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A proposal for a Wildfires Digital Twin Framework through Automatic Extraction of Remotely Sensed Data: the Italian Case Study of the Susa Valley

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1.A proposal for a Wildfires Digital Twin Framework through Automatic Extraction of Remotely Sensed Data: the Italian Case Study of the Susa Valley

Abstract

Wildfires are among the most common forms of natural disaster in many regions. Climate change has increased the probability and severity of wildfires across Europe, fueled by heatwaves and facilitated by drought which is uncommon since the past 500 years. Forest fires in 2017 have been recorded as one of the worst one during the last 30 years for Italy as vast fire occurrences have taken place during summer, adding to the already important events in the autumn season. In 2017, almost the whole Italian National territory suffered a period characterised by very high temperatures and absence of significant rain processes. shaping to become a recurrent problem in the future and creating a need for better integration in the management and information sources, possibly accessible in real time.

This thesis proposes a framework based on existing literature for wildfire assessment using Digital Twin (DT) technology combining remote sensing open source data and cloud computing techniques to create virtual representations of real-world environments to model the extent of the damage and help with recovery and reconstruction efforts. The focus of the research is to develop and generate the basic data necessary for the creation of a wildfire assessment DT on the Susa valley such as thematic maps, generated from the processing of Copernicus Sentinel2 imagery, of burned area, burn severity, vegetation recovery index and their relative statistics using GEE platform to automate the process as much as possible.

The resulting burned area extracted using the developed methodology demonstrates conformity to the reference sources (such as the European Service of Copernicus Emergency Management Rapid Mapping product) and more accuracy compared to other open source products in GEE. Moreover, the vegetation recovery obtained by the research highlighted the correct trend of recovery over the years. False values have been detected as well, for which complementary methods have been adopted to help with the interpretation. Further outputs of the thesis include the provision of other building blocks for the wildfire assessment DT such as potential stakeholders in the case of Susa Valley and sensors to cover other aspects of the damage assessment. Overall, the adoption of Sentinel2 imagery provided by the GEE platform proves to be beneficial for the context of research, however there are some still open challenges related to dataset unavailability and inaccuracy, or memory management limitations due to hardware storage capacities, additionally to the human expertise and complementary sources such as field observations and complementary usage of sensors, that would be needed for further accuracy and improvement.

Keywords : *Digital Twin, Forest Fires, Wildfires, Remote Sensing, Sentinel2, GEE, Susa valley, Alpine region*

Introduction

A natural hazard is a naturally occurring extreme event with a negative effect on people or the environment (Baltic Earth website). When the hazardous threat actually happens and harms humans, we call the event a natural disaster (Abbott, P. L., & Samson, C.; 2008).
Natural hazards have the potential to cause catastrophic damage and loss to infrastructures, and have increased significantly in recent decades. The frequency and scale of natural hazards have been increasing since the 2000s and lead to losses that threaten the economy, environment, and human life (Yu, D., & He, Z. (2022). Among natural hazards we can name Earthquakes, Volcanic Eruptions, Landslides, Floods, Wildfires, Droughts etc. In comparison with the other factors (e.g., pests, plant diseases, wind, and frost), fire often acts as the most threatening disturbance for forestland and trees in the southern Europe and Mediterranean area (Michetti, M; Pinar, M, 2019).
Forestland and trees offer fundamental services such as commercial and recreational uses, water and climate regulation services, and carbon sequestration activity. However, several forest disturbances undermine these service provisions.Wildfires are among the most destructive disasters, with an immense impact on populated regions, houses and infrastructures, and even in the isolated ones, natural vegetation and animals are affected. They can disrupt transportation, communications, power and gas services, and water supply and lead to a deterioration of the air quality, loss of property, crops, resources, animals and people(Kerr, 2007).
The World Health Organisation(WHO) website defines wildfire as an unplanned fire that burns in a natural area such as a forest, grassland, or prairie, and often caused by human activity or a natural phenomenon such as lightning.
According to the website of the Centre of Climate and Energy, the risk of wildfires is higher in extremely dry conditions, such as drought, and in situations of high winds. Over the last few years, the size and recurrence of wildfires have been amplifying due to climate change. As the “World Meteorological Organisation” reports, Wildfires and climate change are mutually exacerbating .Hotter and drier conditions are drying out ecosystems and increasing the risk of wildfires,simultaneously impacting weather and the climate by releasing large quantities of carbon dioxide, carbon monoxide and fine particulate matter into the atmosphere leading to more and more air pollution with health consequences.
However, some forest ecosystems in their natural state rely on wildfire based on the type of vegetation present.
Wildfires are often classified by characteristics like cause of ignition, physical properties, combustible material present, and the effect of weather on the fire(Flannigan et al. 2006).Wildfire behaviour and severity result from a combination of factors such as available fuels, physical setting, and weather. Climatic cycles that include wet periods that create substantial fuels, are usually followed by drought and heat often precede severe wildfires and will become worse by heat waves and droughts caused by climate change.
Wildfires are among the most common forms of natural disaster in some regions. Areas with Mediterranean climates or in the taiga biome are particularly inclined to be involved in wildfire. At a global level humans have contributed to major factors to increased wildfires, increased heat and dry periods due to climate change and other more direct human activities, such as land-use change and wildfire suppression. This incrementation in the number of fires creates a negative feedback loop releasing naturally sequestered carbon back into the atmosphere, creating further global warming(*Parmesan, Camille; Morecroft, Mike; Trisurat, Yongyut; et al, 2022)*.
As a report by Euronews on 19 August 2022, climate change has increased the probability and severity of wildfires across Europe, fuelled by heatwaves and facilitated by drought which is uncommon since the past 500 years. Italy is not an exception being affected by relevant fire risk where it lists as the fourth country for having fire events in the Mediterranean area, after Portugal, Spain, and France (San-Miguel-Ayanz et al. 2017) Through the whole Italian peninsula, 7077 fire events were registered on average each year between 2000 and 2011 with around 76,350 hectare (ha) of area burnt annually on average. According to the “Forest Fires in Europe, Middle East and North Africa 2020” Report by EFFIS, Italy had the highest number of forest fires in the period of 2019_2020, resulting in 63907 hectares of burnt areas.

Forest fires in 2017 have been recorded as one of the worst one during the last 30 years for Italy as vast fire occurrences have taken place during summer, adding to the already important events in autumn (Michetti, M; Pinar, M, 2019). In 2017, almost the whole Italian National Territory suffered a period characterised by very high temperatures and an absence of significant rain (Emergency Management Copernicus _2017). Nimbus Web _ A website for local Climatology in Piedmont Region of Italy_ Describes the situation as the following paragraph: "...October 2017 saw the drought situation in the North-West of Italy further aggravate, while in the rest of the country the rains of September (and the further showers of October on the Adriatic and in the South) had alleviated the water crisis that had dragged on since spring. In addition to the problems of supplying drinking water in many municipalities, especially in southern Piedmont, the extreme aridity of the soil and undergrowth penalised the sowing of wheat in the plains and favoured the spread of numerous and serious forest fires in the Alps, especially at the end of the month.
According to the same report by the "Climatology in Piedmont Region of Italy", from 20 till 30 of October, a serious sequence of extensive and persistent forest fires hit the western Alps and in particular the Cuneo and Turin hills, with the most important episodes concentrated between 22 and 29 in the Stura di Demonte, Varaita, Chisone valleys, Susa, Orco, Chiusella, and in the territories of Cumiana and Cantalupa (Pinerolese), to which were added, at the end of the month, other events in the Lombardy Alps and Prealps.
Based on a report done by the "Alpine Region Action Group 8", forest fires are defined as uncontrolled fires in forested areas, independent of cause, size and fire type. The most important factors that determine fire ignition are the ignition source and the moisture content of the fuel (dead burnable material). The report states that about 90% of fires in the Alpine region are ignited directly or indirectly by humans. Main causes are cigarettes, fires getting out of control, sparks flying from trains or during work, arson, hot ashes and power lines and the other 10% of the fires are caused by lightning strikes. Fire behaviour, including propagation and intensity, depends on fuel moisture content, vegetation structure and continuity, topography and wind.
It is estimated that due to the increasing intensity of drought periods and heat waves and the increasing fire hazard resulting from rural abandonment and more recreational activities, forest fires in the Alpine region will probably increase in the near future. The mountain forests in the Alps provide numerous ecosystem services to the population and fulfil an important protection function against natural hazards. Forest fires can lead to new avalanche-prone slopes, a higher risk of rockfall, mudslides, soil erosion and a local change of hydraulic regimes. Especially forests on steep, southern slopes are at risk, which play an important protective role against all kinds of natural hazards. Firefighting is generally difficult in the Alps due to the rugged topography and low accessibility. Given a change in fire regime, it is likely that costs of firefighting, civil protection measures, post-fire restoration and necessary protective measures will strongly rise. The negative impacts of forest fires in the Alps can be summarised as: ... Reduction of the protection function of mountain forests Increased vulnerability to natural hazards Loss of natural resources and decreased productivity through increased soil erosion High costs for firefighting and post-fire management Increased danger for humans and infrastructure at the wildland-urban-interface (WUI) Increased air pollution and carbon release Total direct costs for firefighting and post-fire management (excluding prevention measures) associated with forest fires in the Alpine region are estimated to be currently around 75 Mio. Euro per year(Forest fires in the Alps, 2020).
In the context of the 2030 Agenda for Sustainable Development (United Nations, 2030 Agenda for Sustainable Development Goals), the agenda recognizes and reaffirms the urgent need to reduce the risk of disasters. In addition to direct references to the outcomes of the Third UN Conference on DRR (Sendai Framework), there are specific opportunities to achieve SDGs through reducing disaster risk one of which is SDG 11.5 that refers directly to the Reduction of the Adverse Effects of Natural Disasters_to be more accurate_ aiming at significantly reducing the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations by 2030. One of the indicators in order to measure is Collections-based research that supports the understanding and management of disasters of all kinds.
However, forest fires have been an increasing threat across Europe since 1980 (European Environment Agency Website, 2021) and . This is because there are more fire prone areas, a longer fire season and in

general, larger more damaging fires. For this reason, wildfire risk management programmes and policies that are effective against forest fires in normal weather are now insufficient to prevent extreme events such as megafires. As a matter of fact, the report on forest fires in the Alps by the Alpine Region Action Group 8 (2020) indicated that the present efforts to manage forest fires in the Alpine region are unable to prevent the occurrence of extreme forest fire events. The implementation of a foresighted and integrated forest fire management is highly needed and includes measures on fire prevention, fire suppression and post-fire management. Chapter 03 covers all the programs, projects, documents, regulations at the Europe level, national level (Italy) and Regional level (Piedmont) for preparedness, management and tackling the wildfire issues.
Timely and accurate burned area mapping is essential for quantifying the environmental impact of wildfires, for compiling statistics, and for designing effective short- to mid-term impact mitigation measures (e.g., prevention of soil erosion or possible impacts of the fire/heavy rainfall combination). To support such use cases on a national level, however, the burned area mapping methodology should be as automated as possible, requiring minimum—or none—human interaction (Stavrakoudis, D et al, 2020). Remote sensing techniques are now recognized as one of cost-effective sources of information for mapping burned areas from regional/national up to global scale (Stroppiana et al, 2012). Satellite imagery analysis as remote sensing inputs, has been successfully employed for mapping burned areas for several decades, since it offers a more precise, seasonable, and resource-efficient alternative to field surveys, considering the potential various levels of automation of the mapping process, especially in view of the great advancements the field of machine learning has seen the last few years (Stavrakoudis, D et al, 2020). The current research, reviews the already performed researches on the automatic extraction of the burnt area, and possible incorporation of the data as part of the information fed to the Digital Twin.
One important area to improve disaster response and emergency management is the employment of information and communication technologies. To this end, various streams of research across different disciplines such as information science, computer science and social science have devoted efforts to developing and employing information and communication technology (ICT) and artificial intelligence (AI) approaches for enhancing disaster response and emergency management processes.
To better manage future disaster responses, it will be critical to prebuild a streaming analytics system before a disaster strikes that can combine real-time telemetry from all needed data sources. With this system, response teams can gain needed insights in the moment, and emergency management teams and aid organisations can maximise the effectiveness of their response.Such system can also be designed for post-fire assessments. A digital twin is simply a data-driven digital representation of assets, processes or systems in the built or natural environment. A twin can provide an evolving picture of an asset's current performance and weaknesses, and help identify where investment needs to be prioritised. Digital twins allow users to make data-driven predictions powered by runtime data.
During an emergency response, real-time digital twins can track the key parameters of each individual asset, such as a shipment of food, water, medical supplies, or a smart power pole, and update these parameters in milliseconds as messages flow in from systems and personnel in the field. This difference creates a crucial opportunity for decision-makers that maximises their situational awareness in rapidly evolving situations (W.L.Blain, 2020).
Development of a theoretical framework based on existing literature, to develop a digital twin for wildfires, with suggestion of indexes and necessary datasets for alimentation to a digital twin and the proposed data integration methods.
The research continues with generation of basic data necessary for the creation of a digital twin on the Susa valley (i.e. 3D model from satellite data processing; gathering of historical information of fires that have occurred in those areas, with a focus on year 2017 event and on post-fire vegetation recovery; fire risk assessment to identify future potential events from current conditions)

The Thesis is structured in 8 sections :

1. The Introduction, where the general themes, methodology, research goal are discussed and the keywords on which the research is based are identified.

2.The Digital Twin concept, in which the present literature for Digital Twins and its definitions and applications are discussed and the usage of Earth Observation data and their applications especially in terms of wildfire management and risk assessment are considered. In this section, the focus is on limited keywords such as Digital Twin, forest, forest fires, satellite data, etc. The final part of the chapter a Wildfire Digital Twin framework is proposed identifying all the elements/indexes related to the topic (wildfires) that must feed a potential DT and the Datasets and Data Sources used for feeding the Digital Twin.

3.The European framework: strategies, initiatives, researches and reports in terms of creation of digital twins and natural disaster digital twins, focusing on wildfire.

4.Wildfires: international management approach methods. This chapter gathers different case studies on experience of different countries confronting wildfire management, preferably using open data, for risk management, crisis management and different programs at different levels.

5. The role of remote sensing in wildfires management. This chapter focuses on different remote sensing data types, Indexes ordinarily used for wildfire management, commonly adopted methods for wildfire mapping, and existing European services that allow us to do the task.

6.Case study on the Italian Alps: the Susa Valley. The main scope of this chapter is the Generation of basic data necessary for the creation of a digital twin on the Susa valley (i.e. 3D model from satellite data processing; gathering of historical information of fires that have occurred in those areas, with a focus on year 2017 event and on post-fire vegetation recovery; fire risk assessment indexes to identify future potential events from current conditions

7.Proposed methodology and workflow. This chapter includes notions on data gathering and Fire Risk Assessment, technicalities of the automatic extraction of the indexes and related statistical analysis and Three-dimensional model generation

8.Main findings and conclusions, including results of automatization of the process, results of research and planning suggestions

As far as adopted methodology is concerned, the research starts by synthesising the evolved literature, focusing on the keywords of Digital Twin, Forest Fire, Wildfire management, Remote Sensing, in order to propose a possible framework for creation of a digital twin to confront forest fires, suggesting Indexes, datasets and data sources to integrate considering the European Union and Italian Context, using only Open Data for the feeding of the proposed digital twin. Consequently, the research continues, focusing on the implementation of Burnt area extraction on the wildfire of the 2017 in Susa Valley, extracting the burnt areas, and creating a 3D model of the Alps in the Susa Valley relatively to three time periods: before, during and after the fire event. The technologies used in the research are Google Earth Engine platform to automatically identify the burned area, the burn severity and the vegetation recovery (through NDVI computation) followed by the related statistics to complement the obtained results, and QGIS for development of 3D models.

Chapter 2 - The Digital Twin concept

Introduction

Digital Twin technology is an emerging concept that has become the centre of attention for industry and, in more recent years, academia. The advancements in industry 4.0 concepts have facilitated its growth, particularly in the manufacturing industry. The Digital Twin is denied extensively but is best described as the effortless integration of data between a physical and virtual machine in either direction. The challenges, applications, and enabling technologies for Artificial Intelligence, Internet of Things (IoT) and Digital Twins are presented.
The Digital Twin can tackle the challenge of seamless integration between IoT and data analytics through the creation of a connected physical and virtual twin (Digital Twin). A Digital Twin environment allows for rapid analysis and real-time decisions made through accurate analytics.
This chapter provides a comprehensive review of Digital Twin use, its enabling technologies, challenges and open research for cities or forest environments.

