC PARAMETERS	SCORE
5.1 Exposure		
5.1.1	Southern and plain	20
5.1.2	East and West	10
3.1.3	North	5
5.2 Elevation		
5.2.1	Up to 400 m (500)	15
5.2.2	401-800 m (501 – 800)	10
5.2.3	Above 800 m	5
5.3 Slope		
5.3.1	Greater than 40 o (45 o)	15
5.3.2	31 o - 40 o (45 o)	10
5.3.3	15 o - 30o	5

(d) Orography

	OROGRAPHIC PARAMETERS	SCORE
6.1	Managed	40
6.2	Partly managed	20
6.3	Unmanaged	10

(e) Forest management and landscaped stands

Forest management is classified as follows.

- managed: forests with fire-fighting facilitation such as roads /or access roads where cleaning and pruning is done as well as thinning and reduction of ground combustible materials
- partially managed: forests in which some of the above measures are implemented
- unmanaged: forests in which none of the above measures are implemented

Overview maps indicating forests according to their degree of fire risk must be at a scale of 1:25,000 or more.
The methodology described above concerns forest management, without consideration of other processes or the potential impact of wildfires. Lack of local information on forest management inhibits the application of such a methodology on a regional basis.

4.3 Machine-learning approach for wildfire risk mapping

To enhance wildfire risk mapping capabilities, an innovative mapping methodology based on the Machine-Learning (ML) approach is provided.

The methodology comprises the following:

1. risk mapping based on evidence from past burnt areas
2. consideration given to open data, used in susceptibility mapping and identification/ characterization of exposed elements
3. climate data for risk assessment used in present climate situations as well as for forecasting future climate scenarios
4. definition of fuel maps for fire propagation simulation and improvement of early warning systems for intermediate and complementary results

Definitions:
Wildfire risk is defined as the likelihood that a wildfire, characterized by a certain level of intensity, can affect specific assets or harm the population. Generally, the risk equation can be modelled as follows:

$$R = H * V * E / C$$

Where H is the wildfire hazard that, in turn, is defined as:

$$H = f(S, FT)$$

Where S is the wildfire susceptibility and FT is the fuel type map.
And returning to the first equation, where V is the vulnerability associated with the exposed elements; E is the exposure; and C is the coping capacity.

4.3.1 Wildfire susceptibility

The wildfire susceptibility map is the first item assessed in the risk assessment procedure and is defined as the static probability of experiencing wildfires in a certain area, depending on the intrinsic characteristics of the terrain. This can be achieved by adopting approaches, ranging from statistical hierarchical to ML-based algorithms. For example, ML techniques can be used by training a model to cross information on past wildfires with geo-physical and climatic descriptors collected for each of the countries. The spatial domain of the analysis can vary from local to national and supranational level. This chapter focuses on the national, however the procedure can be replicated at different levels. Fire perimeters at national level will be used to train the algorithm in order to identify correlations between fire occurrence and fire regimes with topographic, climatic and socio-economic conditions. The Random Forest (RF) Classifier algorithm is proposed for this type of analysis, due to its proven performance on testing datasets. Being an ensemble model, it can combine predictions of multiple decision models providing a continuous output between 0 and 1 instead of an integer value that is associated with a single cell of the study area. As a result, the susceptibility map expresses the tendency for an area to experience wildfires rather than a probability in a strict mathematical sense. This is preferred as it identifies the main territorial characteristics that influence a fire's susceptibility to spread following its ignition.

The susceptibility map is valid for present climate and land cover conditions, and therefore it is not related with a specific timeframe, but is considered static as the conditions remain the same.
The dataset for training the ML model includes a set of cells (pixels), the size of which depends on the spatial resolution of the analysis, sampled from the entire study area. Every cell has a set of variables, called 'features', corresponding to the main topographic and climatic input selected for the analysis. The greater the number of features relating to wildfire behaviour inputted into the model the more accurate the outcome. Another input involves the dataset of historically burnt areas from which the algorithm identifies relations with other variables, ultimately predicting the areas affected by fire, and expressing the likelihood of its occurrence.
Table 11 is an example of features included in a dataset for national wildfire susceptibility assessment.

Table 11: List of features included in the Machine Learning Model

FEATURES	TYPE OF VARIABLE	SOURCE
Historical burned area	Wildfires	EFFIS
Land cover map	Land cover	COPERNICUS (CORINE 2018)
Digital elevation model	Topographic	MERIT DEM
Slope	Topographic	MERIT DEM
Aspect (north and east-facing)	Topographic	MERIT DEM
Average of annual cumulative precipitation (climate variable)	Climate	COPERNICUS (climate data store)
Average temperature	Climate	COPERNICUS (climate data store)
Number of consecutive dry days	Climate	COPERNICUS (climate data store)
Average relative humidity	Climate	COPERNICUS (climate data store)

Susceptibility is categorized in three classes of likelihood: low, medium and high. The thresholds to define such classes are set at national level computing the 25th and 75th percentiles of the susceptibility values. Based on observations over the past 30 years of fire occurrences from regional[48], national[49] and continental[50] levels, with sufficient degrees of heterogeneity (climatic, vegetational, topographic), the majority of burnt areas are found in 25% of the territory characterized by the highest values of susceptibility. In these areas, under extreme weather conditions the spreading of a fire is essentially uncontrollable, even in cases of high coping capacities. On the other hand, it is possible to classify 25% of a territory where no fires are expected. The remaining territory can be considered affected by a wildfire regime where most fires can be controlled, even under extreme weather conditions

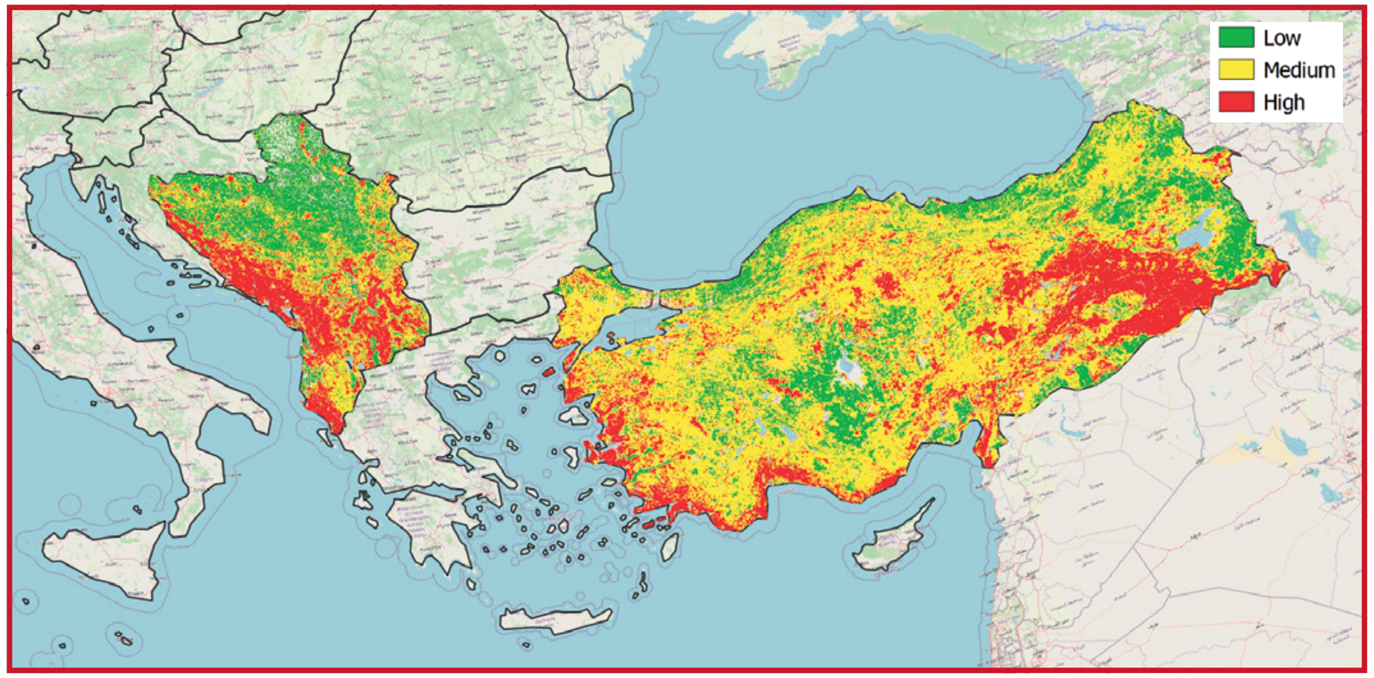


Figure 10: Wildfire susceptibility map of western Balkans (including Albania, Serbia, Bosnia and Herzegovina, Montenegro, Kosovo*, North Macedonia) and Türkiye using a machine learning approach

4.3.2 Wildfire hazard

Wildfire hazard considers the susceptibility map and accessory land cover data to define a fire's likelihood of occurence and its potential behaviour. One method to draw up a hazard map is to combine the categorized wildfire susceptibility with the fuel type map by means of a contingency matrix.
Fuel type maps can be defined from common land cover/ land use maps. Four fuel types are listed (Table 12), so as to identify the potential behaviour of the fire given the land cover characteristics.