2.1.Definitions of three-dimensional model and of digital twin

The concept of a virtual, digital equivalent to a physical product or the Digital Twin was introduced in 2003 at the University of Michigan Executive Course on Product Lifecycle Management (PLM) and later documented in a white paper setting a foundation for the developments of Digital Twins (grieves, 2014). Grieves and Vickers saw a world where a virtual model of a product would provide the foundations for product life-cycle management.
The initial description defines a Digital Twin as a virtual representation of a physical product containing information about the aforementioned product, with its origins in the field of product life-cycle management. Later on, Grieves expands on this definition by describing the Digital Twin as consisting of three components, a physical product, a virtual representation of that product, and the bi-directional data connections that feed data from the physical to the virtual representation, and information and processes from the virtual representation to the physical. Grieves pictures this flow as a cycle of data from the physical to the virtual, and of information and processes from the virtual to the physical (see Fig.2-1). The virtual spaces themselves consist of any number of sub-spaces that enable specific virtual operations: modelling, testing, optimisation, etc*(Snider,D , Nassehi,A, Yon,J, Hicks, B, 2020)*.

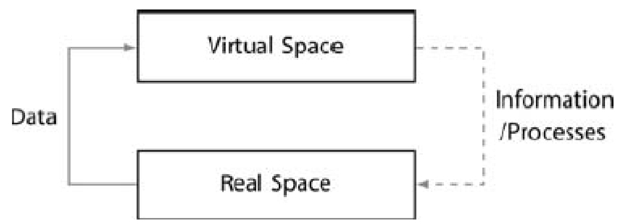


Fig.2-1.Mirroring and Twinning between the physical and Virtual Spaces_Source(Snider et al, 2020)

Consequently, the Aeronautical Space Administration (NASA) released a paper in 2012 entitled “The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles", setting a key milestone or defining Digital Twins. Based on this source, A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, history, etc., to mirror the life of its corresponding twin (Glaessgen, E., & Stargel, D. 2012).
Chen(2017) in their article called “Integrated and intelligent manufacturing: Perspectives and enablers” describes digital twin as a computerised model of a physical device or system that contains all functional features and links with the working elements. ***LIU et al.(2018)*** discuss the digital twin to be a “living model

of the physical asset or system, which continually adapts to operational changes based on the collected online data and information, and can forecast the future of the corresponding physical counterpart."

ZHENG et al. (2018) in an article called "An application framework of digital twin and its case study" emphasise on the digital twin being a set of virtual information thoroughly describing a potential or actual physical production from the micro atomic level to the macro geometrical level.

VRABI et al. (2018)wrote an article titled **"**Digital twins: understanding the added value of integrated models for through-life engineering services", stating that a digital twin is a digital image of a physical item or assembly using integrated simulations and service data. The digital representation holds information from multiple sources across the product life cycle. This information is continuously updated and is visualised in a variety of ways to predict current and future conditions, in both design and operational environments, to enhance decision making. The ***Defence Acquisition University*** definition of digital twin, commonly used in defence, aerospace and related industries, is:

"an integrated multiphysics, multiscale, probabilistic simulation of an as-built system, enabled by Digital Thread, that uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin." and ***NAFEMS council member Rod Dreisbach*** recently in the April 2018 issue of Benchmark Magazine defined it as:

"a physics-based dynamic computer representation of a physical object that exploits distributed information management and virtual-to-augmented reality technologies to monitor the object, and to share and update discrete data dynamically between the virtual and real products" *(Wright, L., & Davidson, S. 2020)* .One of the most recent definitions of digital twin is by ***MADNI (2019)***, illustrating digital twin as a virtual instance of a physical system(twin), being continually updated with the latter's performance, maintenance, and health status data throughout the physical system's life cycle. *IBM website* describes digital twin as a virtual model designed to accurately reflect a physical object(for example a wind turbine) which is equipped with sensors related to vital areas of its functionality, producing data about different aspects of the physical object's performance, namely energy output, temperature, weather conditions and more. The data is then processed and applied to the digital copy.

From these definitions it is clear that there are three important parts in the digital twin of an object:

A model of the object, an evolving set of data relating to the object, and a means of dynamically updating or adjusting the model in accordance with the Data (Wright, L., & Davidson, S. 2020).

The virtual model being fed with the data received, can be used to run simulations, study performance issues and generate possible improvements, all with the goal of generating valuable insights — which can then be applied back to the original physical object (IBM Website).

It is important to know that the model does not need to be a data-driven model, but it should produce results that are directly equivalent to a measured quantity (so that the model updating process is data-driven).

The use of evolving data means that it provides an accurate description of objects that change over time. A validated model can provide a snapshot of the behaviour of an object at a specific moment, but using that model within a digital twin can extend the use of that model to timescales over which the object and its behaviour will change significantly (Depending on the object or process, it can be seconds, or minutes, hours or even days).

The article "8 Myths About Digital Twins Exposed—Here's the Reality" by Joe Walsh In MyEngineering Website in July 2020. The article explains that any physical twin may have multiple associated digital twins for different purposes. Each digital twin can provide a specific capability or functionality. Different digital twins are developed for different purposes, with each digital twin providing the functionality to meet that particular purpose.

A digital twin does not need to cover the entire lifecycle of its physical counterpart. Different digital twins are each developed for different purposes, with a digital twin covering an appropriate portion of the physical twin lifecycle to align with the purpose of that particular digital twin. Communication of the digital twin with the physical twin can be intermittent or periodic (based on the reason), rather than streaming.

2.2. Digital Twin Misconceptions

There are some misconceptions and misunderstandings about the concept of digital entities. Some of these misconceptions are related to the functionality of the digital twin, some are the terms that have similarities to the concept and continue to be used interchangeably in the literature while in reality they are different types of entities by nature. This section tries to clarify the concept of digital twin by pointing out some points on the digital twin, and the differences with different types of entities.

2.2.1. Digital Model

A digital model is described as a digital version of a pre-existing or planned physical object, to correctly define a digital model there is to be no automatic data exchange between the physical model and digital model. Examples of a digital model could be but not limited to plans for buildings, product designs and development. The important feature is there is no form of automatic data exchange between the physical system and digital model. This means once the digital model is created a change made to the physical object has no impact on the digital model either way.

2.2.2. Digital Shadow

A digital shadow is a digital representation of an object that has a one-way flow between the physical and digital object. A change in the state of the physical object leads to a change in the digital object and not vice versus. Figure 1. Illustrates a Digital Shadow(Fuller, A., Fan, Z., Day, C., & Barlow, C. ,2020).

2.2.3. Digital Twin

If the data flows between an existing physical object and a digital object, and they are fully integrated in both directions, this constitutes the reference “Digital Twin". A change made to the physical object automatically leads to a change in the digital object and vice versa. Figure(2-2) illustrates a Digital Twin(Fuller, A., Fan, Z., Day, C., & Barlow, C. ,2020).

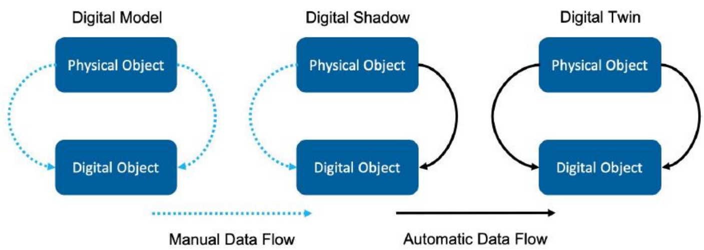


Fig.2-2.Digital Model,Digital Shadow & Digital Twin_Source:(Fuller et al, 2020)

2.2.4. Digital twins vs. simulations

Although both digital twins and simulations use digital models to reproduce a system's many operations, a digital twin is truly a virtual world, making it far more rich for research. The main distinction between a digital twin and a simulation is scale: A digital twin can run as many meaningful simulations as necessary to explore multiple processes, whereas a simulation normally only studies one specific process.
There are yet more variances. For instance, real-time data is typically not advantageous for simulations. However, digital twins are built around a two-way information flow that begins when object sensors give the system processor pertinent data, and continues when the processor shares insights with the original source object(IBM Website).

2.3.Types of digital twins

According to the IBM website, There are various types of digital twins depending on the level of product magnification. The biggest difference between these twins is the area of application. It is common to have different types of digital twins co-exist within a system or process. The following paragraphs are a brief explanation on their application and definitions.

Component twins/Parts twins
Component twins are the basic unit of the digital twin, the smallest example of a functioning component. Parts twins are roughly the same thing, but pertain to components of slightly less importance.

Asset twins
When two or more components work together, they form what is known as an “Asset”, which allows the study of the interaction of those components, creating a rich source of high performing data that can be processed and then developed as actionable insights.

System or Unit twins
The next level of magnification involves system or unit twins, which enable you to see how different assets come together to form an entire functioning system. System twins provide visibility regarding the interaction of assets, and may suggest performance enhancements.

Process twins
The macro level of magnification, called process twins, reveals how systems interact to build a whole manufacturing plant. Are all of those systems synchronised to run as effectively as possible, or will delays in one system have an impact on others? The specific timing schemes that eventually affect overall efficacy can be found with the use of process twins.
With the release of Mirror Worlds by David Gelernter in 1991, the concept of digital twin technology was first presented. But Dr. Michael Grieves, who was then a professor at the University of Michigan, is recognized as having introduced the idea of digital twin software and used it in production for the first time in 2002. Finally, in 2010, NASA's John Vickers coined a new phrase: "digital twin."
However, the core idea of using a digital twin as a means of studying a physical object can actually be witnessed much earlier. In fact, it can be rightfully said that NASA pioneered the use of digital twin technology during its space exploration missions of the 1960s, when each voyaging spacecraft was exactly replicated in an earthbound version that was used for study and simulation purposes by NASA personnel serving on flight crews.

2.4.Key concepts surrounding digital twin

D.Jones et al(2020) in their article called “Characterising the digital twin: A systematic review” describe some relative terms to the Digital Twin concepts, followed by a detailed review of the literature on the subject that led to the extraction of 13 characteristics that define a digital twin. These characteristics help us understand the nature of the digital twin as it should be and also how it should behave in the twinning process. The characteristics also help in the initial phase of the defining of a digital twinning project because they provide the basic elements to be decided before starting.
They defined digital twin as a complete virtual description of a physical product that is accurate to both micro and macro level. They introduced *“Digital twin prototype”* concept, as the virtual description of a prototype product, containing all the information required to create the physical twin; *“Digital Twin Instance”*, as a specific instance of a physical product that remains linked to an individual product throughout that product's life; *“Digital Twin Aggregate”* as the combination of all the Digital Twin instances; and finally *“Digital Twin Environment”* described as a multiple domain physics application space for operating on digital twins(Fig.2-3). Their provided diagram of twinning cycle(Fig.2-4) helps with further understanding the process of

twinning, and in more detailed way, they have depicted the use-cases and technologies in the twinning cycle(fig.2-5)

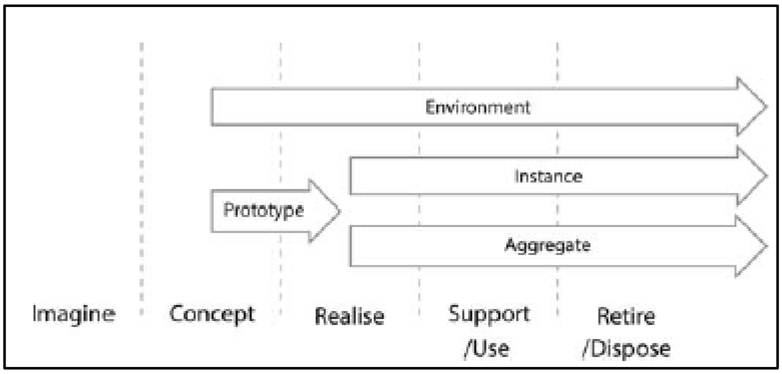


Fig.2-3.The scope and transitions/relationships between the Digital Twin elements and physical product_Source: (Jones et al, 2020)

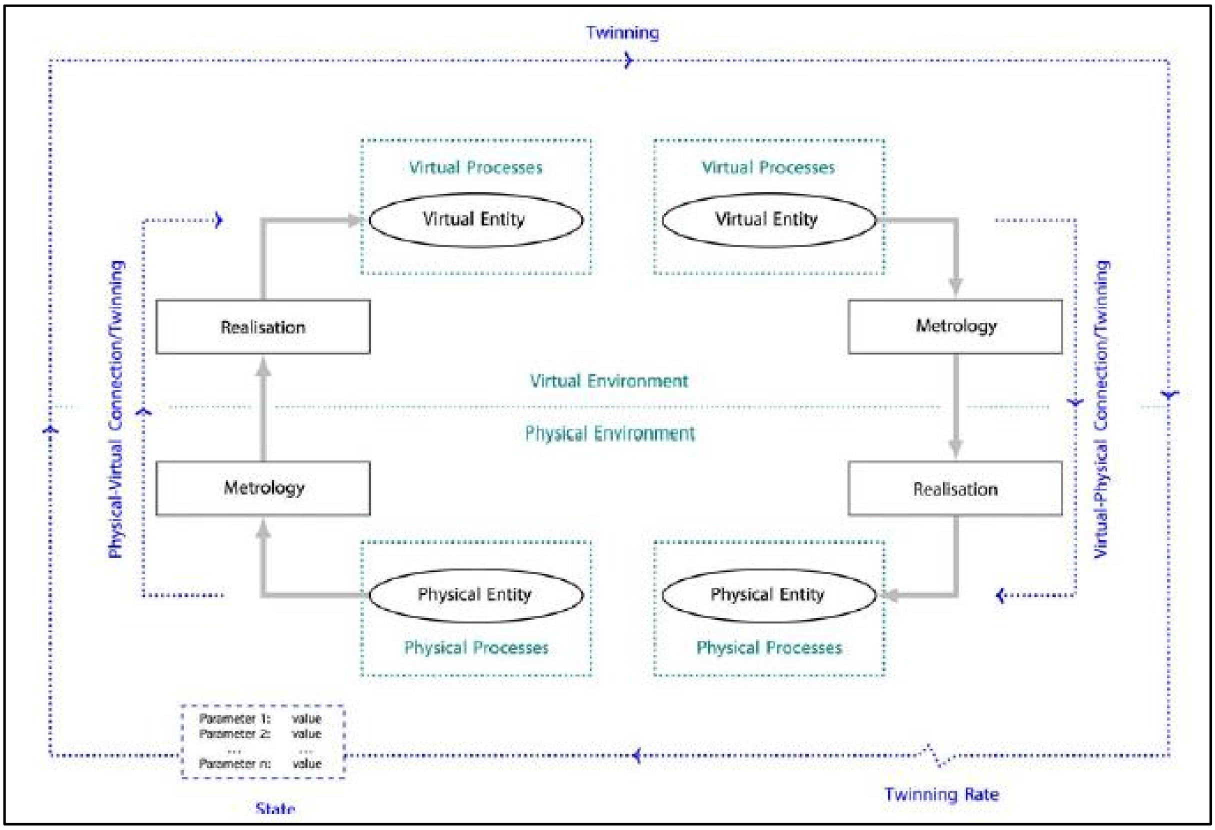


Fig.2-4.The physical-to-virtual and virtual-to-physical twinning process_Source: (Jones et al, 2020).

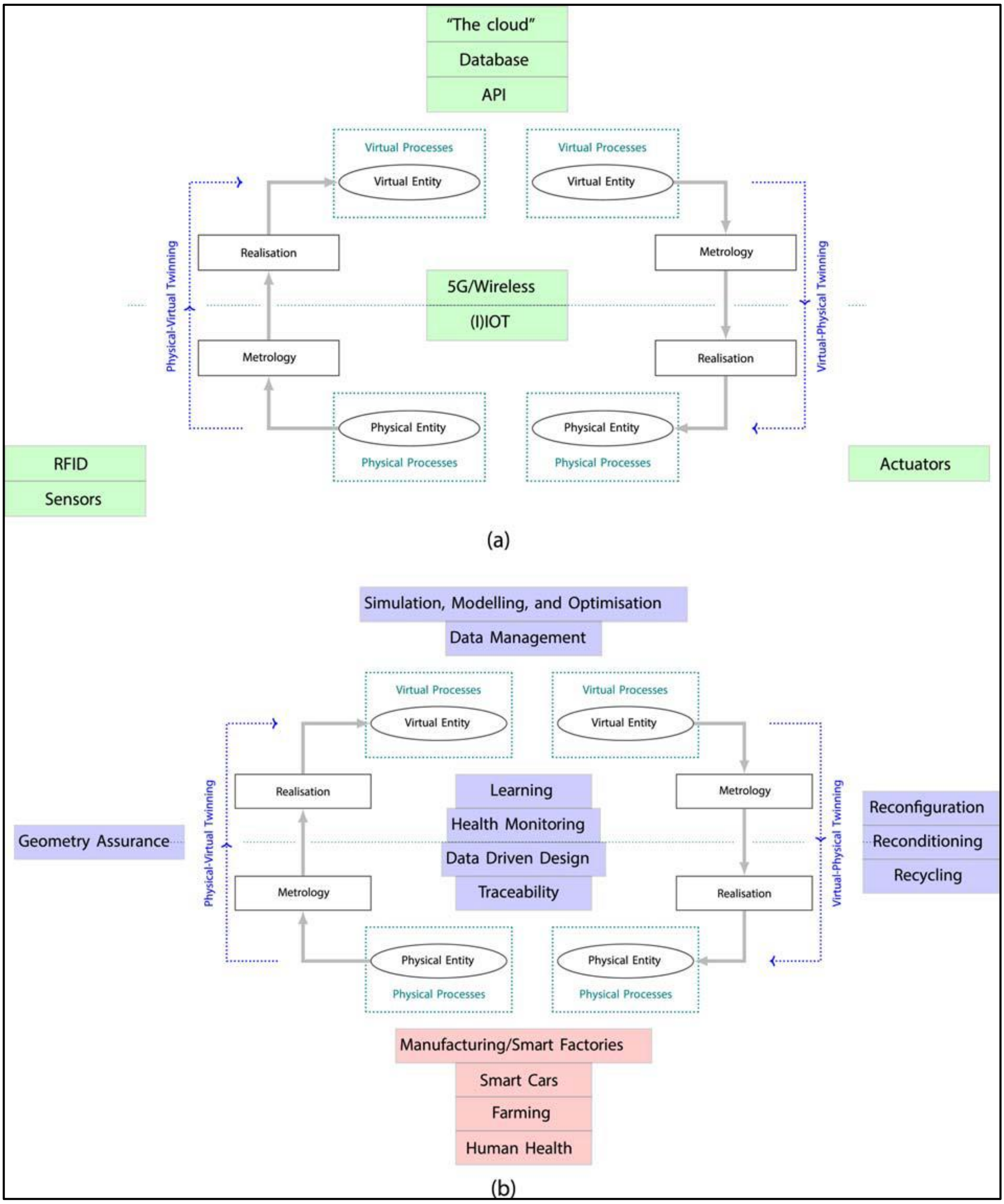


Fig.2-5. Use-cases (a) and technology (b) mapped to the twinning cycle_Source: (D.Jones et al. 2020).

Digital Twin Characteristic	Description
Physical Entity	A ‘real-world’ artefact, e.g. a vehicle, component, product, system, model.
Virtual Entity	A computer generated representation of the physical artefact, e.g. a vehicle, component, product, system, model.
Physical Environment	The measurable ‘real-world’ environment within which the physical entity exists.
Virtual Environment	Any number of virtual ‘worlds’ or simulations that replicate the state of the physical environment and designed for specific use-case (s), e.g. heath monitoring, production schedule optimisation.
Fidelity	The number of parameters transferred between the physical and virtual entities, their accuracy, and their level of abstraction. Examples found in literature include: fully comprehensive, ultra-realistic, high-fidelity, data from multiple sources, micro-atomic level to the macro-geometrical level.
State	The current value of all parameters of either the physical or virtual entity/environment.
Parameters	The types of data, information, and processes transferred between entities, e.g. temperature, production scores, processes.
Metrology	The act of measuring the state of the physical/virtual entity/twin
Realisation	The act of changing the state of the physical/virtual entity/twin
Physical-to-Virtual Connection	The connection from the physical to the virtual environment. Comprises physical metrology and virtual realisation stages.
Virtual-to-Physical Connection	The connection from the virtual to the physical environment. Comprises virtual metrology and physical realisation stages.
Twinning and Twinning Rate	The act of synchronisation between the two entities and the rate with which synchronisation occurs.
Physical Processes	The physical purposes and process within which the physical entity engages, e.g. a manufacturing production line.
Virtual Processes	The computational techniques employed within the virtual-world, e.g. optimisation, prediction, simulation, analysis, integrated multi-physics, multi-scale, probabilistic simulation.
Perceived Benefits	The envisaged advantages achieved in realising the Digital Twin, e.g. improved design, behaviour, structure, manufacturability, conformance, etc.
Digital Twin across the Product Life-Cycle	The life-Cycle of the Digital Twin – (whole life cycle, evolving digital profile, historical data)
Use-Cases	The applications of the Digital Twin, e.g. reducing cost, improving service, supporting decision making.
Technical implementations	The technology used in realising the Digital Twin, e.g. Internet-of-Things.
Levels of Fidelity	The number of parameters, their accuracy and level of abstraction that are transferred between the virtual and physical twin/environment
Data Ownership	The legal ownership of the data stored within the Digital Twin.
Integration between Virtual Entities	The methods required to enable communication between different virtual entities.

Table 2-1.Characteristics of a digital twin_Source:(D.Jones et al. 2020)

2.5.Digital Twin: Enabling Technologies, Challenges and Open Research

2.5.1.Digital Twin Applications

For the moment the term and concept of a Digital Twin are growing across academia, and the advancements in IoT and artificial intelligence(AI) are enabling this growth to increase. At this stage, the primary areas of interest are smart cities and manufacturing with some healthcare-related applications of Digital Twin technology found.

Smart Cities

The use and the potential for Digital Twins to be dramatically effective within a smart city is increasing year on year due to rapid developments in connectivity through IoT.
With an increasing number of smart cities developed, the more connected communities are, with this comes more Digital Twins use. Not only this, the more data we gather from IoT sensors are embedded into our core services within a city, but it will also pave the way for research aimed at the creation of advanced AI algorithms .

Manufacturing

The current growth is in line with the "*Industry 4.0"* concept, coined the 4th industrial revolution, this harnesses the connectivity of devices to make the concept of Digital Twin a reality for manufacturing processes. The Digital Twin has the potential to give real-time status on machines performance as well as production line feedback. It gives the manufacturer the ability to predict issues sooner. Digital Twin use increases connectivity and feedback between devices, in turn, improving reliability and performance. AI algorithms coupled with Digital Twins have the potential for greater accuracy as the machine can hold large amounts of data, needed for performance and prediction analysis. The Digital Twin is creating an environment to test products as well as a system that acts on real-time data, within a manufacturing setting this has the potential to be a hugely valuable asset(Fuller et al, 2020).
Digital Twins is used also in the automotive industry, most notably demonstrated by Tesla. The construction industry is another sector that hosts a range of applications for Digital Twin use. The development stage of a building or structure is a potential application for a Digital Twin. The Digital Twin gives construction teams greater accuracy when carrying out simulations as the algorithms can be applied in real-time within the Digital Twin before the physical building.
A common goal seen so far across the field of Digital Twins is this idea of real-time simulation as opposed to low detailed static blueprint models. The use of these models serves a purpose, but they are not using real-time parameters which limit the predictability and learnability. The Digital Twin can be learning and monitoring simultaneously, as well as applying machine and deep learning algorithms(Fuller et al, 2020).

2.5.2. Digital Twin In Industry

General Electric(GE) initialised their first digital twin patent in 2016 _ called **"Predix"** platform, which is a tool for creating Digital Twins, and used to run data analytics and monitoring processes(Fuller et al, 2020).
Siemens launched a cloud based platform, called "Midsphere", that helps with connecting machines/physical infrastructure to digital twins. The platform uses all the connected devices and billions of data streams(Fuller et al, 2020).
IBM, on the other hand, launched **"Watson IoT"** platform, which is an all around IoT data tool that can be used to manage large scale systems in real time, through data collected from millions of IoT devices. It also offers add-on services which are cloud based services, data analytics, edge capabilities and blockchain services(Fuller et al, 2020).
Talking about Digital Twin platforms using open data, we can name "Ditto" by ***Eclipse***, which is a ready to use platform that can manage the state of a digital twin, giving .. to the physical object and the digital twin.

Basically, it is a Backend role technology providing support for already connected devices and simplifies the connection and management of the digital twin. Another technology using open data, is imodel.js by ***Bentley Systems*** that facilitates creating, accessing and building the digital twin(Fuller et al, 2020).

2.5.3.Enabling Technologies of Digital Twin

Internet of Things(IoT) / Industrial Internet of Things (IIoT)

The Internet of Things is the term given to devices connected to the internet. It is about giving so-called “things" a sense of intelligence and the ability to collect information on their environment. The term was first published in the late 1990s With Kevin Ashton setting out his vision for IoT (K.Ashton, 2009). The idea that all devices that are interconnected gives the developer the ability to track and monitor everything we do, thus leading to a smarter world. An example of this is to be found many years earlier at Carnegie Mellon University in Pittsburgh(Fuller et al, 2020).

Here a programme would connect a Coca-Cola machine via the Internet to see if the drink was ready and cooled enough for a user to buy and consume: a simple but effective use case for Ashton's vision(Fuller et al, 2020).

Very much connected to the Internet of things, in literature there is also the term Industrial Internet of things with an added emphasis on industrial processes with the main focus outlined on improving productivity for industry(Boyes et al, 2018) .

Both IoT and IIoT have a wide range of essential areas that ensure the running of connected systems. These enabling technologies are classified into four main functional domains, which cover the individual enabling technologies from network communication, hardware and software to data processing, power and energy storage all with specific goals to enable the full development of an IoT system facilitating an Industry 4.0 architecture.

Data Analytics and Related Technologies

The term data analytics stems from the field of “Data Science", a multidisciplinary subject that covers a range of concepts, with an emphasis on collecting and presenting data for analysis to gain greater insight. needed. The term data analytics stems from the field of “Data Science", a multidisciplinary subject that covers a range of concepts, with an emphasis on collecting and presenting data for analysis to gain greater insight. The 5 building blocks of Data Analytics include the **Data** (Raw data to then be turned into usable information, ready for use in algorithms and statistical analysis), **Statistics** for collection, classification, analysis and interpretation of the data used to describe the observations of the data, underpinning the machine learning algorithms And finally **Artificial Intelligence** and in specific a subset of the AI _ **Machine learning_** which develops algorithm that enable computer to learn and act on behalf of the user without being explicitly programmed. Programs that employ advanced algorithms to gather and analyse data automatically, are made using machine learning. “Supervised Learning” and “Unsupervised Learning” are two different machine learning approaches that are applied in satellite image analysis methodologies. The most common type of machine learning is supervised learning. Large volumes of tagged data are analysed and learned by the algorithms. The algorithms receive test data to gauge their accuracy after learning from training data. (P. P. Shinde and S. Shah,2018). On the other hand, unsupervised learning algorithms learn using its own methods in classifying and highlighting patterns within data instead of relying on user feedback. Deep learning techniques, a subset of machine learning, learn from unstructured and unlabeled data utilising sophisticated neural networks with automatic feature extraction rather than manual feature extraction. These networks use machine learning to build deep learning models, which can be more accurate but need longer to train due to the considerably larger neural networks. Semi-supervised learning is a different sort of learning that uses some labelled data along with other unlabeled data to examine how the algorithms might improve over time.(A. S. Modi,2018).

Data Visualisation is the last step of the process of Data Analytics. Fuller et al (2020) describes data visualisation as the graphical representation or visualisation of data or results, which can be different based on the data types and their complexities and dimensions of the result data.

2.5.4.Building blocks of a Digital twin

Fuller et al(2020), refer to work of Bibri and Krogtie(2017) to provide an architectural model for realising a digital twin, classified in 4 main domains described in this section.

1.The application domain(D9) which is made up of three important layers:

1.The model architecture and visualisation layer essential for creating high-fidelity models of the physical entity(Based on the characteristics that need to be studied). Examples of the enabling tools are Simulink and Twin Builder.

2.The Software and API(Application programming interface) layer, specifically used to aid in the modelling of such Digital Twin architecture facilitating the third layer (pre-processing and collection).

3.Pre-processing & Collection layer: This layer ensures the data is harvested correctly to facilitate the use of IoT and analytics for a Digital Twin while also bridging domain D9 to D10. Some common tools to be used in this layer are Predix, Mindsphere and Storm.

2.The middleware domain(D10), consists of:

1. storage technology/Database Layer: namely MongoDB, MySQL services and on-demand databases which are needed for Digital Twin use.

2.Data processing Layer: it is essential to transfer the stored data between D10 and D11.

3.The Network Domain(D11) with two enabling layers:

1.The communication Technology layer essential in ensuring the data collected is communicated between domains

2.The wireless communication layer, which is needed to ensure the transmission of data wirelessly follows the correct protocol within a Digital Twin architecture as well as bringing data to the next domain, D12.

4.The object domain(D12), consists of two enabling layers, both of which are needed to ensure the correct hardware is in place to conduct Digital Twin analysis, as well as facilitating the collection of data through sensor technology.

1. The hardware platform

2.The sensor technology.

Domain	Enabling Technology
D9 Application Domain	Model Architecture and Visualisation
	Software and APIs
	Data collection and Pre-processing
D10 Middleware Domain	Storage Technology
	Data Processing
D11 Networking Domain	Communication Technology
	Wireless Communication
D12 Object Domain	Hardware Platform
	Sensor Technology

Table 2-2.Enabling Technologies & Functional Blocks of Digital Twin_Source:(Fuller et al, 2020)

2.5.5.Challenges

The challenges for both the Industrial IoT/IoT and data analytics are also shared challenges for the application of a Digital Twin(Summarised by the end of the section). Despite the challenges Digital Twin shares with IoT and data analytics from a user perspective to the privacy and infrastructure challenges of Digital Twin, there are also specific challenges relating to the modelling and building of the Digital Twin, listed below:

1) IT Infrastructure
The Digital Twin needs infrastructure that allows for the success of IoT and data analytics; these will facilitate the effective running of a Digital Twin. Without a connected and well thought through IT infrastructure, the Digital Twin will fail to be effective at achieving its set out goals(Fuller et al, 2020).

2) Useful Data
Data collection for a digital twin presents the next challenge. It must have high-quality data that is noise-free and has a continuous, unbroken data stream. If the data is inaccurate and inconsistent, there is a chance that the Digital Twin will perform poorly since it will be acting on inaccurate and missing data. For Digital Twin data, the strength and quantity of IoT signals are crucial. To choose the appropriate data to be gathered and used for an effective use of a Digital Twin, planning and analysis of device usage are required(Fuller et al, 2020).

3) Privacy And Security
It is obvious that the privacy and security issues with digital twins present a barrier in an industrial context. They are problematic for sensitive system data both because of the enormous volume of data they use and because of the risk they offer. Data analytics and IoT, the two essential enabling technologies for Digital Twins, must adhere to the most recent security and privacy rules in order to overcome this problem. Trust difficulties with digital twins are addressed in part by taking security and privacy into account(Fuller et al, 2020).

4) Trust
Both from an organisational and user perspective, trust has its difficulties. To ensure that end users and organisations understand the benefits of a Digital Twin, which will strive to overcome the trust barrier, more discussion and foundational explanation of the technology is required.
Another approach to overcoming the problems with trust is model validation. For user trust to be maintained, it is crucial to confirm that Digital Twins are operating as anticipated. With more knowledge, digital twins are more widely trusted. The enabling technology will provide deeper understanding of the procedures to be followed to secure privacy and security practices throughout development, addressing difficulties with trust(Fuller et al, 2020).

5) Expectations
Industry leaders Siemens and GE are speeding up the use of digital twins, but caution is needed to emphasise the problems with expectations for digital twins and the need for additional knowledge. Organisations will employ Digital Twin technology if they have strong IoT infrastructure foundations and a better grasp of the data needed for analytics. It can be difficult to refute the notion that the Digital Twin should only be employed in light of current developments. To guarantee that the proper steps are taken while establishing Digital Twin systems, the advantages and disadvantages of the expectation of Digital Twins must be explored(Fuller et al, 2020).

6) Standardised Modelling
Because there is no standardised technique to modelling, the next issues in all types of a Digital Twin development relate to the modelling of such systems. Whether it be physics-based or design-based, there needs to be a uniform approach from the initial design through a simulation of a Digital Twin.
In addition to ensuring information is shared across each step of the creation and implementation of a Digital Twin, standardised methodologies also ensure domain and user knowledge(Fuller et al, 2020).

7) Domain Modelling
Making sure information about the domain use is conveyed to each of the development and functional stages of the modelling of a Digital Twin presents another issue as a result of the requirement for standardised use. As a result, the Digital Twin will be effective in the future when applied to fields like IoT and data analytics.

Table 03 shows a summary of challenges for both data analytics and I/IoT while showing the overarching combined challenges for a Digital Twin, with challenge six and seven specifically for Digital Twin implementation.