Table 12: Fuel type classification and association with the potential intensity

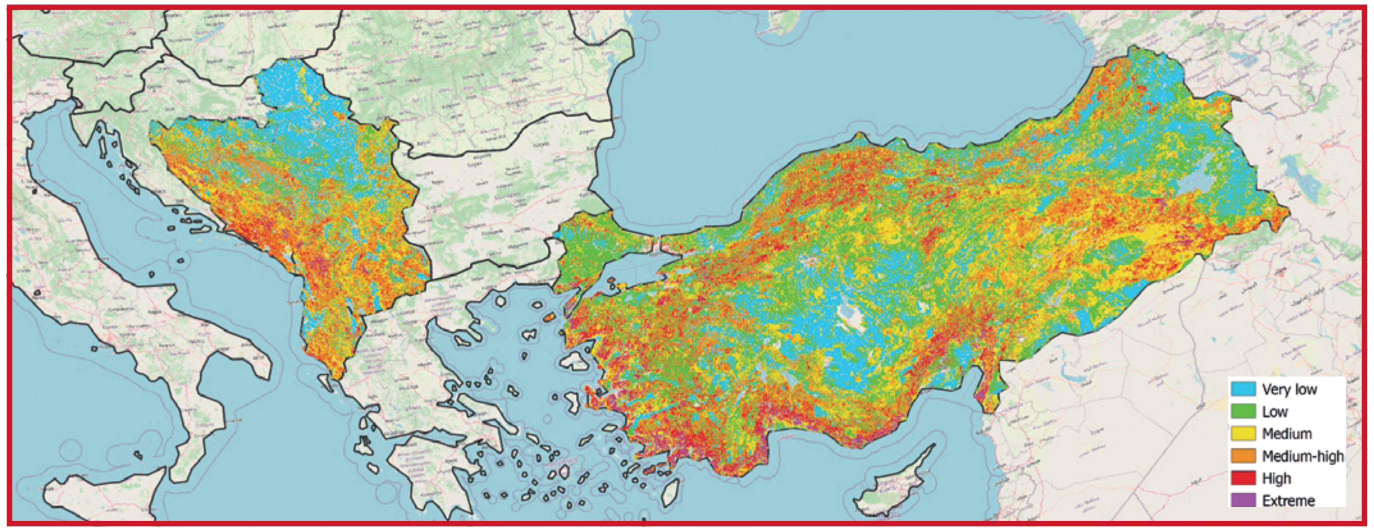
FUEL TYPE	DESCRIPTION OF FIRE BEHAVIOUR
Grassland and cropland	LOW maximum potential intensity
Low flammable forest	MEDIUM maximum potential intensity, forests composed mainly by broadleaves
Shrub-land	HIGH maximum potential intensity
High flammable forest	VERY HIGH maximum potential intensity characterized by crown fires with forests composed mainly of coniferous trees

Figure 11: Contingency matrix for defining the wildfire hazard levels

SUSCEPTIBILITY /FUEL	GRASSLAND	LOW FLAMMABLE FOREST	SHRUB	FUEL TYPE
Low susceptibility	Very low	Low	Medium	Medium-High
Med susceptibility	Low	Medium	Medium-High	High
High susceptibility	Medium	Medium-High	High	Extreme

Adopting the above approach, a wildfire hazard map for Western Balkans and Türkiye is presented below (Figure 12).

Figure 12: Wildfire hazard using a contingency matrix approach between wildfire susceptibility and fuel type map



The extent of each hazard class provides useful information on which country is most likely to be affected by high intensity forest fire events.

As illustrated above, Türkiye, Albania, Bosnia and Herzegovina and Montenegro contain the greatest amount of high and extreme hazard areas, while Kosovo* and Serbia have the lowest land coverage with extreme hazard levels.

Table 13: Extent of each hazard class per country in km2

HAZARD	VERY LOW	LOW	MEDIUM	MEDIUM -HIGH	HIGH	EXTREME
AL	2303	3971	7677	6387	5575	894
BiH	10307	11705	11230	10110	5358	545
KOS	1309	2381	3209	2346	1049	91
ME	316	1229	2835	4406	3283	478
SER	35039	16719	11737	6609	2904	178
NMK	1994	4090	8086	4978	4200	251
TK	112061	263938	168481	93802	88529	14866

4.3.3 Risk assessment – elements at risk and vulnerability

Risk is the combination of both the hazard and exposed elements that could be affected by a wildfire event, producing a loss. The link between hazard and loss of an exposed asset (or element-at-risk - EaR) is known as vulnerability.

Different types of vulnerability can be defined, as follows:

- physical: potential impact on the physical environment, expressed as EaR. The degree of loss to a given EaR (or set of EaRs) resulting from the occurrence of a natural phenomenon of a given magnitude is expressed on a scale from 0 (no damage) to 1 (total damage)
- economic: potential impact on economic assets and processes (i.e. business interruption, or secondary effects such as increased poverty and job loss)
- social: potential impact on vulnerable groups such as the poor, disabled, children, and elderly. This is highly correlated with the public awareness of risk, possibility to conduct self-coping actions, and organization of fire-wise communities adopting resilient wildfire risk behaviours
- environmental: potential impact on the environment (flora, fauna, ecosystem services, biodiversity)

In addition, losses can be classified as direct or indirect as shown below:

Table 14: Examples of direct and indirect losses across different categories of vulnerability

	HUMAN - SOCIAL	PHYSICAL	ECONOMIC	CULTURAL ENVIRONMENTAL
Direct losses	• Fatalities • Injuries • Loss of income of employment • Homelessness	• Structural damage or collapse of buildings • Non-structural damage and damage to contents • Structural damage infrastructure	• Interruption of business due to damage to buildings and infrastructure • Loss of productive workforce through fatalities, injuries and relief efforts • Capital costs of response and relief	• Sedimentation • Pollution • Endangered species • Destruction of ecological zones • Destruction of cultural heritage
Indirect losses	• Diseases • Permanent disability • Psychological impact • Loss of social cohesion due to disruption of community • Political unrest	• Progressive deterioration of damaged buildings and infrastructure which are not repaired	• Economic losses due to short term disruption of activities • Long term economic losses • Insurance losses weakening the insurance market • Less investments • Capital costs of repair • Reduction in tourism	• Loss of biodiversity • Loss of cultural diversity

A comprehensive and systemic approach to vulnerability should be able to assess the impact of wildfires on each element considering the four classes of vulnerability listed above and their interrelation. This can result in a complex analysis that requires data on the exposed elements at local scale and an evaluation of potential impacts using different approaches and methods. This guideline focuses on direct losses and physical vulnerability, including the number of people exposed. The extension to other types of vulnerability and indirect losses can be included if local data is availed. Vulnerability functions correlating the degree of damage with each level of hazard have been defined. The hazard is considered as the maximum intensity that a fire can generate in the specific vegetation representing the worst-case scenario. This guideline aims at identifying priorities for planning purposes and not at evaluating risk according to weather dynamics.

EaR can be subdivided into categories (asset), such as healthcare and educational facilities, commercial or residential structure, roads infrastructure, population and forests. Each category has its own characteristics (physical, structural, etc.) and can be impacted in different ways even with fires showing the same level of severity. This implies the use of different vulnerability functions according to the asset.
The vulnerability can be represented as a curve or discretized in a matrix. This guideline adopts a matrix linking the degree of damage (shown as a percentage) to a specific hazard class (representing the wildfire severity).

Table 15: Example of vulnerability table for physical infrastructure

HAZARD LEVEL	POTENTIAL DAMAGE [%]
1 (Very Low)	0
2 (Low)	0
3 (Medium)	10
4 (Medium-High)	20
5 (High)	30
6 (Extreme)	50

Each category or asset includes a set of elements. The national level assessment defines a unique function for all the elements of a category as opposed to the local level analyses that includes more specific information on the structure. With a detailed structure, it is possible to assign the appropriate vulnerability function to a single element. At national level due to the scarcity of information on the type of structure, a more general analysis is made, which can be applied to a wider domain.

The exposure term defined in the risk equation, beyond identifying the main categories at risk, includes a weight for each specific asset or an economic value. If an economic value is estimated, the data can be used to assess potential losses. If no value is defined, a weight indicating the category's importance should be attributed so as to prioritise what to protect in case of a fire event.

Table 16: Example of categories with its weight from 0 (not relevant) to 100 (very relevant)

EXPOSED ELEMENTS (ASSETS)	IMPORTANCE WEIGHT [0 - 100]
Education	100
Healthcare	100
Commercial	90
Crops	90
Conifers	90
Broadleaves	80
Primary roads	70
Secondary roads	60
Tertiary roads	50
Shrubs	50

Finally, a potential damage map is assessed for each asset. These maps will be categorized at different risk levels based on pre-defined thresholds of potential losses. Since the data type and geometry associated with each EaR can vary, specific risk maps are defined: for spatially distributed grid assets, risk maps can be provided with or without levels of aggregation (i.e. municipal administrative unit). Ultimately, to indicate linear assets a level of risk could be directly associated to each element.

4.3.4 Technical methodology to assess the wildfire risk index: a working example

A technical procedure on how to evaluate the risk index for a set of exposure elements is presented using a computed hazard map. It aims at providing a methodological approach to build a wildfire risk index for a set of exposed elements at national scale. The identified assets used in this section are listed in Table 17.

(Currently, given the lack of available spatial information, the IT tool delivered by the IPAFF WP 2.1 is still unable to produce a risk map to show coping capacity.)

Table 17: List of categories of exposed elements used in the risk assessment methodology

ASSET	SOURCE
Healthcare facilities	OpenStreetMap points of interest
Education facilities	OpenStreetMap points of interest
Commercial buildings	OpenStreetMap points of interest
Primary roads	OpenStreetMap roads network
Secondary roads	OpenStreetMap roads network
Conifer forests	CORINE 2018 land cover map
Croplands	CORINE 2018 land cover map
Broadleaved forest	CORINE 2018 land cover map
Shrubland	CORINE 2018 land cover map
Population	Global Human Settlements/ World Pop
Wildland Urban Interface	CORINE 2018 land cover map

4.3.5 Risk index for point data

A methodology for assessing the wildfire risk index for assets characterized by / assimilated to a point geometry (buildings, critical infrastructure, etc.) is presented. OpenStreetMap (OSM) offers a set of open data that suits rapid national risk assessment studies. In the working example above, geo-referenced points of interest (POI) from OSM have been used to assess the risk index. However, residential buildings, present in the OSM database, can improve the analysis.