Digital Twin	
Data Analytics	***Industrial IoT/IoT***
IT Infrastructure Data Privacy Security Trust Expectations	IT Infrastructure Data Privacy Security Trust Expectations Connectivity

Table 2-3_ shared challenges of Digital twin with Data Analytics and Industrial IoT_Source: (Fuller et al2020)

2.6.DT and Earth Observation

2.6.1.DT and Earth Science applications: State of the Art

Earth observations are invaluable for assessing and mitigating the negative impacts of the increasingly powerful influence of human civilization. Furthermore, they can be used for exploiting new opportunities, such as the sustainable management of natural resources.
Earth observation is the collection of data using remote sensing technologies, typically using satellites carrying imaging equipment, regarding the physical, chemical, and biological processes of planet Earth. Earth observation is used to track and evaluate changes in the environment, both natural and artificial, as well as their condition. When paired with suitable method development and study, space-based technologies give repeatable datasets that offer a singular way to collect data about the globe. Examples include the ability to quickly analyse situations during crises like extreme weather occurrences or times of human conflict and the monitoring of the condition and evolution of our environment, be it on land, at sea, or in the air(European Commission website, earth observation).
A birdwatcher's notes on bird sightings, numerical measurements taken by a thermometer, wind gauge, ocean buoy, altimeter or seismograph , photographs, Radar and sonar images, analyses of water or soil samples and processed information such as maps or forecasts are a few examples of many different kinds of Earth observations (GEO Website). Today's Earth observation instruments include floating buoys for monitoring ocean currents, temperature and salinity, land stations that record air quality and rainwater trends, sonar and radar for estimating fish and bird populations, seismic and Global Positioning System (GPS) stations, and over 60 high-tech environmental satellites that scan the Earth from space.

Today's problems that are most threatening to the planet take the form of scarcity of food, water, human health, disasters, habitat endangerment and climate change. Earth observation products, including remotely sensed satellite data and the vantage of space can help achieve the common goals of today's globalised community by providing a common data resource and global-view infrastructure that can be used for making various critical decisions.
Satellite data is nowadays used in many different fields of studies and has opened many possibilities for our world including tracking biodiversity and wildlife trends, measuring land use change such as deforestation, mitigating, and managing the impact of natural disasters, including fires, floods, earthquakes, and tsunamis, sustainably managing natural resources, such as energy, freshwater, and agriculture, address emerging diseases and other health risks, and predicting, adapting to, and mitigating climate change (Anderson,K et al, 2017).
Here we will review some examples with the technologies used:
Thanks to the Soil Moisture Active Passive (SMAP) mission, high resolution global soil moisture data is available for worldwide use with potential application in operational meteorology, disaster management, and

food security. Similarly, highest resolution topographic data generated from NASA's Shuttle Radar Topography Mission (SRTM) has been released globally with successful applications in hydrology, land cover analysis, carbon biomass assessment to name a few (Kansakar, P., & Hossain, F. , 2016).

Land-use and land-cover (LULC) maps are another application of earth observation that can be a very useful tool in understanding the causes and consequences of climate change on hydrology, biodiversity, carbon dynamics, population, migration, and urbanisation. The LULC maps can effectively present visual data that inspires both decision-makers and the general public to use resources more sustainably. For LULC mapping, Landsat imagery is particularly advantageous because of its spatio-temporal consistency and reliability with data collected over the last four decades. However, when using Landsat images, image corrections may be necessary to interpret the data accurately as there could be issues with image resolution and quality (Kansakar, P., & Hossain, F. , 2016).
Another purpose of using the Earth observation data can be Carbon biomass assessment since forest biomass is a critical indicator of carbon sequestration. In addition, satellite data is used in order to monitor agricultural crops and agriculture and food security. For example MODIS satellite data is used in developing vegetation indices that provide consistent spatial and temporal comparisons of vegetation properties used to track drought conditions that may threaten subsistence agriculture . Another service of the earth observing satellite data, is for disaster management. Maps showcasing the spatial extent of disaster, and assessing the pre- and post-disaster effects are some of the most simplistic ways that remote sensing technology can help with disaster management efforts.

Other sophisticated applications include using water extent data from instruments like Moderate Resolution Imaging Spectroradiometer (MODIS) and near real- time precipitation data to model potential flood inundation and ultimately improve flood management (Kansakar, P., & Hossain, F. , 2016).
Some natural disasters cause other problems, for example landslides. Resources like Global Landslide Catalogue developed by NASA provide an inventory of the effects of landslides around the world including the associated number of fatalities. Complex technologies are currently being explored to provide a more in-depth understanding of conditions that induce landslides. Sensors like optical remote sensing such as MODIS, Shuttle Radar Topography Mission (SRTM), Soil Moisture Active Passive (SMAP), and Synthetic Aperture Radar techniques are being used to assess landslide density, areal extent, frequency, and other variables important in assessing the vulnerability of an area to landslides such as soil moisture, slope, aspect, etc. Another available resource is the susceptibility map developed using Landslide Hazard Assessment Situational Awareness (LHASA) model (Kansakar, P., & Hossain, F. , 2016).

2.6.2.Digital twin and earth observation data

Using real and runtime data provided by Digital Twins in urban planning can lead to better decision-making that is efficient in terms of cost and operation, and allows better management of problems related to urbanisation and other levels of spatial management (Lee et al, 2022).
Cities are the most geographical spaces for which digital twin creation is attempted. The different technologies used in order to create the digital twins so far are Surveying and mapping technology, building information modelling (BIM) technology, IoT, 5G, collaborative computing, blockchain, and simulation. The technologies mentioned above play different roles in City Digital Twins:
Surveying and mapping technology is the basis for collecting the static data of the buildings in cities. BIM technology is the basis for the asset and infrastructure management of cities. IoT and 5G are the bases for collecting dynamic data and feedback effectively. Blockchain technology is the basis for the trust mechanism of transactions, logistics, and human behaviour. Collaborative computing with 5G is the basis for efficient real-time responses. Simulation technology is the basis for policy support, planning, and early warning mechanisms (Hudson,2022).

The DTC focuses on instantaneity and accuracy, which requires highly automated mapping and surveying technology. Surveying and mapping technology in cities has two segments: surveying the topography,

environment, and spatial structure of the city, and mapping this information into an integrated system based on geographic information system (GIS). In the surveying part, four technologies are considered: tilt photography, unmanned aerial vehicle (UAV), 3D laser scanning, and global positioning system (GPS). In the mapping part, two technologies are considered: real-world 3D reconstruction technology and multi-source geographic data processing technology (Hudson,2022).
In recent years, with the maturity of tilt photography and UAV technology, real-time and accurate acquisition of local ortho, tilt, or Lidar point cloud data in cities can greatly reduce the workload of field mapping. These unmanned facilities make full use of their respective advantages to make comprehensive measurements of urban entities from the land, sky, rivers, and underground space while implementing iterative data updates(Deng a, T et al, 2021). As mentioned before, the role of Earth observation technologies- here Unmanned aerial vehicles(UAV)- in feeding a digital twin are undeniable and cruicial. In fact, drones are effectively employed to monitor environmental catastrophes in unsafe locations, such as during floods or after storms. Drones may be used in cameras, thermometers, humidity and pressure sensors, wind gauges, and other sensors, allowing them to collect vital environmental data and to be incorporated within the digital twin(Hudson,2022).

Some studies, on the other hand, focus on the managerial capacities that a Digital Twin for a spatial domain can offer. For example (Lee et al, 2022) realised that the suggested digital twins of the cities, lacked attention for managing individual mobility data, such as those of the vehicles and pedestrians, which constitute major components of a city. They proposed a geospatial platform based on the universal game engine Unity3D, which managed large-scale individual mobility data for a UDT platform. The proposal consisted of a platform which stored and managed individual vehicles or pedestrians using information from public closed circuit television. It also allowed the generation of long-term route information for a unique vehicle based on its licence plate. In addition they proposed methods to anonymize licence plates, to ensure the security of individuals, and to compress individual mobility data (Hudson,2022).

Earth Observation and the Sustainability Goals

The *"Group on Earth Observations(GEO)"* was described in the *"2002 World Summit"* on "*Sustainable Development Implementation Plan"*, launched in 2005, and has been supported by a succession of G20 and G7/8 meetings, responding to the need for coordinated observations relating to the state of the Earth. In September 2015, the United Nations (UN) General Assembly endorsed "Transforming Our World: the 2030 agenda for Sustainable Development", a global development agenda for all countries and stakeholders to use as a blueprint for progress on economic, social, and environmental sustainability. Seventeen *Sustainable Development Goals(SDGs)* and associated Targets and Indicators anchor the *2030 Agenda*, which specifically calls for new data acquisition and exploitation of a wide range of data sources to support implementation (Anderson,K et al , 2017).

GEO and the GEOSS contains EO from diverse sources, including satellite, airborne, in situ platforms and citizen observatories, which, when integrated together, provide powerful tools and insights for understanding the past and present conditions of Earth systems, as well as the interplay among them. Taken together with geospatial information and technologies, EO offers a unique global platform for pursuing societal benefits towards a more sustainable, safer, and viable future. At a national level, EO are carried out by a variety of actors, such as the US National Oceanic and Atmospheric Administration (NOAA), the US National Aeronautics and Space Administration (NASA), the US Geological Survey (USGS), the ESA, the UK Meteorological Office, Geoscience Australia and others, all using the 200 million data sets available. The use of GEOSS data and information has grown exponentially, receiving more than 4 million inquiries in 2016 alone. The statistics are live at GEO DAB STATISTICS (GEO DAB 2017). GEO curates the GEOSS Portal and the GEOSS Discovery and Access Broker component, allowing the end-user to discover, access and retrieve EO. The combined portal and data access broker are referred to as the GEOSS Common Infrastructure (GCI) (Anderson,K et al, 2017).

2.7.Forest and Forest Digital Twin

The Principal Scientist at VTT, Matti Motus, describes the Forest Digital Twin's operation in an article that can be found on the website of the European Space Agency. "This digital twin will be a specialised Digital Twin of Earth, providing a reconstruction of the forest system at levels of detail not possible with generic land surface models" he writes. We can obtain distinctive and consistent data for all forests worldwide thanks to satellite-based Earth observation, particularly the high-quality Copernicus Sentinel data.This needs to be translated into an understanding of forest structure and used to inform models of how forests work. Local measurements are far more dispersed and varied (ESA Website ,2021).
This section is dedicated to the definition of common terms in forestry and continues to describe a framework based on the available literature.

2.7.1.Forest Definitions

Forests are viewed, defined, assessed, and valued through different lenses. From different vantage points, forests can be seen as a source of timber products, an ecosystem composed of trees along with myriad forms of biological diversity, a home for indigenous people, a repository for carbon storage, a source of multiple ecosystem services, and as social-ecological systems, or as all of the above From the ‘‘land cover’’ perspective, forests are viewed as ecosystems or vegetation types supporting unique assemblages of plants and animals. But from the ‘‘land use’’ perspective, forests
are landholdings that are legally designated as forest, regardless of their current vegetation. Within this construct, a legally designated ‘‘forest’’ can actually be devoid of trees, at least temporarily. No single operational forest definition can, or should, embody all of these dimensions (Chazdon, R et al. 2016).

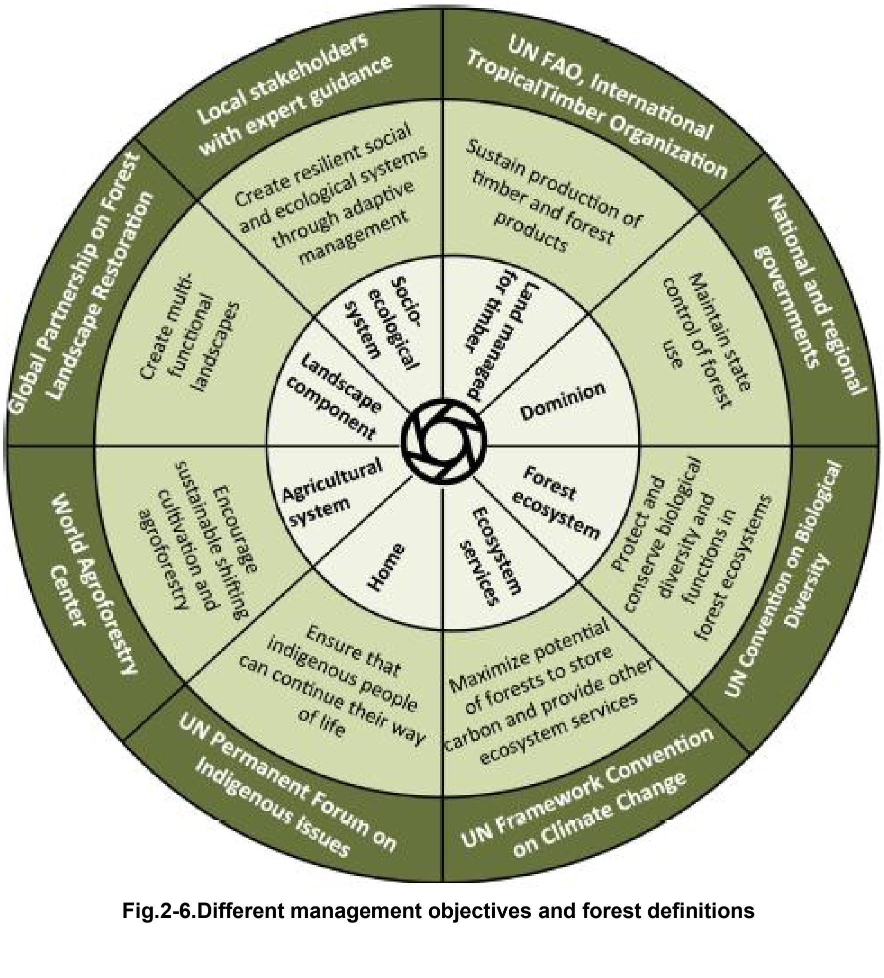


Fig.2-6.Different management objectives and forest definitions

Forest definitions adopted by major international environmental and forestry organisations:

United Nations Food and Agriculture Organisation (FAO):
land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. The trees should be able to reach a minimum height of 5 m at maturity in situ. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 % or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest (SDG Indicator metadata, 2022).

United Nations Framework Convention on Climate Change (UNFCCC, 2009)
The UNFCCC defines a forest as an area of land 0.05–1 hectare in size, of which more than 10–30% is covered by tree canopy. Trees must also have the potential to reach a minimum height of 2-5 metres. Countries participating in the UNFCCC can choose how they want to define a forest from within those ranges.A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown cover of 10–30 % or tree height of 2–5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest (Nature website, 2009)

United Nations Convention on Biological Diversity (UN-CBD,2010)
A land area of more than 0.5 ha, with a tree canopy cover of more than 10 %, which is not primarily under agriculture or other specific non-forest land use. In the case of young forest or regions where tree growth is climatically suppressed, the trees should be capable of reaching a height of 5 m in situ, and of meeting the canopy cover requirement United Nations Convention to Combat Desertification (UN-CCD; 2000) Dense canopy with multi-layered structure including large trees in the upper story;

International Union of Forest Research Organisations (IUFRO,2002)
A land area with a minimum 10 % tree crown coverage (or equivalent stocking level), or formerly having such tree cover and that is being naturally or artificially regenerated or that is being afforested

2.7.2.Forest Functions

Forests provide a variety of ecological, economic and social functions. Some ecological functions of forest include moderating role of forests(albedo, evapotranspiration, etc.), buffer role (carbon cycle, etc.), precipitation stimulation (increases rainfall volume, humidity, rough surface, fog condensation, etc.), wind action protection (hedges protect fields and buildings, mixed woodland and pasture protect microclimates, roughness slows wind speed down, stabilises dunes, etc.), air quality and purification functions, Controlling rising water levels(runoff reduction, infiltration of excessive rainfall, water reserves, etc.), water purification and sediment reduction, Reduction of diffuse erosion and in fragile areas, natural risk protection(torrential and sudden rises in water levels, avalanches, landslides and falling rock), noise pollution filtering, biological diversity(conservation at all levels (genetic,species and habitat diversity) and preservation of evolution potential, maintaining liaisons and corridors, dynamic conservation by linking up forest areas into a network (Gabban,A et al, 2008).

Considering the economic aspect, forests are the source for Industrial wood and fuel wood. In addition, they are the source for other raw materials, namely Wood-derived chemicals, cork and bark(isolation, cork stoppers), decorative plants (production of the decorative plants i.e christmas tree). They are also a source for gathering for domestic or commercial use (mushrooms, small fruit, chestnuts, honey, seasonal flowers, etc.). Forests also provide different services that produce economic revenue, for example environment for recreation and providing nourishment (i.e grazing), agricultural and mining resources (tropical forests), hunting rights, source of employment, leisure activities and tourism, rural area maintenance and activities (Gabban,A et al, 2008).