The POIs include a set of geo-referenced infrastructure belonging to several categories. These filter out some elements, and group specific categories into macro classes, as shown in Table 17. For instance, healthcare facilities encompass the following OSM categories:

- hospitals
- clinics
- nursing homes

Once a macro category has been defined, the geometry is converted from polygon to a central point of the mapped area for each building. This operation insures that all infrastructure falls within a single cell of the hazard grid.

A spatial intersection between the buildings and hazard map is applied attributing the maximum hazard value in a spatial window of ~200 m (depending on the working resolution) around the specific infrastructure. This is a conservative choice and considers the maximum impact expected on the exposed element. Once a hazard level is attributed to each element, the vulnerability function is applied, thereby defining the relation between the hazard class and the degree of potential damage in percentage (Table 15 above).

The potential damage value is then calculated by multiplying the degree of damage by the weight (or economic value) of each element. This is defined as the maximum level of damage that a specific infrastructure can suffer, and is shown as follows.

$$D_{i,j} = V_j * E_j$$

Where D is the potential damage related to the building i of the asset j, V is the vulnerability function for the category j and E is the exposure term, representing the weight or the economic value of the category j.

While the weight is representative for the whole category, the economic values can be modified so as to assign a different value for each element (building) belonging to the same category. After the computation, a potential damage value is attributed to the point elements. This procedure is replicated for each asset extracted from the POI layer. Finally all categories are merged to have a unique set of infrastructures with their levels of damage assigned.

A risk index can be derived applying common damage thresholds to each element (Table 18).

Table 18: Thresholds to categorize the potential damage map

RISK LEVEL	DAMAGE THRESHOLDS [0 - 100]
Low	< 25
Medium	25 < x < 50
High	50 < x < 75
Very High	> 75

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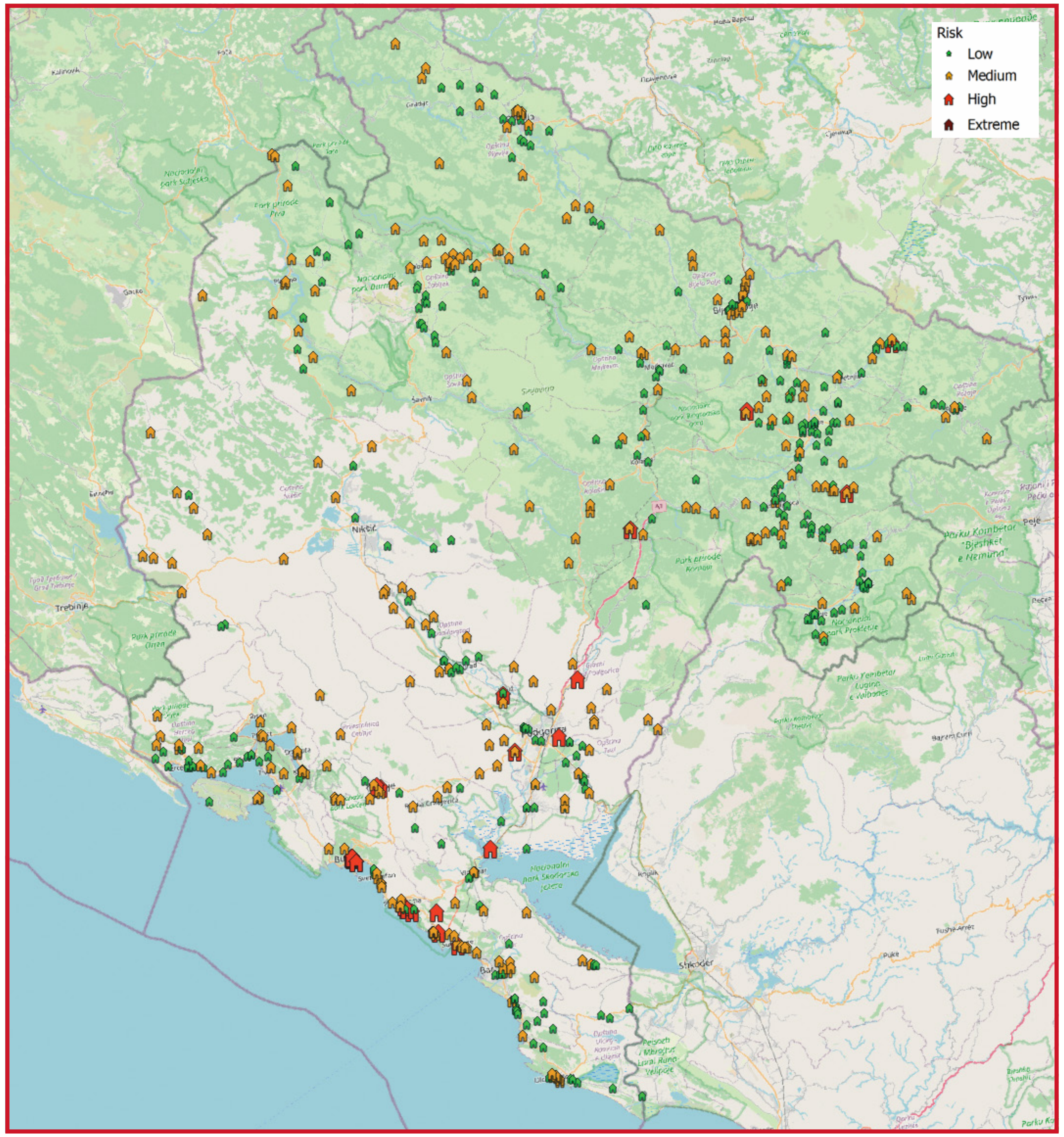
Below is a risk map indicating POI extracted from the OSM database for Montenegro (Figure 13).

Figure 13: Example of wildfire risk index for point of interest extracted from OpenSreetMap database in Montenegro



4.3.6 Risk index for gridded data

The risk index can be computed with a methodology using gridded data. Gridded distributed data and polygon geometries are treated using the same methodology; thus polygon assets have been rasterized in order to be able to compute the risk level at the resolution of the hazard map.

Environmental risk index

In the set of exposed elements (Table 17) the vegetation categories are identified as polygon layers as the input source is the shapefile of CORINE land cover. With this procedure, within the same vegetation type, the risk level can vary depending on the hazard defined by the homogeneous vegetated area. For each type of vegetation in the set of exposed elements a gridded data is produced, representing the exposed element.

The main steps required to produce the damage map are summed up as follows:

- multiply the raster of vegetation category by its weight or economic value obtaining an exposure map
- apply a spatial window (average moving window) of ~1km diameter to the hazard map to include the surrounding areas for each vegetation class
- apply the vulnerability function pixel by pixel to the processed hazard map to get the degree of damage raster
- multiply the exposure map by the degree of damage to obtain the potential damage map
- apply the thresholds (specified in the previous section) to assess the wildfire risk index of the specific vegetation type
- merge the risk indices for the different vegetation types to obtain the environmental risk index

In this case, vulnerability functions are represented by a table with three levels of damage, from less affected to totally destroyed.

Table 19: Vulnerability matrix for conifer forests

CONIFEROUS FOREST	
HAZARD LEVEL	**POTENTIAL DAMAGE [%]**
1 (Very Low)	0
2 (Low)	0
3 (Medium)	0
4 (Medium-High)	10
5 (High)	50
6 (Extreme)	100

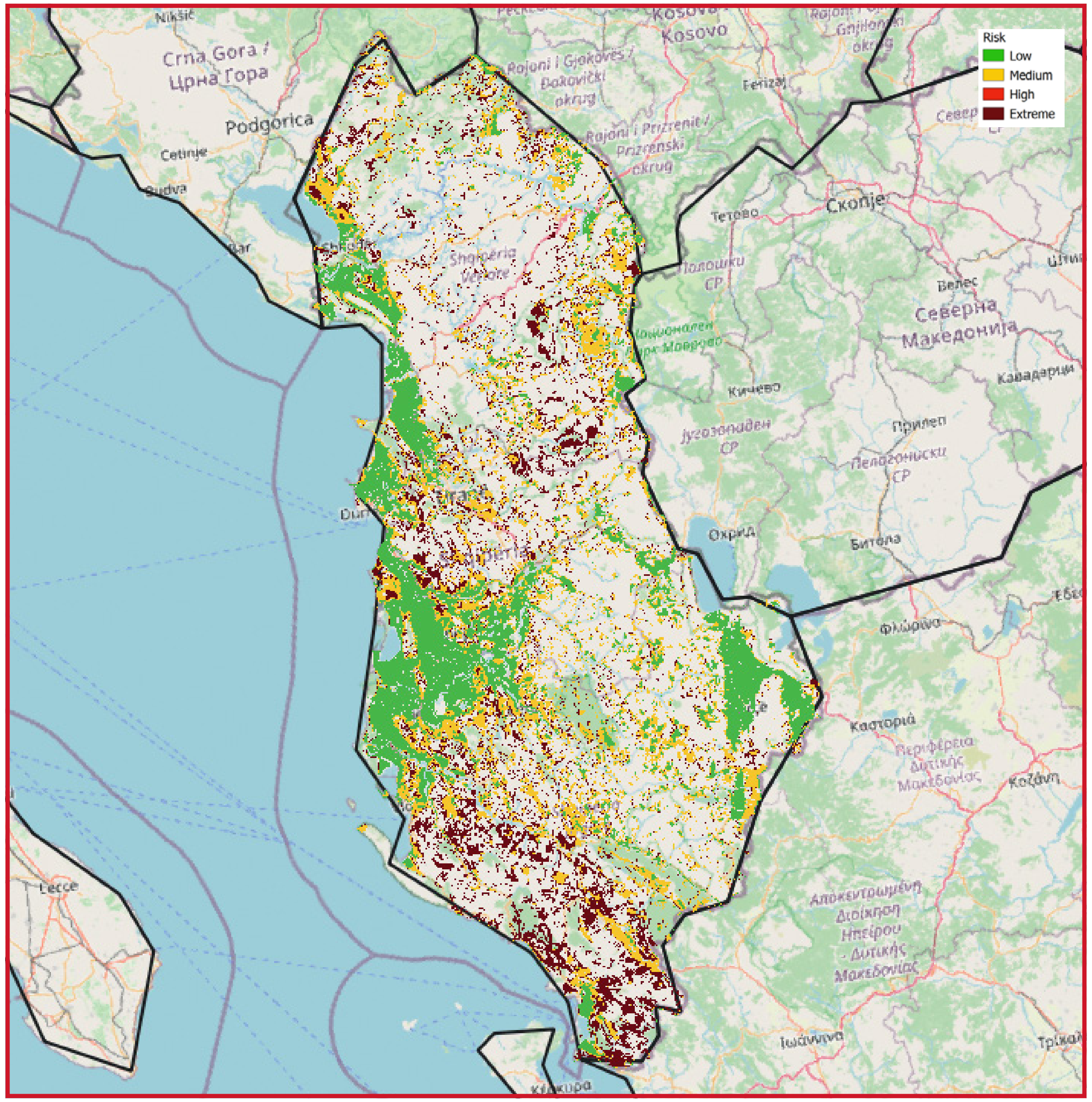
From the damage levels it is possible to see that coniferous forests are not affected below hazard level 4, while they would be partially destroyed with a hazard 5 event and totally destroyed after an event of extreme severity (hazard class 6).