Forests affect the social aspect of societies by providing landscape, leisure activities such as hunting, and other leisure sports and ecotourism. Furthermore, forests assist in information-sensitising for the citizens through various modes like the contact between foresters and the public, and some events and guided visits etc. Forest-related concepts can also be incorporated into educational programmes to raise more awareness (Gabban,A et al, 2008).

2.7.3.Digital Twin of Forest (The literature)

Searching into the available literature at the current time, it is evident that the literature on digital twins in the context of forest systems seems to be new. In fact, the number of researches about forest digital twin or wildfire digital twin is still not well-developed, and is in the phase of formation in the past few years since using digital twins in the field is an extremely new trend. Among the present literature, few of the papers or projects focused on using the remote sensing “satellite data” among the other data sources used to feed the digital twin, and not all of them use it in order to monitor or deal with wildfire, rather they focus on the forest and its general processes. The objectives of the digital twins in the following papers/projects are different based on the users and stakeholders, but monitoring, prediction and real-time communication have been among the main purposes.

Zohdi (2022), in his paper called “A machine-learning framework for rapid adaptive digital-twin based fire-propagation simulation in complex environments”, proposed a machine learning algorithm(MLA) with multistage/multicomponent fire spread models. The presented framework was designed to run quickly on laptops and handheld devices, with the guiding principle being to make it potentially useful for first-responders in real-time, integrated with firefighting tools, harmoniously incorporating rapid data collection from satellites, UAVs, social media, etc to communicate the fire-behaviour (Zohdi, 2020).
In 2022, Jiang et al in their article called “Forestry digital twin with machine learning in Landsat 7 data”, presented a research for which they used “Landsat7” remote sensing time series images as the input of a machine learning data processing algorithm, to create a digital twin of the fire. Their digital twin goal is developed to be an effective tool in forestry succession analysis based on the LSTM model to fit the historical image data of the study area so that it could predict the future remote sensing images. The prediction results show that the method can predict the development of forestry images to a certain extent and works effectively as a forestry prediction twin and future remote sensing images (Jiang et al, 2022).
Buonocore et al. (2022) in his research paper named “A Proposal for a Forest Digital Twin Framework and Its Perspectives”, tries to demonstrate that it is possible to examine forest ecosystems through the combined analysis of various data sources thanks to cutting-edge technological advancements in the systems for recording the state variables of forest ecosystems at both tree and forest levels, as well as the availability of quickly scalable cloud services like servers, storage, and database, networking, and connectivity. Depending on the use cases that a particular implementation of the framework would support, the integration of various data sets might be utilised for research purposes, for reporting the health condition of forests, and finally for adopting sustainable forest management techniques. In his proposed framework for forest digital twin(FDT), among various technologies, he suggests using satellite images to monitor species diversity, stand structure and hydrological basin parameters (Buonocore et al, 2022).
Some of the available projects and activities regarding digital twin of forest/ forest fires, referred to the projects that would be completed in the future, therefore very few technical details and the output results are accessible at the moment. For example, the European Space Agency (ESA) commissioned VTT Technical Research Centre of Finland, collaborating with the University of Helsinki, the Romanian Forest Research and Management Institute and companies from Germany, Poland and Finland to develop a prototype version of the forest digital twins in 2021 to be supposedly delivered by the end of the same year.

There is not much clarity of how the digital twin would look like, but, according to the researchers of the project, the characteristics of the output Digital Twin will depend on the needs of its users, however, in addition to showing changes in the forest carbon storage, it could be used to model and predict such things as the increase of timber stock and the health of trees on the basis of changes in forestry operations or the climate. Satellite images would be used to model the forests. In addition to forest data, important input includes weather data and climate scenarios KAUPPI, 2021).

Castillo(2021) reported about a digital twin project based on Nvidia's annual GPU Technology Conference, in which Rev Lebaredian, vice president of simulation technology and Omniverse engineering at Nvidia, highlighted the launch of an artificial intelligence (AI) simulation lab in Silicon Valley that would be dedicated to predicting and responding to wildfires. The project will be carried out with Nvidia's digital-twin technology by a collaboration between the tech brand, Lockheed Martin with its Cognitive Mission Manager system, the U.S. Department of Agriculture Forest Service and the Colorado Division of Fire Prevention & Control. Fire officials will be able to study a real-world wildfire's behaviour in the virtual space, in real time, and run simulations projecting what could happen in the future using this digital twin (Castillo, 2021).

Another ongoing project is the EU-funded SPACE TWIN project, which would investigate how drought, fire and logging disturbances influence a variety of tropical and temperate forest ecosystems. Utilising the most detailed structural and radiometric 3D forest models ever built, it will digitally reproduce real-world forest areas. By using time series of the most detailed structural and radiometric 3D forest models, it will lead to an improvement in our ability to observe, quantify and understand forest disturbances. Among the main targets of the forest digital twin were the near-real time inversion of remote sensing of forest disturbances using emulation and the embedding of forest structure in the global observation process to understand the uncertainties in monitoring disturbances (CORDIS Website, 2022). Another digital twin forest project developed by Metsä Group in Finland in collaboration with Tieto4. In the Mistra digital forest, there is no particular focus on novel visualisation techniques. It starts from the needs of the end users to create a smart twin of the forest to demonstrate the added value, creates a platform that can increase the ability to show the added value of the products and services of the participating partners for a specific part of the market, and shows how information can support forestry. The sources have not clarified which input types would be fed to the digital twin, and similar to the other presented projects, the results are still not available (VisualSweden Website).

Brook (2022) in a website article, explains how digital twin technology can create a highly accurate 3-D model of an entire network, which — when combined with other data sets — can be used to accurately model risk relating to the network and its surroundings and manage the wildfire risks. According to the article, One digital twin technology being adopted by utilities in the wildfire-prone parts of Australia is Neara Platform. This physics-enabled platform builds 3-D interactive models of critical infrastructure networks and assets, providing the ability to run real-world scenarios, assess current and future risks, and prioritise network investment, maintenance and disaster response. For better Vegetation Management Neara ingests and classifies light detection and ranging (LiDAR) data to produce highly accurate virtual representations of network assets and their surroundings. It can simulate all these conditions and highlight areas where conductor clashing or pole failure might occur and lead to wildfire, so utilities can easily identify potential problems in the network model before they occur. Another key part of fire mitigation is ongoing asset maintenance, because fire is often caused by failure of aged and damaged infrastructure and digital twins can facilitate it (Brook, 2022).

Yun, Kwon & Kim(2022), in their recent papers titled "A Novel Digital Twin Architecture with Similarity-Based Hybrid Modeling for Supporting Dependable Disaster Management Systems", proposed a digital twin architecture to provide accurate disaster prediction services with a similarity-based hybrid modelling scheme which would compensate for the errors of physics-based prediction results with a data-driven error correction model to enhance the prediction accuracy. For monitoring behaviour, the digital twin updates the sensing attributes to track the real-time status of the physical twin by collecting disaster observation data through the IoT interface. Evaluations in wildfire scenarios showed that the proposed digital twin decreases prediction errors by approximately 50% in the disaster spread prediction results compared with the existing disaster models (Yun, Kwon & Kim, 2022).

Wallgrun et al (2021) in their research titled “Embodied digital twins of forest environments” addressed the concept of embodied digital twins of real-world forest environments to support research, education, communication, and decision-making. They also presented the prototype of an iVR embodied digital twin intended as an interactive workbench for analysing remotely sensed forest data. They generated the iVR environment from 360° images taken at different locations and heights including drone-based images, and then added audio narrations and complementary media. According to the paper, while a pure 360° based approach allows for producing a highly realistically looking digital twin quickly and cost-efficiently, the movement and interaction options are typically too limited to provoke a high sense of embodiment (Wallgrun et al, 2021). Another research aiming for prediction, is the work of Zhang et al(2022), titled “ Reduced order digital twin and latent data assimilation for global wildfire prediction”, concatenated the climate and wildfire data and processed into time-series data and fed into the training predictive model. To increase the accuracy of global wildfire predictions, they developed a JULES-INFERNO-based digital twin fire model employing ROM methods and deep learning prediction networks. The suggested model's iterative prediction technique can use data from the current year to forecast fires in succeeding years. Latent data assimilation (LA) was used in the prediction process to prevent the accumulation of mistakes from iterative prediction. LA is able to effectively modify the prediction results in order to guarantee the predictability and sustainability of the outcome. The 20 models that have been developed may successfully encode the actual data and produce reliable surrogate predictions, according to numerical results (Zhang et al, 2022).

This section reviews the efforts done by scientists, businesses and organisations in order to implement the concept of digital twin for forests/forest fires and further on describes a main theoretical framework based on the paper done by Buonocore et al(2022) in order to summarise the main building blocks and the technological enablers of a possible forest digital twin, that could be used for different purposes, and be then tailored down for the purpose of the research _wildfire monitoring using remote sensing.

2.7.4.The benefits of the Forest Digital Twin Framework

Creating a FDT based on the aforementioned framework, considers biotic and abiotic interactions among trees enabling the prediction of the forest not only by a sum of tree behaviours but also from their interactions, taking into account also non-linear effects at forest stand scale. Which could help for a better understanding of drought-induced tree and forest mortality.

Furthermore, the suggested paper enhances the monitoring and verifiability of the status of the forest ecosystem services leading to lower the risk of the health of the forest ecosystem services by incorporating early warning systems based on the tracking of state variables at the tree and forest levels. Lastly, it helps increase the liquidity of the ecosystem assets and boost capital flow towards sustainable methods of forest management (Buonocore et al, 2022).

The framework studied by Buonocore and his colleagues, has had a thorough approach that benefits it with various advantages. Firstly, since the information is recorded in different ways and forms (e.g., IoT, remote sensing, and national forest inventories), it helps create a new data lake from tree to forest level available for modelling. In addition, thanks to a cloud-native design, similar to the digital twin implementations for manufacturing, the solution would underpin the collection, storage, and analysis of data recorded in different ways and forms (e.g., IoT, remote sensing, and national forest inventories), creating a new data lake from tree to forest level available for modelling. Finally, punctual monitoring at tree level could enable a better prediction of the impact of forest management actions on ecosystem services (Buonocore et al, 2022).

2.7.5.General Building Blocks of the Framework

The proposed framework suggests designing a forest digital twin(FDT) to ultimately exploit the technological advancements of data collection at tree level in combination with well-established forest monitoring technologies like remote sensing. The research, suggests a five-step approach as follows in order to design the digital twin of forest area:

1.Twinning the tree and the surrounding environment as the fundamental unit of the forest—this design principle could ensure the highest data granularity by having a stream of information on the physical and physiological processes of trees forming the forest.
2.Integration of the data from the trees with data sources at stand and forest level—which would unlock the possibility to cross-validate and enhance the results of models applied at a forest level.
3.Assess the risk posture of the forest and define how the data collected can provide early warnings on the major threats the forest faces. Forest main disturbances under climate changes should always be assessed.
4.Define the ecosystem services to be monitored and use the data at tree level to support the estimation of these ecosystem services at the forest level.
5.Consider the usage of blockchain technology to store the data captured and to enable economic transactions on the ecosystem services monitored.

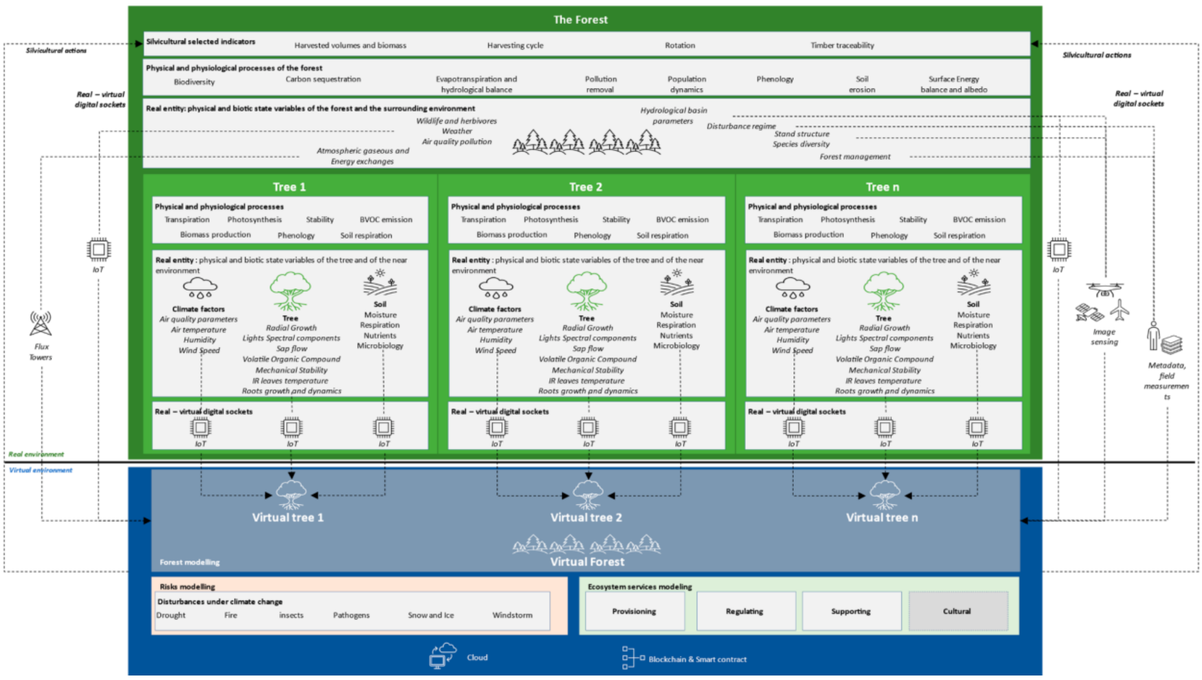


Fig.2-7.Forest digital twin framework.Source:(Buonocore et al, 2022)

2.7.6.Twinning Process

The twining process includes twinning the tree and the twining the forest as a whole, both considering 3 layers including the physical and biotic state variables of the tree/forest and the surrounding environment, the real–virtual sockets capturing and digitising the key data of forest status and The physical and physiological processes of the tree/forest. To create a digital twin of the tree,it is suggested to measure and record 15 sets of variables clustered by tree (IR leaves temperature, lights spectral components, radial growth, roots growths and dynamics, sap flow, volatile organic, tree mechanical stability), by the soil where the tree stands (soil microbiology, moisture, nutrients, respiration) and, by the climate factors in the near space of the tree (air temperature, air quality parameters, humidity, wind speed). The real–virtual sockets should be made by IoT devices operating in wireless mode to ensure the highest level of resolution and frequency (ideally sub-hour)(Buonocore et al, 2022). To create a digital twin of the forest Buonocore suggests measuring and recording state variables related to 9 clusters: air quality and pollution, atmospheric gaseous and energy exchanges, disturbance regime, forest management, hydrological basin parameters, species diversity, stand structure, weather, wildlife and herbivores.
This flow of information enables the modelling of at least eight physical and physiological processes of the forest, forming the behaviour of the FDT in the virtual space:
biodiversity, carbon sequestration, evapotranspiration, phenology, population dynamics, pollution removal, soil erosion, surface energy balance and albedo.

The real environment at the forest level could ultimately implement a set of indicators such as harvested volumes and biomass, harvesting cycle, rotation and timber traceability to monitor the impact of silvicultural actions.

Typologies of State Variables	Real–Virtual Sockets
Air quality and pollution	IoT
Atmospheric gaseous and energy exchanges	Flux towers
Disturbance regime	Immage sensing/metadata
Forest management	Field measurements and metadata
Hydrological basin parameters	Remote sensing, IoT
Species diversity	Remote sensing
Stand structure	Remote sensing, IoT
Weather	IoT
Wildlife and herbivores	IoT

Fig.2-8.Twinning the forest. The table reports the state variables and the related real-virtual socket..Source:(Buonocore et al, 2022)

2.7.7.Digital Twins for Wildfire

In order to accurately anticipate how the fire will behave and how it will affect the communities and environment around it, a wildfire digital twin should use a variety of data and modelling techniques. This will help decision-makers and first responders handle their responsibilities more effectively. Assessing the activities done for different phases of the wildfire, different thematic wildfire digital twins can be suggested as we summarise them as follows:

1. **Terrain and Vegetation:** Accurate and precise information on the topography and vegetation of the region where the wildfire is most likely to appear should be included in a digital twin. This can aid in determining the fire's course and the regions most vulnerable to it.
2. **Weather Conditions:** The spread of the wildfire under various circumstances can be predicted using real-time weather information. Important variables to take into account include temperature, humidity, and wind speed and direction (Gatto, M., Lafortezza, R., & Sanesi, G. , 2018).
3. **Fire Behaviour:** The behaviour of the fire should be modelled using a synthetic twin under various circumstances. This includes variables like the size, duration, spread, and intensity of the fireline. A report from the National Institute of Standards and Technology (NIST) describes how computational fluid dynamics can be used to simulate fire behaviour (T. G. Filley et al, 2015)
4. **Fire Suppression:**The digital twin should consider the efficacy of various fire suppression methods, such as bulldozer lines or water drops from aeroplanes (olly, W.M., et al. , 2013) .
5. **Emergency Response:** The response of emergency services, such as fire departments, police, and medical staff, should be modelled by the digital twin. This could aid in estimating how fast and effectively they can put out a wildfire (NIFC Website).
6. **Evacuation Planning:** The digital twin can be used to simulate different evacuation scenarios, including the most effective ways to evacuate people and vehicles as well as the probable paths of the fire (Nikos et al, 2013).