Table 20: Vulnerability matrix for crops and grasslands

CROPLANDS AND GRASSLAND	
HAZARD LEVEL	**POTENTIAL DAMAGE [%]**
1 (Very Low)	10
2 (Low)	50
3 (Medium)	100
4 (Medium-High)	100
5 (High)	100
6 (Extreme)	100

The vulnerability table for croplands and grasslands indicate how exposed elements can be affected even by low hazard levels. For this reason, a certain percentage of damage is considered for very low and low hazard and is assumed to be totally destroyed by the impact of fire from medium to extreme hazard levels. Figure 14 shows the wildfire risk index in Albania agricultural and grassland areas.

Figure 14: Wildfire risk in agricultural and grassland areas in Albania.



Population risk index

Population data can be spatially distributed on the grid, and refer to population density as 1 km2 cells. Vulnerability functions are not defined at an individual level, but as the number of persons potentially affected by severe wildfires. In order to compute this index, a contingency matrix is applied combining the number of people and hazard classes.

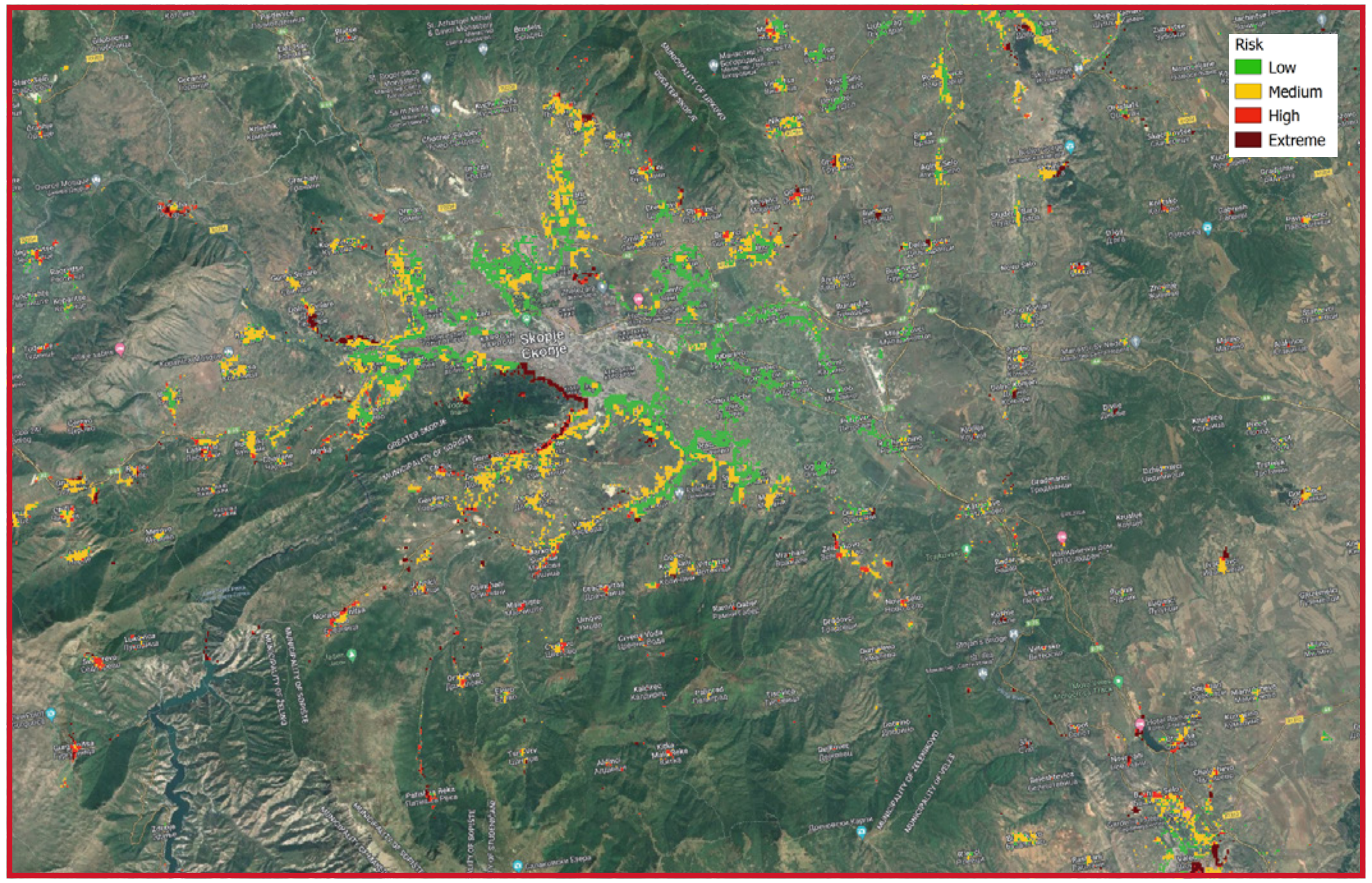
As a first step, the population density has been categorized in four classes from low to very high, after which the risk index has been assessed using the contingency matrix in Figure 15.

Figure 15: Contingency matrix indicating hazard level versus population density to retrieve the population at risk

RISK INDEX FOR POPULATION DENSITY			POP [NUM/KM2] POP [NUM/KM2]			
			10-500	500-1500	1500-3000	>3000
			1 LOW	2 MEDIUM	3 HIGH	4 VERY HIGH
Hazard	Very Low	1	1	1	1	1
	Low	2	1	1	2	2
	Medium	3	1	2	3	3
	Medium-High	4	2	3	3	4
	High	5	3	4	4	4
	Very High	6	4	4	4	4

Below Figure 16 shows the population exposed to wildfire risk in Skopje.

Figure 16: Population at risk in Skopje, North Macedonia, and surroundings. The risk is null if the hazard level has not been defined (not burnable areas) or where population density levels are too low (<10/km2).



Urban interface risk index

The WUI plays a critical role in WRA and management. The WUI refers to the area where homes and other human development encounter wildlands or vegetative fuels. Since at national level it is not possible to characterize structures present in this interface, a vulnerability function has not been adopted. The aim is to identify a risk level where the WUI is calculated according to the hazard assessment. The process to retrieve the WUI is as follows:

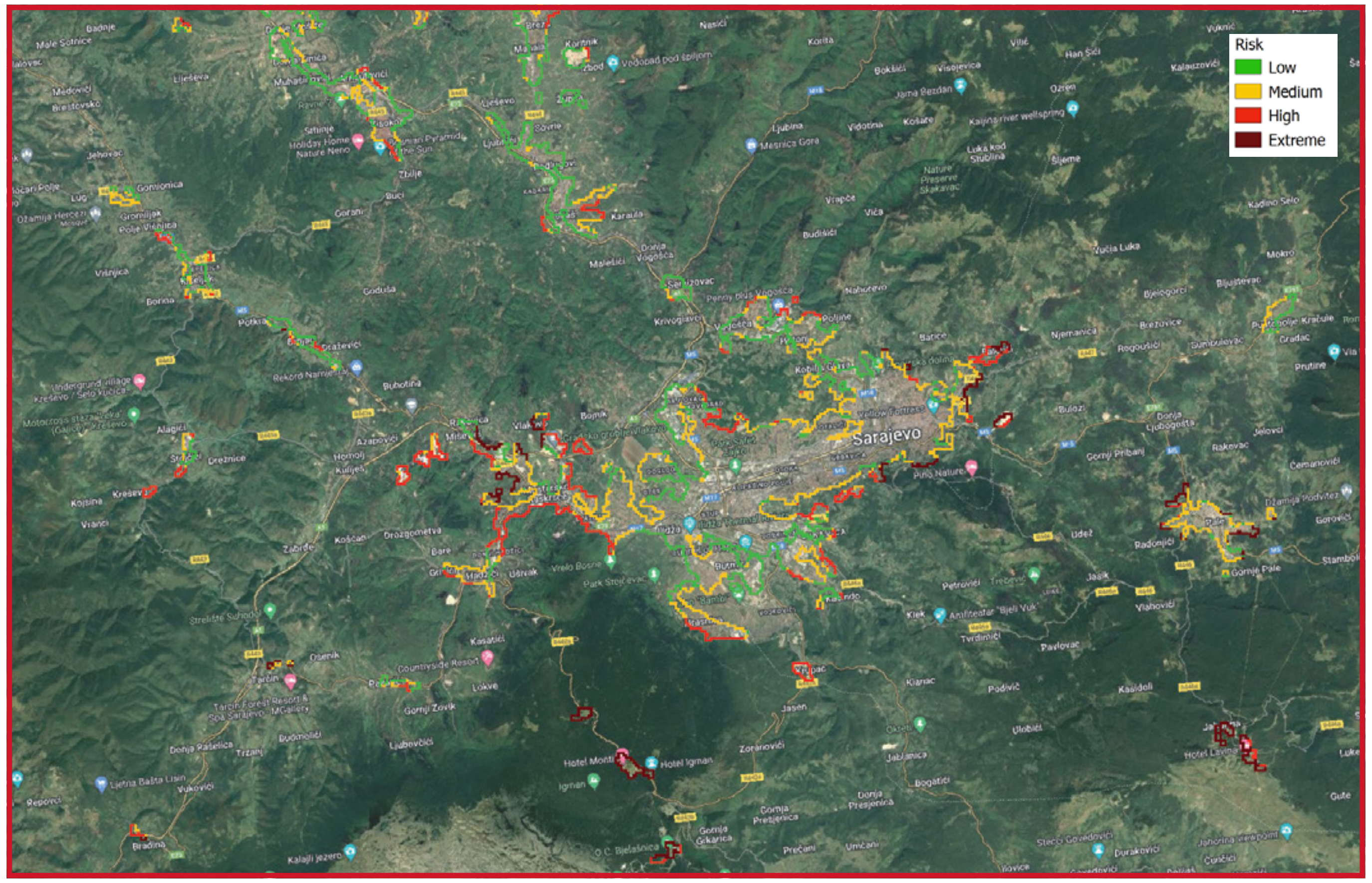
- extract the urban area from CORINE 2018 land cover map
- rasterize the urban polygons over the hazard grid
- buffer the urban area of ~100m in order to include the WUI
- mask the urban area in order to retrieve only the location of the cells in the WUI
- apply a maximum sliding window on the hazard in order to retrieve the maximum level of hazard around ~100m of each WUI cell
- aggregate the hazard classes in four risk levels from low to very high.

Table 21: Table representing the correlation between hazard and risk levels

HAZARD LEVEL	RISK LEVEL
1 and 2	1 - Low
3	2 - Medium
4	3- High
5 and 6	4 – Very High

The risk levels for the WUI are provided in Table 21. Figure 17 shows the wildfire risk in WUI in Sarajevo

Figure 17: Risk in urban area interface in Sarajevo, Bosnia and Herzegovina, and surroundings. Here the risk level is valid only in wildland urban interface depending on the wildfire hazard level



Risk index for linear data

Linear exposed elements are common when evaluating risk of networks such as road infrastructure. This guide considers primary, secondary and tertiary roads to establish a risk index for road networks. The procedure adopted is similar to the polygon and gridded data. OSM database is used to gather data with different categories of roads as shown in Table 22.

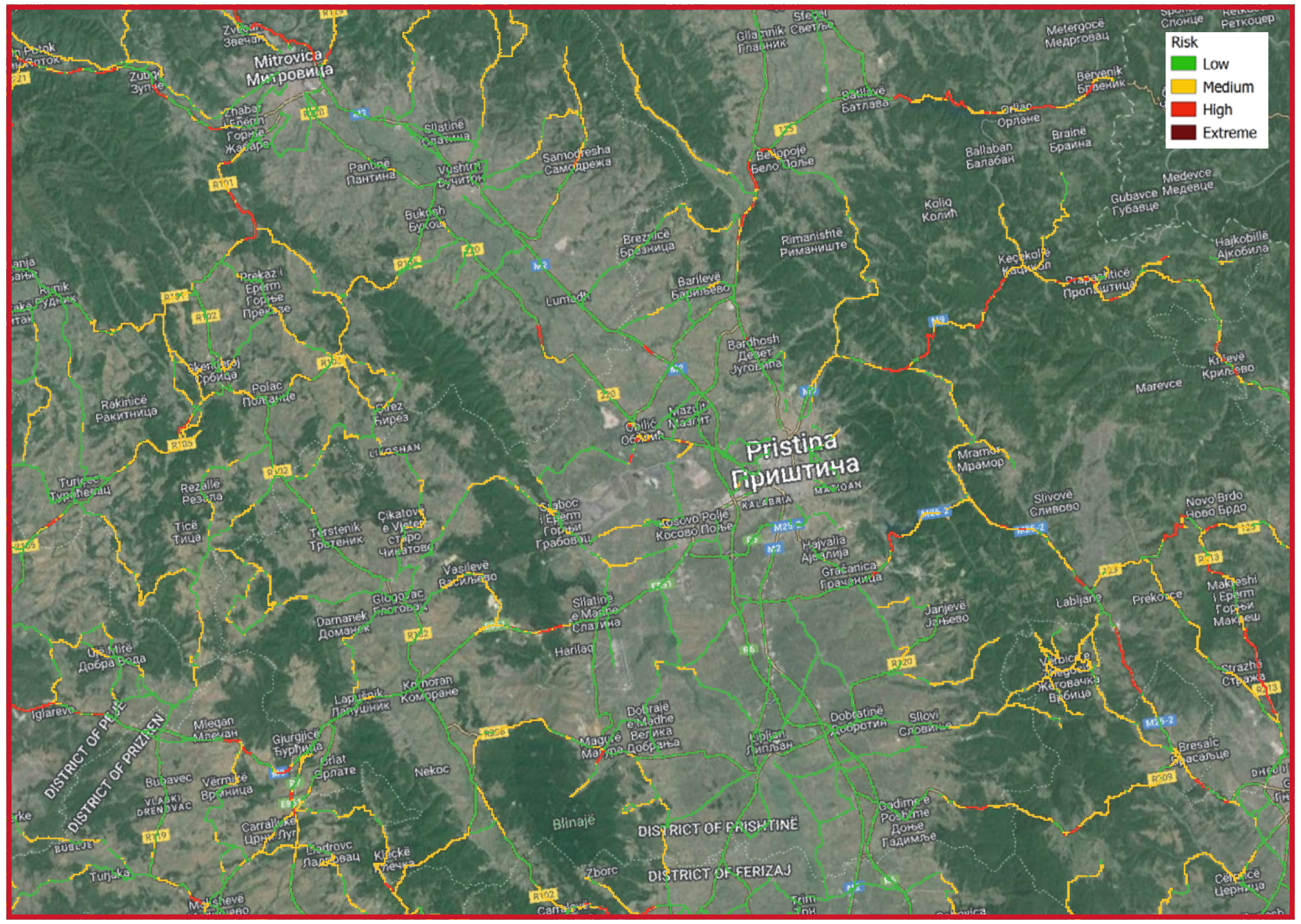
Table 22: Road network information used in the risk assessment

ROAD CATEGORY	OSM CATEGORY
Primary	Primary, Trunk, Motorway
Secondary	Secondary
Tertiary	Tertiary

For each category, a vulnerability function is assessed along with its importance value (weight). The weight is higher for bigger and more important roads (i.e. primary roads). Similar to polygon elements, the data are put into a grid and the assigned hazard level for each cell is equivalent to the maximum value of a spatial window of about 100m around each exposed pixel. The vulnerability function is then applied linking the hazard class with the degree of damage. For each cell the values are combined with the weight factor to retrieve the potential damage and risk level.

Figure 18 shows the road network at risk in Pristina.

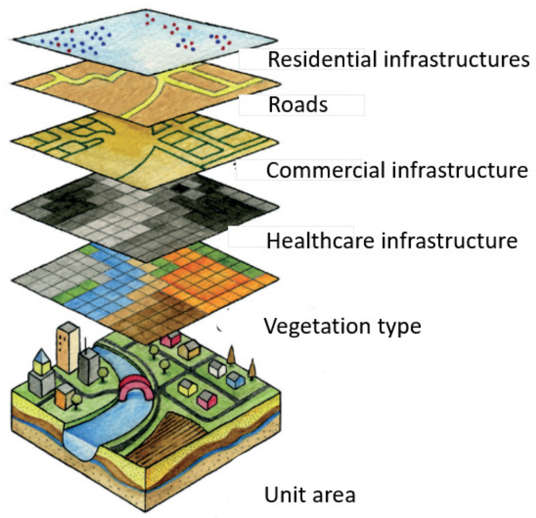
Figure 18: Road network at risk in Pristina, Kosovo*, and surroundings. Here the risk level depends on the presence of flammable vegetation close the infrastructure (which determines the hazard level) and the type of road (primary, secondary or tertiary road)



Total risk index

The total risk index is produced by overlapping the specific risk index for each category of assets. Several approaches can be used to assess a unified risk index. Here, two approaches are employed. In this framework, the presence of more than one exposed element in a grid cell increases the level of risk manifesting the same level of hazard. This operation enables the identification of areas at higher risk due to the presence of multiple EaR as shown in Figure 19.

Figure 19: Example of overlapping categories of assets for total risk mapping



The aggregation into a single risk map can be achieved either by combining risk indices of each exposed element through a weighted average (accounting for the relative importance of each EaR) or by combining the potential damage layers to get the total damage on the study area. A drawback to this approach is that it can decrease the final risk level of a single element, such as forests at high risk.