7. **Damage Assessment:** The digital twin can be used to simulate the harm caused by the fire and assist with recovery and reconstruction efforts (US National Park Service Website).

2.8.Research Methodology

Current section tries to illustrate a possible framework for a wildfire digital twin that would be the big picture for the present research. In compiling this research, we are attempting to answer the following research questions:
RQ1: What are the possible thematic digital twins regarding wildfire?
RQ2. What is a possible framework for creation of a Wildfire Assessment Digital Twin?
RQ3: Who are the potential stakeholders for the decided wildfire digital twin?
RQ4: How can we use cloud-based platforms such as Google Earth Engine to enhance wildfire assessment?

The main Goal of the research is to achieve a rough methodology for creation of a wildfire assessment digital twin, along with the calculation methods and public documents to **integrate** that would eventually assist in the processes of decision making.
As per **Research Design**, this study uses a mixed-methods approach, integrating spatial analysis with GEE and QGIS and quantitative analysis of satellite data with public reporting on the case study to improve interpretation. Due to its capacity to integrate many data sources, show spatiotemporal trends, and aid in decision-making, the digital twin strategy is preferred.

Regarding the **Data Collection** phase, the Primary data sources include satellite imagery and publicly available reports on wildfires. Satellite imagery is acquired from the **Sentinel-2** platforms, which compared to Landsat and Modis satellite imagery has advantages especially considering the temporal and spatial resolution. Sentinel-2 delivers a higher frequency of image acquisition compared to Landsat (16 days), thanks to its 5-day revisit length. Sentinel-2 has a higher spatial resolution of 10 metres, making it possible to identify and characterise fire-affected areas with greater accuracy.
For the sake of cost-effectivity and time-consumption, it was preferable to obtain the necessary data from the public/Open data sources which should of course be selected with utmost care and attention for authenticity. Public reports on wildfires are obtained from reliable sources such as government agencies, regional platforms and archives, online fire incident databases and news websites. The suggested digital twin consists of 3 main data types, namely “Remote Sensing Data” obtained from open data platforms (in this case GEE), “Fire Risk Assessment Data” which is obtainable from governmental and public platforms and reports, and “Administrative Data” such as reports.
The data such as “Fire Risk Assessment”, which includes themes such as “Fire Weather Index”, “Drought Code”, “Slope & Wind”, “Ecological Value” and “Socio_Economical Value” are available on some public documents such as “Basic criteria to assess wildfire risk at the pan-European level” or similar documents that could be used for the purpose.

During the **Data Preprocessing** phase, Satellite imagery is preprocessed using Google Earth Engine platform and coded in Javascript language.It involves image recall, atmospheric correction techniques to account for atmospheric interference. Cloud filter algorithms are applied to ensure more clear and accurate imagery.

For the **Data Analysis** phase, regarding the Remotely Sensed data, the Satellite images from Sentinel2 are recalled from the Google Earth Engine database and processed by using Javascript language. The operations done in the GEE aime at analysing the Sentinel 2 image to produce indexes beneficial for wildfire assessment including burned area (NBR index) ,burn severity analysis (using dNBR index) and vegetation recovery trend (NDVI index). The **NBR** index was selected due to its superior sensitivity over the other indexes used for burned area extraction and its compatibility with Sentinel2 data. In order to support the

findings and interpret the data better, visualisation of different band combinations (true colour/ false colour) and statistical methods (for example histogram to visualise pixel distribution and scatter plot to highlight the trends) would be utilised.
Finally, some complementary data could be included in the digital twin, categorised as Administrative data, which could include Statistics and archived data and the potential stakeholders are suggested followed by planning suggestions for the said wildfire assessment digital twin.
In order to perform **Validation** and **Accuracy Assessment**, the results are compared with the existing calculations for example in case of burned areas, they are compared with the public reports and CEMS report. The existing reports such as Piano AIB of the Piedmont region have assisted with the verification of the results.
During the studies
In the course of the research process some **limitations** have been encountered including the availability and quality of data sources, as well as potential biases and incongruencies in the reporting of wildfires among different sources. Data collection challenges may include data availability, accuracy, and preprocessing requirements.
The **generalizability of the findings** is influenced by the specific study area, time period and climate, affecting the definition of thresholds for index calculation and the image interpretation. In addition, the necessities of the datasets incorporated into the wildfire digital twin, varies based on stakeholder requirements and goals, as well as the major driving factors of the wildfire in the specific area which affect the management approach and objectives towards the matter. So the main structure of the workflow and calculations can be incorporated but need to be adapted to the case studies situations.
In conclusion, the technique offers a thorough strategy for evaluating wildfires utilising a digital twin approach with GEE and QGIS, combining public reports. Wildfire patterns are better understood and decision-making processes are supported by the incorporation of various data sources and the use of spatial analysis tools.

3.Digital Twin of Earth Systems in the European framework

Introduction

Digital twins would be helpful assets for information integrations which could include various data types, helping stakeholders and decision-makers with monitoring, decision making, tracking and managing the different systems on the earth. This chapter is dedicated to the european-level frameworks, action plans and documents, regarding earth systems and digital twins and forests.
Specifically, in the first section of the chapter, the European strategies and agendas for sustainability are discussed, including the Sustainable Development Goals, the Sendai Framework and the Green Deal, focusing on their strategies and goals related to the Digital Twin and disasters, and in specific forest fires.
The second part of the chapter, some european-level initiatives are disclosed, which are in-line with the aforementioned agendas.

3.1.European strategy for sustainability

3.1.1.The Sustainable Development Goals(SDGs) for the Global Agenda

Sustainable development is a well-known and well-understood term that is gaining more attention globally as a result of the increasing severity of climate events and the continuation of economic crises. The eight Millennium Development Goals (MDGs), which had been the foundation for global development since 2000 (WHO website), were replaced with the 17 Sustainable Development Goals (SDGs) of the United Nations (UN) in 2015 (Focus2030 Website). The new and ambitious strategy intends to accomplish the remaining MDG targets and achieve a better balance between human development and environmental protection.
Though the idea of sustainable development was first introduced in the late 1980s, it has recently received major public attention, especially after 2015, and it continues to be a top trending term across all industries internationally (Hassani et al, 2022).
According to Hassani et al (2022), only few of the Sustainable Development Goals have benefited from the use of digital twins thus far. Manufacturing is the industry from which digital twin technology emerged, and it is also the industry that has so far enjoyed the greatest benefits from its adoption. Therefore, digital twin empowered PLM has become a crucial demand among industrial firms going through rapid transformation in the era of industrial revolution 4.0. This is true for Sustainable Production, Maintenance, Logistics, and Circular Economy. Research on a single digital twin service has been identified. For instance, digital twin applications have enabled design, logistics, production stage maintenance, employing green materials, and recycling.
The construction sector may be able to realise its full potential by utilising digital twin technology, given the significance of deploying them in manufacturing and their tremendous contributions to the fourth industrial revolution. Given that different UN SDGs are advanced by building management and construction, including general engineering, the digital twin might successfully illustrate the benefits of the digital future in this circumstance (Hassani et al, 2022).

Fig.3-1.Digital twin implementations supporting UN SDGs_Source: (Hassani et al, 2022)

Energy and resource optimization is not entirely new ground for digital twins. Energy conservation is a common goal of implementation in both manufacturing and construction, and by working together, they have had a good impact on resource and energy management and more sustainable output. Digital twin applications for power plant systems have appeared recently from the supply side (Hassani et al, 2022).
This manufacturing industry's transferrable advantage is also the key to the digital twin's expansion into other industries, such as agriculture, livestock farming, etc., where the last ten years have seen a significant rise in the use of concepts like smart agriculture, smart farming, and smart fishery. Insights and successes from other sectors indicate that adopting technological advancements like the digital twin could offer better solutions to the growing food and climate challenges and help achieve the relevant UN SDGs, despite the fact that these fields typically have fewer interactions with smart technologies and lack a data culture (Hassani et al, 2022).
Understanding how the earth is changing and how the accelerating climatic issues are being faced requires the use of Earth observation technology and its related big data platforms.
The ambitious goal of creating a digital twin for the Earth is the result of years of work, the rapid expansion of data infrastructure, breakthroughs in data processing technology, and a common vision for a greener future (Hassani et al, 2022), aligned with the sustainable development goals.
In particular, there are a number of sustainable development goals that are related to the natural resources, and human settlements which we argue are connected with the research in hand. The above-said goals, collected from the knowledge platform for disaster risk_PreventionWeb_ which is connected with the UN platform_UNDRR(United Nations Office for Disaster Risk Reduction) are mentioned as follows:

Goal 11.*Make cities and human settlements inclusive, safe, resilient and sustainable*, with specific targets:
Target 11.4: "Strengthen efforts to protect and safeguard the world's cultural and natural heritage"
Target 11.5: " By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations"(PreventionWeb Website).
Target 11.b: "By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels"(PreventionWeb Website).

Goal 13. Take urgent action to combat climate change and its impacts
Target 13.1: "Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries".
Target 13.2: "Integrate climate change measures into national policies, strategies and planning".
Target 13.3: "Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning".

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Target 15.1: "By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements".
Target 15.2: "By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase"(PreventionWeb Website).

3.1.2. The Sendai Framework

The Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework) was the first major agreement of the post-2015 development agenda and provides Member States with concrete actions to protect development gains from the risk of disaster. It works hand in hand with the other 2030 Agenda agreements, including The Paris Agreement on Climate Change, The Addis Ababa Action Agenda on Financing for Development, the New Urban Agenda, and ultimately the Sustainable Development Goals. Endorsed by the UN General Assembly following the 2015 Third UN World Conference on Disaster Risk Reduction (WCDRR), the Sendai framework advocates for the significant decrease of disaster risk and losses in terms of people's lives, livelihoods, and health as well as their countries and individuals' own economic, physical, social, and cultural assets (UNDRR Website).

3.1.3.the Green DEAL

The European Green Deal is a package of policy initiatives, which aims to set the EU on the path to a green transition, with the ultimate goal of obtaining climate neutrality by 2050.
The Green Deal also calls "to boost the EU's ability to predict and manage environmental disasters" as an immediate priority since large-scale and more intense wildfires are becoming an increasing concern. A Growing number of EU citizens suffer directly and indirectly from wildfires. In addition to southern Europe, Central, Eastern, and Northern Europe have seen an increase in the number of fires between 2017 and 2020, which have killed hundreds of people and destroyed forests and Natura 2000 sites, often irreparably. Furthermore, wildfires account for up to 20% of annual global greenhouse gas emissions, making them one of the primary causes of climate change. Wildfires in the EU spread and deepen as a result of climate change, forestry changes, ecosystem degradation, and rural population decline. With longer fire seasons, more frequent fires, new fire-prone locations, and more intense fire behaviour, climate change is

anticipated to increase the risk of fires. All the aforementioned facts are the reason for which the Green Deal explicitly calls to “reduce the incidence and extent of forest fires”(European Commission,2020).

Forests are an important ally in the fight against climate change and biodiversity loss because of their role as carbon sinks and their ability to mitigate the effects of climate change, such as by cooling cities, protecting us from catastrophic flooding, and minimising the impact of drought. Forests are large ecosystems that are responsible for sustaining a sizable amount of Europe's biodiversity. Their ecosystem services enhance human health and well-being by providing resources, food, medicine, disaster risk reduction and control, soil stabilisation and erosion management, air and water purification, and water regulation. In addition to providing a means of subsistence, forests are also a haven for rest, education, and recreation. Some of the policies suggested by the european commision in the context of the Green Deal are as follows:

Protection, restoration and sustainable management of forests

In order to increase the quantity and quality of forests in the EU and to promote their preservation, restoration, and resilience, the Forest Strategy discloses a vision and specific initiatives. The Strategy fosters resource-efficient wood usage in accordance with the cascade principle, emphasises the need to preserve the use of woody biomass within sustainability bounds, and promotes the most climate and biodiversity friendly forest management techniques. (European Commission, 2021).

Ensuring the multifunctionality of EU forests

The Forest Strategy announces a legal proposal as part of this initiative to increase EU-wide forest monitoring, reporting, and data gathering. A full image of the state, the evolution, and the anticipated future developments of forests in the EU will be possible thanks to standardised EU data collecting, strategic planning at the level of the Member States, and global analysis. This is essential to ensuring that forests can fulfil their numerous services for the economy, biodiversity, and climate (European Commission, 2021). The Commission also plans to design a forest strategy, without providing a specific timeframe for its release. This strategy should include plans for afforestation, forest preservation and reforestation in Europe. The CAP should also incentivise the sustainable management of forests (Constanze Fetting, Esdn , 2020).

3.2.The initiatives

3.2.1.Digital Earth

In September 2020, ESA launched several Digital Twin Earth Precursor Activities to explore some of the main scientific and technical challenges in building a digital twin of Earth. These activities included: Forest, Hydrology, Antarctica, Food Systems, Ocean and Climate Hot Spots. Each activity addressed a different scientific, technical and operational challenge regarding Digital Twin Earth including the role of artificial intelligence and consistent data, stakeholder engagement, scientific credibility and role of sectoral models and Information and Communication Technology (ITC) infrastructure(ESA Website ,2021).
Digital Earth is a concept of an interactive digital replica of the entire planet that can facilitate a shared understanding of the multiple relationships between the physical and natural environments and society. The original idea of Digital Earth (DE) first introduced by USVice President Al Gore in 1998 envisioned a 3D multiresolution representation of our planet embedded with a variety of geo-referenced data to be transformed into understandable information (Marconcini et al, 2020). It is an important contribution to the Digital Agenda and the overall Europe 2020 objectives of smart, sustainable and equitable growth in the European Union.The main functionalities of the digital earth includes being accessible globally from multiple platforms (mobiles, tablets, computers); displaying information understandable by multiple audiences (the public, decision-makers, scientists); and being constantly updated with data coming from sensors (space-based, airborne, in-situ), citizens, and both public and private sectors. According to the European Union Website, the Digital Earth must be able to focus on change (from the past, to present and future) and thus

include not just data but also the outcomes of models and simulations to enable a wider understanding of the consequences of human action on the environment, and of environmental change on society (European Commission Website).
The inputs of the Digital Earth are provided by both governments and academedia, which have contributed by releasing large quantities of public sector and scientific information. In addition, in the past few years, the commercial sector has produced captivating visual depictions of Earth, and individuals are contributing an incredible amount of data via social media. The real difficulty for Digital Earth in this rapidly changing environment is to integrate the numerous information systems, data collections, and participants at all scales, from the most local to the most global, in order to accurately depict the complete complexity of how our planet functions (European Commission Website).

One of the main challenges and necessities of the Digital Earth Project is an information infrastructure _or more precisely_ a mega structure on how multiple different information infrastructures would connect together, in order to facilitate sharing information in different contexts. Sharing information on environmental and social phenomena is at the heart of Digital Earth. The information infrastructure would be part of a framework of technologies, standards, organisational arrangements and policies that makes it possible to find, access, use, share, and publish such information. These infrastructures come in a variety, including platforms created by the private sector to find and share information with the general public, such as social networks like Facebook, as well as information and services for citizens and businesses offered by national and local governments (e-government infrastructures, and more recently open data initiatives and portals). The development of these infrastructures and open data initiatives is supported in Europe by the Digital Agenda, which is a major cornerstone (European Commission Website).

A key building block for Digital Earth is represented by those thematic information infrastructures addressing environmental and geographic information (Spatial Data Infrastructures, or SDIs), which have been developed over the past 20 years largely as a result of government efforts to have better information on which to base sound environmental policies. Europe is a world leader in developing SDIs(spatial data infrastructure initiative launched in 2001) as a result of its INSPIRE initiative, of which the JRC is the technical coordinator (Marconcini et al, 2020).