Table 23: Description of the two main approaches to obtain a single risk index at national level starting from the outcomes of each exposed elements

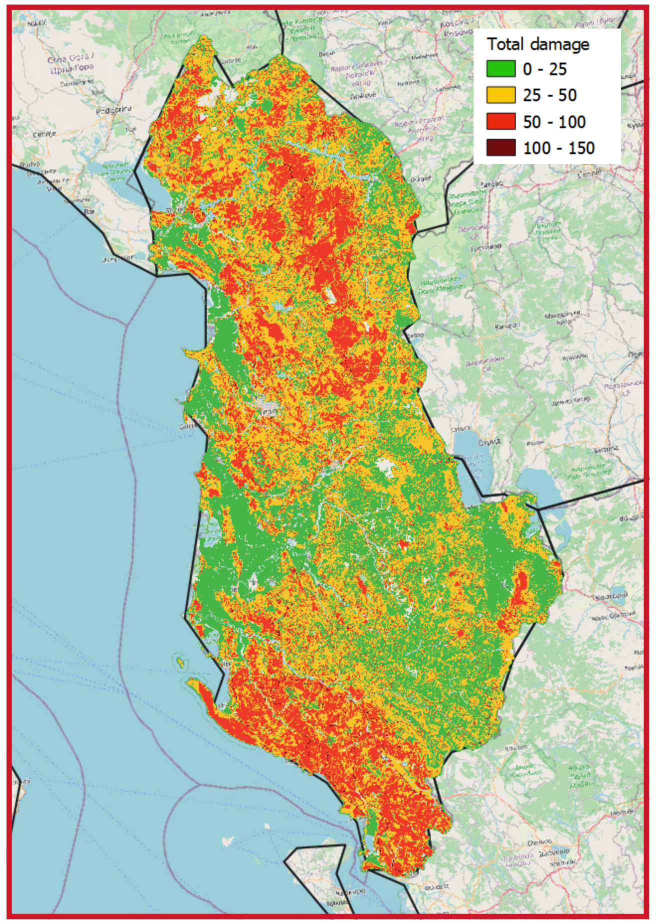
APPROACH TO EVALUATE THE TOTAL RISK MAP	DESCRIPTION
Aggregation of potential damage maps	Sum of potential damage layers for the 3 principal exposed categories (vegetation, POI, roads)
Aggregation of risk maps	Weighted average of risk layers for 5 categories at risk (vegetation, POI, roads, urban interface and population at risk)

In the first approach, to calculate a single map combining all risk information at national level, each and every potential damage layer (which are separate for exposure category) is summed together. This method enables the identification of areas in which the presence of multiple EaR leads to higher potential damage levels. The damage layer is then categorized in four classes, as presented in the following image. This formulation combines three main categories in which the potential damage is available, as expressed by the following equation:

$$Dtot = Droads + DPOI + Dvegetation$$

Where Dtot is the total potential damage; Droads is the potential damage in roads including primary, secondary and tertiary roads; DPOI is the potential damage of the POI divided into healthcare education and commercial; and Dvegetation is the potential damage in the four defined types of vegetation (grassland and croplands, low flammable forest, shrub-lands and highly inflammable forests).
The damage layer is then categorized into four classes, as presented in the following image (Figure 20).

Figure 20: Example of risk map in Albania using the first methodology (aggregation of potential damage maps)



Similarly, in the second approach, the number of exposed elements plays a role in defining the total risk level. The aggregation is performed directly at risk level combining the single layers for each category at risk. Thanks to this formulation the risk indices of population and urban interface can be included in the computation. In particular, for each pixel of the study area a weighted average is applied according to the following equation:

$$R = (w1 * Rroads + w2 * RPOI + w3 * Rvegetation + w4 * Rurb + w5 * Rpop) / wtot$$

Where w1 assumes three different values depending on the classification of the road as primary, secondary or tertiary; while w3 assumes four values depending on the type of vegetation at risk; wtot is the total maximum weight, defined as the sum of all the weights for all categories, considering the highest value that w1 and w3 can assume.

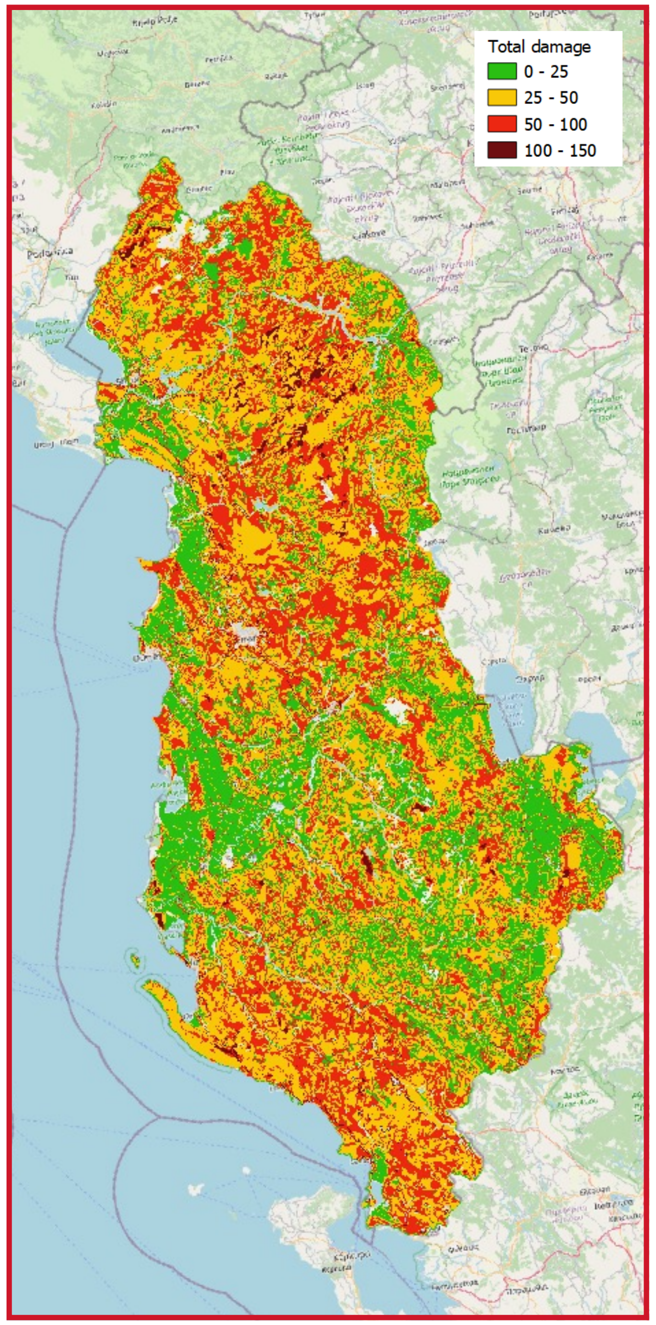
The set of weights applied are identified in the following table.

Table 24: Table representing the correlation between hazard and risk levels

CATEGORY	WEIGHT
Roads (w1)	3 if primary 2 - Medium 3- High
POI (w2)	3
Vegetation (w3)	1 if grassland, cropland or shrub 2 if broadleaf 3 if coniferous
Urban interface (w4)	2
Population (w5)	1
Total maximum weight (wtot)	12

The result is presented in Figure 21

Figure 21: Example of risk mapping in Albania using the second methodology (aggregation of risk maps)



The two approaches show similar results at national scale, highlighting the areas at greater risk. This type of information is essential for prioritizing preventive actions, such as landscape and fuel management, and risk reduction strategies.

05

Uses and adoption procedures

5.1 Uses of Forest Fire Risk Mapping for wildfire management

FFRM plays a crucial role in wildfire management. Feedback gathered from the IPAFF programme questionnaire illustrates the main uses of hazard and risk mapping in each phase, as shown in Table 25. For the "Prevention and Preparedness" phase, risk maps support activities that aim at reducing the incidence of fires and causes of fire ignition, thereby enabling interventions to mitigate the impacts of fire. In particular, FFRM can help to i) identify the areas and periods at risk of forest fires through hazard maps, prepared using meteo-climatic, geophysical and vegetation variables; and ii) define appropriate prevention measures. Moreover, the contribution of FFRM can be crucial for planning and applying land management strategies and practices, including the use of controlled fires. Land management strategies comprise different activities such as fuel management (prescribed burning, vegetation clearing, mechanical brush-clearing); silvo-pastoralism; vegetation replacement by less flammable species that can re-sprout following burning; and bio-economy (forest wood as biofuel, construction timber, paper wood).

Table 25: Uses of forest fire map in all wildfire management phases

ALBANIA	BOSNIA AND HERZEGOVINA	KOSOVO*	MONTENEGRO	NORTH MACEDONIA	SERBIA	TÜRKIYE
a) Prevention and Preparedness						
Land management, fire danger and fire-risk forecasts and civil protection early warnings	Land management strategies	Fire danger and fire-risk forecasts and civil protection early warnings	Land management strategies, fire danger and fire-risk forecasts	Land management strategies, fire danger and fire-risk forecast	Fire danger and fire-risk forecasts	Land management strategies, fire danger and fire-risk forecasts, Civil protection early warnings and activation of restrictions by laws
b) Detection and Response						
Prioritization of intervention and support to fire-fighting strategies	Support to fire-fighting strategies	Prioritization of intervention, risk scenarios	Prioritization of intervention and risk scenarios simulation	Prioritization of intervention, support to fire-fighting strategies	Support to fire-fighting strategies	Prioritization of intervention, risk scenarios simulation and support to fire-fighting strategies
c) Restoration and Adaptation						
Climate change impact scenarios	Activity planning	Shift of vegetation species, climate change impact scenarios and reforestation	Shift of vegetation species	Shift of vegetation species	Shift of vegetation species	Climate change impact scenarios

This guideline merges the prevention and preparedness phases, with the latter aiming at supporting the pre-allocation of aerial and terrestrial resources (e.g. patrolling team), and producing civil protection early warnings and activation of restrictions. In the context of preparedness, FFRM helps improve the capacity to anticipate the potential behaviour of fire, thus supporting the organization of better strategies of fire-fighting interventions. To this end, the interaction with RWG experts revealed how the FFRM and simulation models can be used to integrate Table Top and Full Scale Exercises, thereby demonstrating realistic wildfire risk scenarios and potential impacts on all involved actors.

For the "Detection and Response" phase, the role of the FFRM is crucial in defining the appropriate information to input in simulation models and early warning systems. Indeed, the information provided by FFRM includes the definition of fuel types in terms of flammability and potential fire behaviour, as well as the presence of exposed elements vulnerable to wildfire. Thus, the timely availability of such information increases the capacity to define priorities based on the potential impact of a fire and not only fire hazard. During response or emergency, the inclusion of FFRM in simulation modelling enables the generation of reliable wildfire risk scenarios, thereby supporting better-informed and more effective fire-fighting strategies.

FFRM makes an important contribution to the "Restoration and Adaptation" phase restoring burnt areas according to vegetation regrowth processes, learning from previous events, and considering vegetation at higher risk and the impact of climate change and land-use changes.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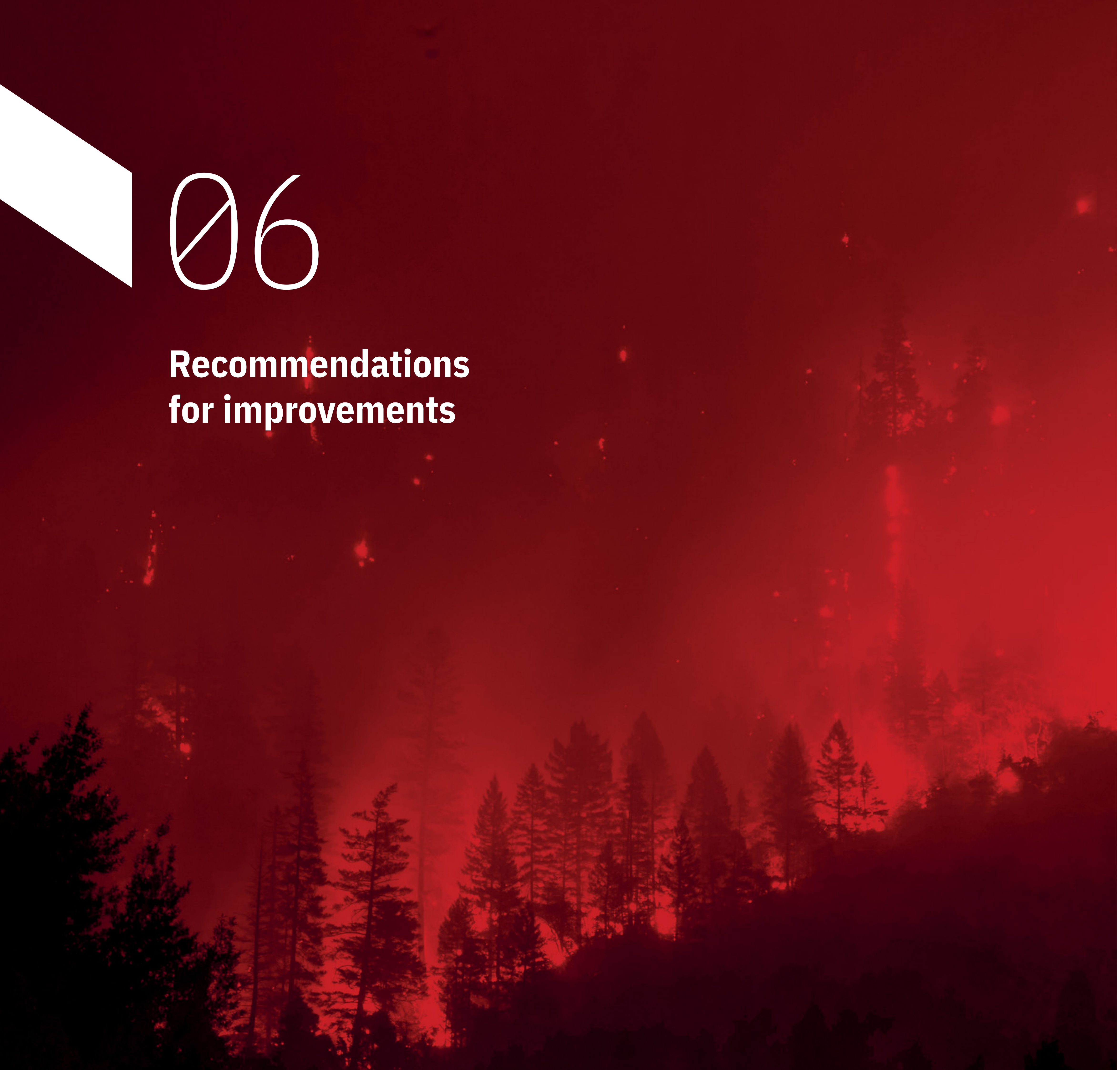
5.2 Adoption procedures and status of application

Following the feedback gathered through the IPAFF programme questionnaires, Table 26 shows the current status of application of FFRM in each country.

Table 26: Application of forest fire risk mapping including status of application and barriers

	APPLICATION OF EXISTING PROCEDURES	STATUS OF APPLICATION	GAPS/BARRIERS FOR APPLICATION
AL	FF Emergency Plans	Not implemented	Lack of qualified staff/ resources for prevention activities
BiH	FF Emergency Plans	Not implemented	Lack of qualified staff/ resources for prevention activities
KOS*	FF Emergency Plans Integrated Emergency Management System	On-going	Lack of coordination between central and local level, legislation, etc.
ME	National Plan and Municipal plans for Rescue and Protection from fires Entrepreneurial Rescue and Protection Plan Plan for fire rescue and protection for each national park (NP) and each regional unit of the Forest Administration	On-going	Lack of qualified staff/ resources for prevention and preparedness activities
NMK	FF Emergency Plans	Not implemented	Lack of qualified staff/ resources for prevention activities
SER	Different legal acts, regulations and action plans	Implemented	Communication and coordination actions among various stakeholders can be further improved
TK	Forest Fire Management/ Action Plans (Regional).	Updating of all framework and policies is planned, including: Forest Fire Management/ Action plans at regional level National Forest Fire Strategic Plan is under development	N/A



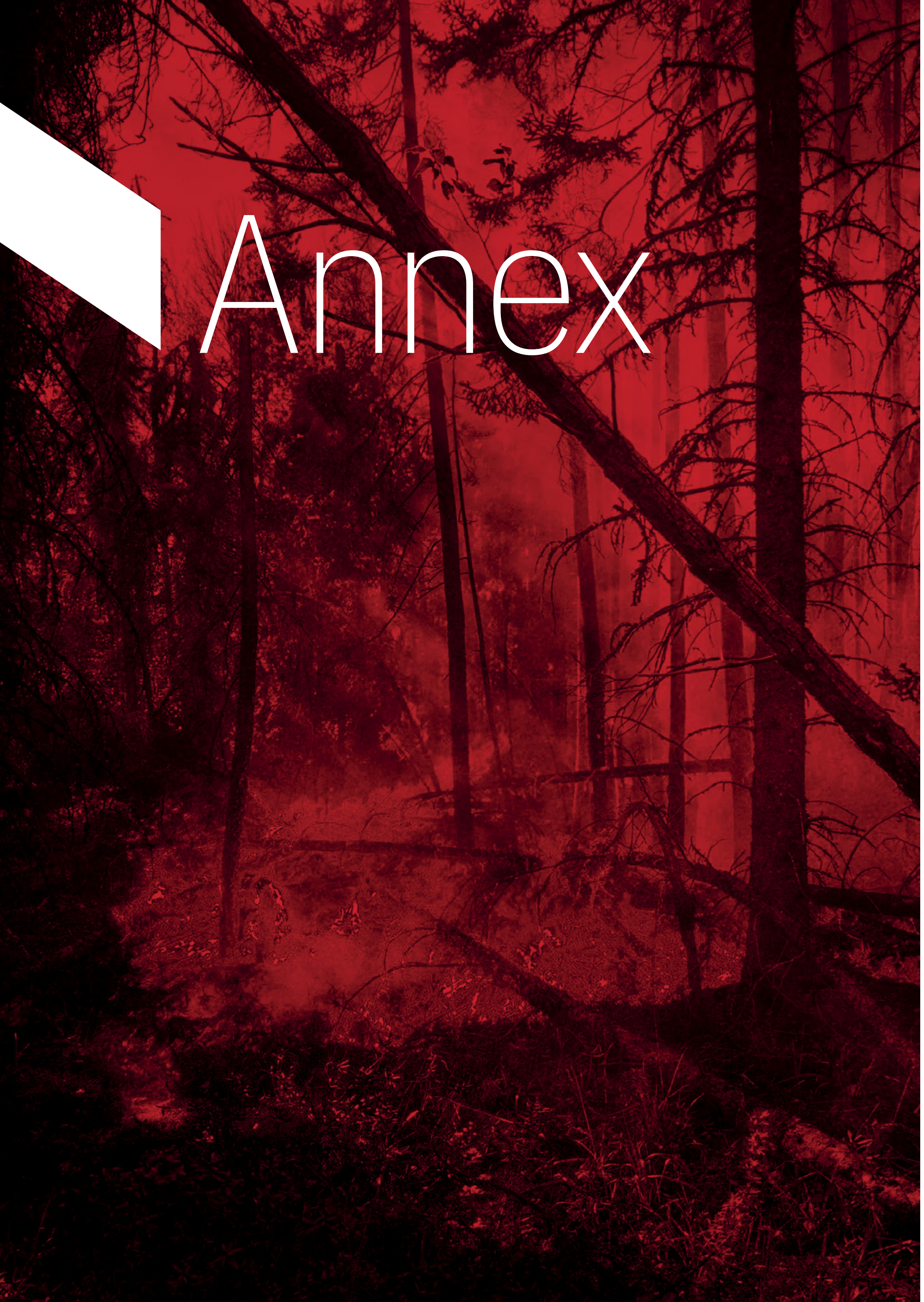
06

Recommendations for improvements

The process behind the preparation of this guideline with experts from each beneficiary country has enabled both the strengthening of capacities for WRA and mapping, as well as the identification of gaps in need of attention. It is in this vein that the following recommendations for improving wildfire assessment and risk mapping are offered:

- procedures and tools for wildfire risk mapping need to be incorporated into the legal and institutional frameworks of each country from national to local level
- the quality of hazard and risk maps needs to be improved, by integrating up-to-date and reliable data, from different sources at each governmental level
- procedures and policies should be set up to encourage data sharing among institutions and government levels within and among countries
- collaboration needs to be strengthened between landscape management and fire management with data sharing and protocols supporting either joint forest management planning and management of trans-boundary wildfire events
- wildfire risk mapping needs to be integrated into early warning systems and wildfire simulation tools, thereby allowing more effective fire detection and response and reducing the catastrophic damage from uncontrolled fire events

The above recommendations will help overcome the silos-based approach to wildfire management that currently characterises the strategic and operational frameworks on wildfire management in the countries examined. This will facilitate the development of integrated wildfire management strategies, already prioritised in Europe, in the Western Balkans and Türkiye.