3.2.2.INSPIRE

Launched in 2007, the Infrastructure for Geographical Information in Europe, or INSPIRE, is a legal framework that mandates that Member States create a technical infrastructure that enables users to find, view, change, and download standardised spatial and environmental datasets and services (Marconcini et al, 2020). The interoperability of the many national and subnational SDIs created and maintained by the Member States throughout Europe forms the foundation of INSPIRE, which is a non-centralised system. The development of the technical specifications for harmonising these datasets under 34 environmental themes and ensuring that the Member States' web services can effectively communicate are coordinated by the JRC, the Joint Research Center of the European Commission service for science and knowledge, in order to achieve such interoperability (European Commission Website).

International attempts to more successfully share Earth observation data benefit greatly from the JRC's experience building a bilingual and interoperable SDI across Europe. 89 countries, the European Commission, and 69 international organisations are working together to develop a Global Earth Observation System of Systems (GEOSS). The cornerstone of GEOSS is a shared infrastructure for accessing and searching information, data, and services from key Earth observing systems. Unlike INSPIRE, which is supported by an enforceable legal framework, GEOSS is a volunteer process with limited financial resources. As a result, imposing a single set of standards proved to be impossible, and the brokering technique developed in the EuroGEOSS research project led by the JRC instead emerged as a significant innovation. The capacity to build bridges to various information systems and infrastructures is proving to be crucial now that social networks have been incorporated into the Digital Earth architecture (European Commission Website).

3.2.3.DestinE

According to the Science Website, The European Union is finalising plans for an ambitious “digital twin” of planet Earth that would simulate the atmosphere, ocean, ice, and land with unrivalled precision, providing forecasts of floods, droughts, and fires from days to years in advance. Destination Earth, as the effort is called, won't stop there: It will also attempt to capture human behaviour, enabling leaders to see the impacts of weather events and climate change on society and gauge the effects of different climate policies(Voosen, 2020).

Destination Earth emerged from the concept of Extreme Earth, a proposal led by the European Centre for Medium-Range Weather Forecasts (ECMWF) for a billion-euro flagship research program (Voosen, 2020). The goal is to allow policymakers to directly determine how climate change will impact society—and how society could alter the trajectory of climate change. For example, the model could predict how climate change will affect agriculture and migration patterns in Brazil—and also how cuts in ethanol subsidies might limit deforestation in the Amazon. Currently, climate scientists extract regional results from global climate models and pass them to experts in agriculture or economics to understand effects on human behaviour. Now, says Erin Coughlan de Perez, a climate hazard scientist at the Red Cross Red Crescent Climate Centre, modellers are “moving from just forecasting what weather will be, to what the weather will do.” Among the main challenges for realising such a project, Science Website reports, is the management of the big load of data received by the digital twins(Voosen, 2020).

The European Union's challenging project _Destination Earth (DestinE)_ aims to build a digital representation of Earth that will be used to track the effects of human and natural activity on the planet, predict extreme events, and modify policy in response to climate-related problems.

By focusing on the issues regarded with climate change, such as on the oceans, water, Earth's ice caps, land use, etc., DestinE will specifically support the prediction of both natural disasters and man-made environmental damage with high accuracy; enable continuous and precise monitoring of the health of the planet; and finally, allow us to better understand the socio-economic effects of climate change and the occurrence of extreme natural disasters.

As the EU works toward its goal of becoming carbon neutral by 2050, and as the European Commission implements the Green Deal and Digital Strategy, Destination Earth will serve as the foundation for effective European adaptation plans(ESA).

The European Commission will lead and coordinate the implementation efforts among a core group of leading European organisations which will be responsible for developing the main elements of the initiative. These core organisations include ESA, the European Centre for Medium-Range Weather Forecasts (ECMWF) and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat). In addition, ESA will be responsible for the DestinE Open Core Service Platform, a user-friendly platform that will rely on the most comprehensive and sophisticated space-based observation data, including data from ESA’s Earth Explorers, the Copernicus Sentinel series, data from ECMWF and, over time, other major data holdings in Europe.

Eumetsat will be responsible for the multi-cloud data lake underpinning DestinE, including its design, establishment and testing, as well as its operations of the online inventory, while ECMWF will be responsible for the Digital Twin Engine, including the development of the two initial Digital Twins: Digital Twin on Weather-Induced and Geophysical Extremes and the Climate Change Adaptation Digital Twin (ESA Website).

The digital twins of earth, will be built under thematic categorisations from the different domains of Earth science, such as extreme natural disasters, climate change adaptation, oceans and biodiversity. The aim is to integrate these digital replicas to form one comprehensive digital twin of the complete Earth system.

DestinE will be developed gradually through the following some key milestones such as “Development of the open core digital platform and the first two digital twins” which includes the Digital Twin on Weather-

Induced and Geophysical Extremes and the Climate Change Adaptation Digital Twin by 2024. These digital twins, managed by ECMWF, will allow the decision-makers to anticipate the occurrence and impacts of extreme natural events, such as flooding and forest fires, with increased precision, and the "Climate Change Adaptation Digital Twin", supporting the generation of analytical insights and testing of predictive scenarios in support of climate adaptation and mitigation policies at decadal timescales, at regional and national levels. The final aim is the integration of additional digital twins to serve sector-specific user cases into the platform by 2027 and a 'full' digital replica of Earth through the convergence of the digital twins available through the platform by 2030 (ESA Website).

3.2.4.SILVANUS project

The SILVANUS project, which was funded by the EU's Horizon 2020 Green Deal program and coordinated by Università Telematica Pegaso, involved 49 partners from the EU, Brazil, Indonesia, and Australia. It would last 42 months and began with a hybrid meeting in Naples, Italy, scheduled for December 13 and 14, 2021, and expected to end in April 2025. The goal of the project is to assemble a sizable group of multidisciplinary experts from across four continents in order to lessen the threat of forest fires and increase the resilience of forests to climate change (European Commission Website).
Release of a platform for climate-resilient forest management to prevent and limit the spread of forest fires is the main project product. Experts in the environmental, technological, and social sciences are consulted by SILVANUS to assist local, state, and federal agencies in managing wildfires. In order to assess fire risk indicators, the project will construct intelligent fire ignition models utilising climate and weather data. It will also implement a stakeholder engagement program in forest zones. Additionally, SILVANUS will develop a technique of educating firemen that uses VR and AR toolkits to replicate real-world settings and life-saving situations (European Commission Website).
The project will include restoration roadmap services for natural resources, advice for soil rehabilitation strategies, and policy recommendations to ensure that the outcomes of SILVANUS have a long-term impact. The project will concentrate on all three aspects of fire suppression: prevention and preparation, detection and reaction, and restoration and adoption throughout its activities and after (Zanasi and partners website).

4.Wildfires: The Related Literature International Management Case Studies

Introduction

There are many different causes as to why a wildfire would start; yet, human factors remain one of the main reasons for wildfires, especially in wildland-urban interface(WUI). The wildland-urban interface (WUI), where dwellings and wildland vegetation overlap or intersect, is the location with the greatest wildfire risk. Additionally, WUI expansion frequently causes an increase in wildfire occurrence, endangering more people's lives and homes. If previous patterns in home growth continue, wildfire concerns won't go away. Wildfires have various negative impacts on ecosystems, human physical and mental health, socio-economic aspects, namely cost of sickness, and willingness to pay, to more obvious incidents such as destroying buildings and decreasing the insurability of the building if fire is a recurrent phenomenon.
This chapter discusses common definitions about wildfire, effects of wildfire on human settlements, and finally how wildfire is managed and prevented and treated afterwards in different spatial and administrational levels(Worldwide, country-level, state-level, European Union level). The chapter also looks at an international example_ United States of America_California State to see the approach towards wildfire. When discussing the European Union levels, it explains about the dynamic of the wildfire management system for the National level(for member states), and also the Alpine region. The chapter concludes by taking a deep dive into the wildfire management system in Italy, discussing also national and regional level, focusing on the Piedmont region.

4.1.Wildfire

Encyclopaedia Britanica describes wildfire, also called wildland fire, as uncontrolled fire in a forest, grassland, brushland, or land sown to crops. The terms forest fire, brush fire, etc., may be used to describe specific types of wildfires; their usage varies according to the characteristics of the fire and the region in which it occurs.
IRDR(Integrated Research on Disaster Risk website) describes wildfire as any uncontrolled and non-prescribed combustion or burning of plants in a natural setting such as a forest, grassland, brush land or tundra, which consumes the natural fuels and spreads based on environmental conditions (e.g., wind, topography). Wildfires many times are started by human actions, such as land clearing, extreme drought or in rare cases by lightning (IRDR website).
Fuel, oxygen, and a heat source are the 3 substantial conditions for starting a wildfire. Fuel is any combustible material surrounding a fire, including trees, grasses, brush, even homes. Air supplies the oxygen a fire needs to burn. Heat sources help spark the wildfire and bring fuel to temperatures hot enough to ignite. Lightning, burning campfires or cigarettes, hot winds, and even the sun can all provide sufficient heat to spark a wildfire (Claire Wolters, 2019).
Since some ecosystems rely on natural flames to sustain their dynamics, biodiversity, and production, wildfires play a mixed function for ecology and economy. However, each year, wildfires consume millions of hectares of forest, woodlands, and other vegetation, resulting in the deaths of numerous people and animals as well as significant economic harm due to the resources lost and the expense of suppression. Additionally, there are effects on society and the environment, such as harm from smoke to human health, loss of biological variety, production of greenhouse gases, destruction of infrastructure and recreational assets(FAO).
According to the food and agriculture centre for the United Nations(FAO), the largest number of fires are caused by humans. There are a variety of motivations leading to wildfires, including land clearing and other agricultural activities, maintenance of grasslands for livestock management, extraction of non-wood forest

products, industrial development, resettlement, hunting, negligence and arson. Only in very remote areas of Canada and the Russian Federation lightning is a major cause of fires.

4.1.1.Fire Triangle

The fire triangle has been used to describe the interacting factors involved in fire fundamentals (figure 2.3). Fuels burn under appropriate conditions, reacting with oxygen from the air, generating combustion products and releasing heat. If the triangle is broken the fire goes out. Fire is strictly dependent by three parameters: fuel, oxygen and heat. Each of those is necessary to avoid the triangle brake and permit the fire to ignite (Gabban,A et al, 2008).

- **Oxygen (air) -** to start and sustain combustion. Air supply can be increased by windy conditions.
- **Heat -** to raise fuel temperatures to their ignition point and to ignite fuels. Common sources of heat are lightning and human activities.
- **Fuel -** to sustain and/or carry flames. Combustible materials include trees, shrubs, grasses and structures. Some properties of the fuel, like size and shape, compactness and moisture, play an important role in the fire ignition and spread. It is known that small fuels ignite and sustain combustion easier than large pieces of fuel; since less heat is required to remove fuel moisture and raise a small particle to ignition temperature. Also compactness influences the spread rate; slower spread rates occur if fuels are compacted whereas loosely compacted fuels normally react faster to moisture changes and have more oxygen available for combustion. The amount of fuel that is available for combustion in a given fire is determined largely by the amount of water in the fuel; referred to as fuel moisture. When the moisture content is high, fires are difficult to ignite, and burn poorly if at all. With little moisture in fuel, fire starts easily, and wind and other driving forces may cause rapid spread at high intensity. (Gabban,A et al, 2008).

4.1.2.Heat Transfer

Once fuels are ignited, heat is transferred in three ways:

1. **Conduction** transfers heat from a warmer object to a cooler object until both temperatures are the same.
2. **Radiation** transfers heat through air by short energy waves (infrared rays), which preheat and dehydrate fuels to their ignition point.
3. **Convection** transfers heat through the movement of liquid or gas. Wildfires generate gases that rise in columns, usually accompanied by sparks, embers and burning twigs. These convective columns move downwind, ahead of the fire front, carrying embers that start spot fires (Idaho firewise website).

4.1.3.Wildfire Triangle

Control and management of a wildfire depend on understanding how it might behave. The way a wildfire burns, how quickly it spreads, and how challenging it is to contain depend on a variety of factors. Weather, geography, and fuels make up the wildfire triangle.

Wind, temperature, cloudiness, moisture, and air pressure are all aspects of the weather. Low humidity and high temperatures enable wildfires to spread quickly and the vegetation to dry up. Wildfires are not only moved by the wind over the landscape, but it also provides oxygen, which can help fires spread quickly. Additionally, wind scatters embers for kilometres, starting fresh spot fires. Fires can be slowed down or put out by rain and high humidity, whilst storms can either boost fire activity or make it utterly unpredictable (Idaho firewise website).

Topography is the physical feature of an area, including slope and aspect/direction. Wildfires burn more rapidly when moving up a slope by preheating unburned fuels and making them more combustible. Wind also moves more rapidly up slopes, increasing the speed at which a fire can spread. Draws can act like

chimneys and funnel flames upwards. South- and west-facing slopes have drier fuels than north- and east-facing slopes.
Wildfires are controlled by removing one side of the fire triangle - simple in theory, but not necessarily simple to do. For example, fuels can be treated or removed to create fire breaks; oxygen can be reduced or eliminated by smothering flames with water; and heat transfer can be reduced by covering vegetation with fire retardants(Idaho firewise website).

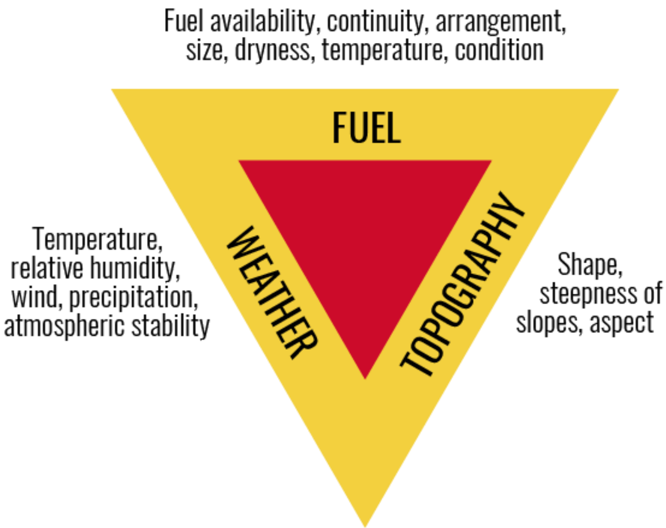


Fig.4-1.Fire Triangle_Source: Internet

4.1.4.Fire types

The surface-fire is the most known fire type, representing the most common propagation regime and consists in rapidly burning fire that sweeps quickly over an area, consuming litter and the above-ground segment of herbs, shrubs, grasses and lower branches of trees. In fact, in favourable conditions, a surface-fire might spread to the upper layers of the crown foliage. Next type of fire is a crown fire, affecting mainly the crowns of the woody vegetation. Often, it leaves most of the steam and the forest floor relatively untouched and being so dependent on wind conditions, and is difficult to control. Finally, a fire could evolve below the terrain-referred to as ground fire- consisting principally in largely flameless fire that burns slowly through thick surface accumulation of organic matter, duff and roots and it is very difficult to detect and control. In some particular conditions, a ground fire can become a flaming surface fire if not adequately treated. It is important to note that, more than one form of fire could take place at the same time (i.e. a crown fire could be accompanied by a ground fire). Figure 4-2 is a diagram of Fire growth, spread and decay from(Gabban,A et al, 2008).
A natural occurrence, such a lightning strike, or a spark created by a person can start a wildfire. However, a wildfire's rate of growth is frequently influenced by the weather. Trees, bushes, fallen leaves, and branches can all become dried up and ready to burn due to wind, hot temperatures, and little rainfall. Additionally, topography is important since flames spread more quickly uphill than they do downward (National Geographic website).