Annex I
Questionnaire on Forest Fire Risk mapping current practices in Western Balkans and Türkiye

PART A – GENERAL INFORMATION

A1 – Forest Fires risk assessment (e.g. hazards, risk) maps available in your country

A1.1 – Which kind of maps (and/or other tools) are produced?

- ☐ a. Hazards map
- ☐ b. Risk map

A1.2 - Who makes it?

____

____

A1.3 – Is it available?

- ☐ a. Is part of an existing process
- ☐ b. Is under development
- ☐ c. Is not yet under development

A1.4 - What does it cover?

- ☐ a. Only restricted areas
- ☐ b. All the territory

A1.5 – At which level is the map defined

- ☐ a. National
- ☐ b. Regional
- ☐ c. Provincial
- ☐ d. Municipal
- ☐ e. Local
- ☐ f. Cadastral
- ☐ g. Regular grid size cell (please specify)

A1.6 – At which scale is the map defined?

- ☐ a. 1:100,000
- ☐ b. 1:10,000
- ☐ c. 1:5,000
- ☐ d. <1:5,000 (please specify: ________________)

A1.7 - For which purpose is it produced?

Flag and explain in which procedure/ tool maps are used and by whom

a. Prevention and Preparedness

- ☐ 1. Land management strategies
- ☐ 2. Fire danger and fire-risk forecasts
- ☐ 3. Civil protection early warnings
- ☐ 4. Activation of restrictions by laws
- ☐ 5. Other: please specify ________________

b. Detection and Response

- ☐ 1. Prioritization of intervention
- ☐ 2. Risk scenarios simulation
- ☐ 3. Support to fire-fighting strategies
- ☐ 4. Other; please specify ________________

c. Restoration and Adaptation

- ☐ 1. Shift of vegetation species
- ☐ 2. Climate change impact scenarios
- ☐ 3. Other: please specify ________________

A1.8 - What are the socio-economic and environmental impacts expected by the application forest fires risk mapping?

For each of the maps, please answer the following:

Do you think fire events can be reduced through improved control of fire-prone areas through risk mapping?

- ☐ a. Yes
- ☐ b. No

1. If you answered yes in the previous question, please specify the percentage by which fire events can be reduced.

- ☐ a. None
- ☐ b. <10
- ☐ c. 10 - 30
- ☐ d. >30
- ☐ e. Other

Estimation of direct damages to all exposed elements (e.g., houses, infrastructures, vegetation)

2. Total burned area during the past 10 years (please specify according to year, or if not available for each year, estimate a total number)

2010	
2011	
2012	
2013	
2014	
2015	
2016	
2017	
2018	
2019	
2020	

3. Average size of burned areas: total burned areas/ number of fire events

____

____

4. Can you estimate the value of damaged houses affecting the total burned area for each year? (please specify according to year, or if not available for each year, estimate a total number)

Houses	Total burned area	Total damage
2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		

5. Can you estimate the value of damaged infrastructures (e.g. transport network, electricity, water pipelines) affecting the total burned area for each year? (please specify according to year, or if not available for each year, estimate a total number)

Infra	Total burned area	Total damage
2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		

6. Can you estimate the economic value of vegetation affected (in Euros) for the total burned area for each year? (please specify according to year, or if not available for each year, estimate a total number)

Infra	Private Forests	Public Forests	Total
2010			
2011			
2012			
2013			
2014			
2015			
2016			
2017			
2018			
2019			
2020			

7. Do you know the number of people affected in your area after fire events?

- ☐ a. Between 0 and 1000
- ☐ b. Between 1000 and 2000
- ☐ c. Between 3000 and 4000
- ☐ d. Estimate a number if possible (please specify: _______________)

Estimation of indirect damages

8. Can you mention any other indirect damage due to fire events?

- ☐ a. Biodiversity
- ☐ b. Wildlife Habitat
- ☐ c. Outdoor activities
- ☐ d. Tourism
- ☐ e. Health issues/ income
- ☐ f. Others (please specify: _______________)

9. Please specify the value of total indirect damages due to fire events.

2010	
2011	
2012	
2013	
2014	
2015	
2016	
2017	
2018	
2019	
2020	

Reduction of operational costs for fire management operations

10. How much do you expect that overall operation costs for fire management operation will be reduced by the application of fire risk mapping (in percentage)?

- ☐ a. None
- ☐ b. < 10%
- ☐ c. between 10% and 30%
- ☐ d. >30%
- ☐ e. Other (_______________)

11. Estimation of the total operation costs for fire management operations.

	Firefighting costs	Other costs	Total
2010			
2011			
2012			
2013			
2014			
2015			
2016			
2017			
2018			
2019			
2020			

12. Do you expect any other benefits/ impacts from the application of forest fire risk mapping?

- ☐ Yes
- ☐ No
- ☐ Please specify (______________)

A2 - Types of fires addressed

A2.1 - Provide a definition of forest fire (according to your legal framework)

A2.2 – Indicate the type of fires addressed

- ☐ a. Forest Fire
- ☐ b. Wildland Urban Interface (WUI)
- ☐ c. Rural Fire
- ☐ d. Urban Fire
- ☐ e. Other (please specify: ______________)

A2.3 – Indicate the fire season

- ☐ a. Winter
- ☐ b. Summer
- ☐ c. Both

A2.4 – Indicate the main causes of fires ignition and rank the causes from more to less frequent (using a Likert scale from 1 less frequent, 5 most frequent)

- ☐ a. Unknown: wildfire with no cause found
- ☐ b. Natural: caused by natural origin, with no human involvement in any way
- ☐ c. Arson: deliberate, intentionally caused by human with the use of fire
- ☐ d. Human activities:
  - ☐ i. Negligence: unintentionally caused by human using fire or glowing object, not connected to fatality
  - ☐ ii. Accident: unintentionally and indirectly caused by human without use of fire, connected neither to will nor to negligence, rather to fatality
- ☐ e. Open fire
- ☐ f. Agricultural and pastoral burns
- ☐ g. Railroad
- ☐ h. Electric power
- ☐ i. Other (please specify: ______________)

A3 – How is your coping capacity to respond to forest fires

- ☐ a. Nr. Firefighters (Ratio of firefighters in relation to exposed fuels or land cover area):
- ☐ b. Surveillance areas (Number of surveillance towers/paths with visibility over the area):
- ☐ c. Available ground suppression resources (type, quantity and location):
- ☐ d. Available aerial suppression resources in the area (type, quantity and location):
- ☐ e. Nr. Water points for aircraft operations:
- ☐ f. Fire-break extension in Km:
- ☐ g. Other:

A4 – Access the forest fires maps

- ☐ a. Maps are freely accessible at desk
- ☐ b. In addition, maps are accessible through the Internet

A5 - In what format are the maps available?

- ☐ a. Hard copy
- ☐ b. Digital GIS
- ☐ c. Pdf-format
- ☐ d. Other formats (please specify: __________)

A6 - Who are the users/stakeholders involved in the map implementation (distinguishing between technical development, execution, approval)?

- ☐ a. Which governments:
- ☐ b. Which local authorities:
- ☐ c. Which other users/stakeholders (environmental agencies, universities, etc.):

A7 – Do the maps follow any quality evaluation and approval procedures?

- ☐ a. Yes
- ☐ b. No

PART B – FOREST FIRES MAPS DEVELOPMENT PROCESS

B1 – Current methodology, process and different steps for producing the following maps

Leave blank if no map is produced

B1.1.1 - Describe the current methodology to produce the hazard map (methods and parameters used, classes of hazard used)

B1.1.2 - Specify data used and sources (satellite, UAV, in-situ, cartographic, meteo, etc.)

B1.2.1 - Describe the current methodology to produce the risk map: methods, classes of risk used, exposed elements considered (population, infrastructures, buildings, vegetation, etc.), vulnerability including coping capacity, etc.)

B1.2.2 - Specify data used and sources (satellite, UAV, in-situ, cartographic, meteo, etc.)

B1.3.1 - Describe the current methodology to produce the damage assessment (methods, classes of damage used, content of the map)

B1.3.2 - Specify data used and sources (satellite, UAV, in-situ)

B2 - Do you take foreseen situations into account? And if yes, how

- ☐ Climate change effects
- ☐ Land use change effects

B3 - Which GIS software is used?

B4 – What critical aspects of the fire risk mapping process need further investigation

B4.1 Technical matters:

B4.2 Management-related matters:

B5 – What are the advantages and disadvantages of your method?

B6 - Other comments

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