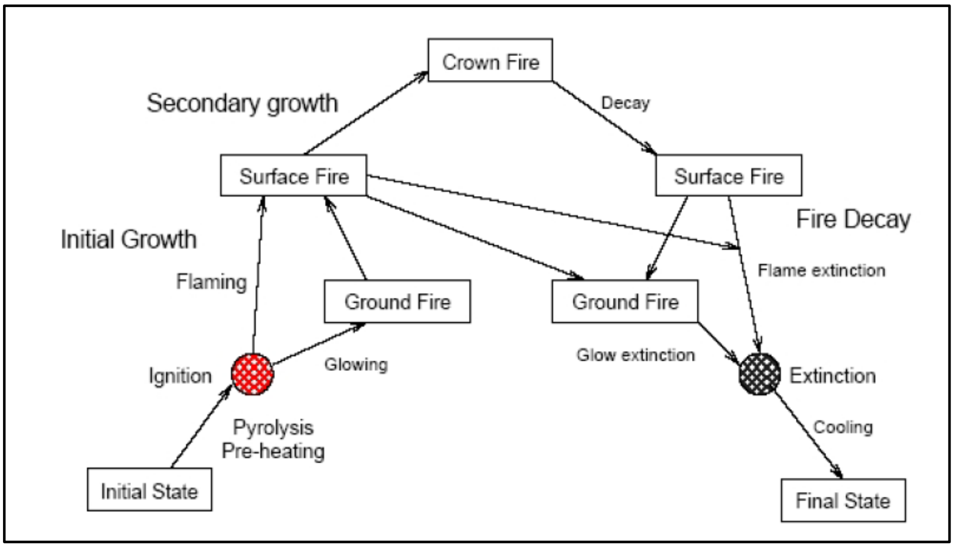


Fig.4-2.Fire growth, spread and decay_Source:(Gabban,A et al, 2008)

4.1.5.What makes a settlement a high fire hazard area

The kind of trees, plants, and grasses that are there will determine how likely a fire is to break out in a certain location. It has been established that some areas of the wildland-urban interface, or the area between urbanisation and wilderness, are much more at risk of burning than others. The sensitivity of the local plants to drying out in a rising climate is thought to be a significant issue. Huge, abrupt changes in land use, such as the urbanisation of coastal regions due to tourism growth and infrastructure construction, can alter fire ignition and raise the likelihood of forest fires (Rao et al, 2022).

Plant Sensitivity and Fire

If a region's vegetation is drought sensitive, meaning it dries up fast after periods of little rainfall and high temperatures, the area that burns when a fire does break out increases dramatically. The amount of burned land may vary for a given amount of dryness depending on how drought-sensitive the trees are. Some plants lose moisture more quickly in dry climates, similar to how a succulent may survive with less water than, say, a citrus tree. Rao et al (2022) discovered that the burned area increases twice as much in the most sensitive sections as it does in the least susceptible regions under the same increase in drought-like conditions.

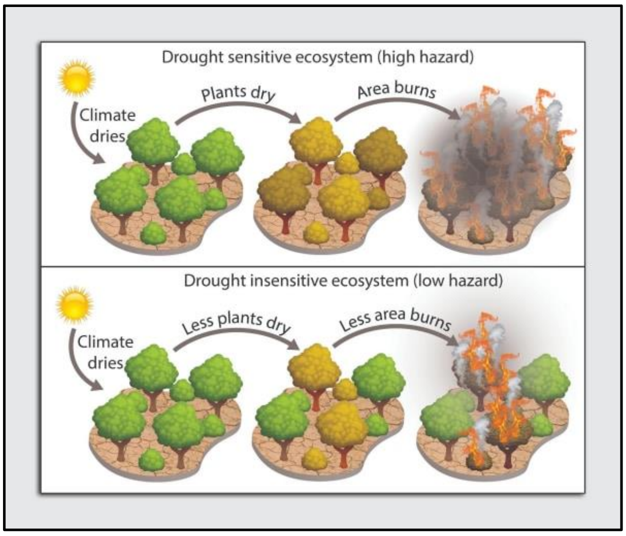


Fig.4-3.High and Low Hazard Ecosystems considering Drought_ Source: (Rao et al, 2022)

Spatial Distribution of Fire Occurrence: The Wildland-Urban Interface Population Boom

The possibility of fires starting increases along with the population growth in the wildland-urban interface areas, putting more people at risk. The steadily growing interface between vegetated land and urban areas resulting from urban growth and sub-urbanisation in recent decades has amplified the risk of forest fires in many residential areas, especially where cities border forest areas (Rao et al, 2022). Factors such as urban density, vegetation characteristics, and the isolation of urban areas from other urban areas and services like transport increase the risk (European Environment Agency website, 2022). The reasons for this population growth are still to be studied, however, building codes, communities reliant on timber, and people seeking residences close to forests are all assumed to have contributed to the establishment of the wildland-urban interface, but they do not alone explain why population growth would be highest in the most vulnerable locations (Rao et al, 2022).

In Europe also, a similar trend of population growth is visible: most ignitions occur in the most populated municipalities and are intentional. A research done by Vazquez and Moreno (1998) demonstrated that, in some parts of Spain,Human-caused wildland fires had a less concentrated geographical pattern than lightning-caused fires; the latter's highest fire ignition density was found where wildland and agricultural fields met, particularly between the northern and southern slopes of the Pyrenees and the Iberian Mountains (Ganteaume et al, 2013).

Koutsias and others (2002) found that elevation was correlated with the spatial distribution of fire ignition points in the Grison region of Switzerland. In contrast to the spatial distribution pattern of lightning-ignited wildland fires, which mostly consisted of mountainous areas, human fire ignition tended to be found within the height ranges corresponding to inhabited and agricultural places. Fuel characteristics, such as moisture content, load, horizontal/vertical structure, have been introduced as the key elements explaining the spatial distribution of the lightning-caused fires (Ganteaume et al, 2013).

Areas with a high density of human-caused fires and the level of landscape heterogeneity seem to be significantly correlated. In fact, in multiple researches by the European Mediterranean region, the edges of rural wildland interfaces were shown to be among the most susceptible areas to wildfires. Thus, fire susceptibility in this region is greatly affected by the level of landscape fragmentation and the so-called edge effect (Ganteaume et al, 2013).

Temporal Distribution of Fire Occurrence

Fire occurrence displays typical temporal patterns that follow the natural cycles of environmental conditions and vegetation phenology, with temporal spans varying from one day to one year, with marked variations introduced when fire causes are taken into account. Where lightning-caused fires occur they tend to be concentrated in a few days of the year, while anthropogenic fires are more evenly spread out in the year (Ganteaume et al, 2013).

Ganteaume et al(2013) compare fire ignition factors to spatial and temporal variations of fire occurrence in the region in European context. They realised that the causes of forest fires are varied and their distribution differs among countries, but may also differ spatially and temporally within the same country. In Europe, and especially in the Mediterranean basin, fires are mostly human-caused principally because of arson. The timing of fires depends on their causes. In populated areas, the timing of human-caused fires is closely linked to human activities and peaks in the afternoon whereas, in remote areas, the timing of lightning-caused fires is more linked to weather conditions and the season, with most such fires occurring in summer (Ganteaume et al, 2013).

Human Factors

According to the available literature, there seems to be a significantly higher occurrence of fires in the distance of urban areas and transport networks. According to Alexandrian and Gouiran (1990), in France, some fires occurred close to roads, around highly populated towns or in forest fragmented areas, whereas other fires were ignited near isolated dwellings in large forest stands. However, they also demonstrated that

there was a concurrent decrease in the total area burned with increasing human densities because of the decrease in mean and maximum fire size (Ganteaume et al, 2013).
Land use and land cover changes that occurred in the last decades in Mediterranean Europe have been generally increasing fire hazard. In a Mediterranean region of Italy, Ricotta and colleagues(2012) demonstrated that the reduced human pressure following the loss of agricultural land decreased the likelihood of fire ignition (Ganteaume et al, 2013).
Further on, they stated, depending on the socio-economic context of the region concerned, Regarding environmental factors, those related to **weather**, **fuel** and **topography** are the most significant drivers of ignition of forest fires, especially in Mediterranean-type regions (Ganteaume et al, 2013).

Environmental Factors

Despite the direct or indirect human origin of most forest fires, environmental factors affecting flammability fuels have also been considered as predictors of fire occurrence. For example, in the European context, It is well established that the Mediterranean summer weather conditions (high temperature, prolonged drought periods and strong winds) play a significant role in the fire regimes in the region. In different research attempts over the years, fire occurrence has been linked with drought, rainfall, wind and topographic factors. Lightning is the main natural cause of ignition all over the world and in some areas where population density is very low, such as the American boreal forest, it can be the main overall cause of ignition. In countries around the Mediterranean basin as well as in other Mediterranean-type areas, where human-ignited fires dominate, lightning can initialise catastrophic events, even if it is not a common source of fire ignition (Ganteaume et al, 2013).

4.2.Effects of Wildfires on Cities

Worldwide, wildfire smoke kills 339,000 people a year, mostly in Asia and sub-Saharan Africa, according to estimates. Tenfold increases in asthma attacks, emergency room visits, and hospital admissions have also been reported when smoke blankets the places where people live. This session discusses the effects of wildfires on cities and city-dwellers.

4.2.1.Human Health Issues and Mortality

Fatalities

Both directly (when people are unable to escape a blaze or when firefighters are killed while containing a fire) and indirectly (when people die as a result of wildfires) (particularly due to the health effects of smoke inhalation).
In a research done by Chen et al(2021), data on daily counts of deaths for all causes, cardiovascular causes, and respiratory causes were collected from 749 cities in 43 countries and regions during 2000–16. The association between wildfire-related PM2·5 exposure and mortality was examined using a quasi-Poisson time series model in each city taking into account both the current-day and lag effects, calculating population attributable fraction and relative risk (RR) of annual mortality due to acute wildfire-related PM2·5 exposure. The results interpreted short-term exposure to wildfire-related PM2·5 was associated with increased risk of mortality (Chen et al, 2021).
Overall, following the smokiest days of a large peat fire in eastern North Carolina in 2008, emergency department visits for heart failure increased by 37% and those for respiratory problems by 66%, according to EPA experts (National Geographic website).

Smoke and caused Health Problems

Wildfire smoke has a substantial detrimental effect on human health, not just in the immediate vicinity of the fire but also hundreds or even thousands of kilometres distant. In actuality, soot and chemicals found in wildfire smoke can be extremely harmful to health, especially for youngsters and the elderly (Wibbenmeyer and McDarris, 2021).
Barraza et al (2021), have attempted to characterise the relationship between the occurrence of wildfires in central Chile and the effects on children's respiratory health. They utilised public databases, which provided the number of emergency care visits, wildfires, and concentration of air pollutants, demographics and meteorological variables for the regions of Santiago and Valparaiso from 2010 to 2013. Significant health risks were observed in Santiago for children younger than 1-year-old of bronchitis (RR 1.007, CI 95% 1.007–1.008; chronic lower respiratory diseases (RR 1.012, CI 95% 1.012–1.013); and pneumonia (RR 1.026 CI 95% 1.026–1.027) and in children aged one to four years old (RR 1.016 CI 95% 1.015–1.016) (Barraza et al, 2021).
Another way wildfire affects human settlements in the vicinity is by producing inversions, layers of stagnant air that hold down smoke where humans can breathe. Inversions are common in regions like the western United States. The blood can start to coagulate, forming a thick sludge, when airborne, minute particles get past the body's defences and reach the outermost reaches of the respiratory system (National Geographic Website).

Mental Health

According to a study done after the 2018 CampFire in California, people who were directly exposed to the wildfire had a much higher chance of developing mental health conditions such as post-traumatic stress disorder (PTSD) and depression. Another study carried out in Arizona a year after the Wallow Fire revealed severe psychological stress brought on by the wildfire's spectacular landscape change and financial responsibilities (Wibbenmeyer and McDarris, 2021).

4.2.2.Economic Damage

Wildfires are capable of causing significant direct damage to buildings and other property, and they frequently result in the destruction of thousands of homes. Nearly 18,000 structures were burned by wildfires in 2020, of which 54% were houses. Especially hard-hit by devastating flames has been California. According to a 2020 study, wildfires in California resulted in about $28 billion in capital losses in 2018, damaging both houses and businesses. Because of recurring annual threats, residences were particularly hard to insure (Wibbenmeyer and McDarris, 2021).

Economic Valuation of Health Effects

Estimates of monetized damages from wildfires must consider human health impacts from exposure to wildfire smoke. A study done on Los Angeles County's modern history, quantified the economic cost of health effects from the largest wildfire. The defensive behaviour method is applied to calculate the willingness to pay for a reduction in one wildfire smoke induced symptom day, which is estimated to be $84.42 per exposed person per day.
Considering wildfire smoke, a basic cost of disease method would not account for the disutility that the health effects from wildfire smoke may bring, such as pain, discomfort, or a loss of recreational time. Second, many people who live in wildfire-prone locations are aware of the possible dangers of wildfire smoke and take expensive precautions to avoid them (Richardson, Champ e Loomis, 2012).
For instance, children with asthma were more likely to take precautions during the 2003 Southern California wildfires, such as wearing masks and remaining inside to reduce their exposure to the smoke. Moreover, during a wildfire in 1999 in Northern California close to the Hoopa Valley National Indian Reservation,

inhabitants followed advice from public service announcements and used face masks, evacuated, ran high-efficiency particulate air cleaners inside their homes, and more (Richardson, Champ e Loomis, 2012).

1.Willingness to Pay

If agencies are evaluating policies on an economic efficiency based criterion, the appropriate measure of the cost of health damages from exposure to wildfire smoke would be the full economic cost of these damages. The theoretically correct measure of this cost is the individual willingness to pay (WTP) to avoid this damage because it will include all costs individuals face when exposed to wildfire smoke: medical expenditures, lost wages, investments of time or money in taking preventative actions to decrease exposure, and the disutility associated with symptoms or lost leisure (Richardson, Champ e Loomis, 2012). A study based on the defensive behaviour method has been conducted to calculate the value of a reduction in health damages from smoke released by California's Station Fire of 2009 and compare this to a cost of illness estimate. The framework of the model is based on the premise that an individual experiences some health output, such as a number of days spent sick which enters into his utility function, causing disutility. According to the research done by Richardson, Champ and Loomis (2012), determinants of home air cleaner use If the respondent experienced ear, nose or throat symptoms or other symptoms such as nausea or anxiety, have a positive effect on the probability of using an air cleaner, compared to other types of symptoms. Higher income levels are associated with a decreased probability of using an air cleaner in the home. This runs contrary to previous findings that higher income levels are associated with an increased probability of taking averting actions. Similarly, during a 1999 wildfire in Northern California, greater use of high-efficiency air cleaners in the home was associated with reduced odds of reporting adverse health effects (Richardson, Champ e Loomis, 2012).

	Number of Survey Respondents	Percentage of Survey Respondents	Average Expenditure
Averting actions			
Evacuated	23	5.6%	$471.59
Wore a face mask	29	7.0%	$16.04
Used an air cleaner	88	21.3%	$36.19
Avoided going to work	19	4.6%	$390.00
Removed ashes from property	237	57.4%	$18.91
Ran air conditioner more than usual	249	60.3%	$27.66
Stayed indoors more than usual	302	73.1%	N/A
Avoided normal outdoor recreation/exercise	321	77.7%	N/A
Mitigating actions			
Obtained medical care/prescription medications	26	6.3%	$77.87
Took non-prescription medications	52	12.6%	$16.86
Went to non-traditional healthcare provider	5	1.2%	$33.00
Missed work	15	3.6%	$691.76
Missed days of recreation activities	114	27.6%	NA

Table 4-1.Averting and mitigating actions taken by respondents and average expenditure on each with outliers included _ Source: (Richardson, Champ and Loomis, 2012)

2.Cost of illness

The research done by Richardson, Champ and Loomis (2012), Probit regression models were used to determine whether the person sought medical attention, used prescribed drugs, used over-the-counter medications, saw a non-traditional healthcare practitioner, and missed work as a direct result of health issues brought on by exposure to wildfire smoke. The cost of illness is an underestimation of the economic cost of health impacts from exposure to a pollutant since it disregards the expense of forgoing activities as well as the disutility associated with symptoms or lost leisure time that results from disease.

Economic Activities Disruption

By disrupting physical capital, disrupting transportation networks, affecting the health of people and the number of hours they work, and lowering tourism and recreational activities, fires can cause economic disruption. About 60% of the projected $150 billion in damages brought on by the 2018 wildfires in California were indirect economic losses brought on by the disruption of economic activities. A 2020 working paper revealed that, on average, between 2006 and 2015, wildfire haze caused annual decreases in labour market activity worth $70 billion. Wildfire smoke can also result in lost productivity distance from the scene of a fire (Wibbenmeyer and McDarris, 2021).

Displacement

Each fire season, wildfires have the power to evict hundreds of thousands of residents. These can be temporary moves brought on by an emergency evacuation or permanent moves brought on by the destruction of homes. As homes are more likely to be threatened by flames in the WUI, those who live there are most impacted. The ability of those without fire insurance—often renters and low-income households—to recover and rebuild is also severely hampered. Additionally, rising insurance costs make it harder for people to rebuild their lives after moving (Wibbenmeyer and McDarris, 2021).

Energy Availability

Energy grid disruption might result from wildfire prevention efforts. For instance, electric providers responded many times to hot, dry, windy weather in California and Oregon by cutting electricity to hundreds of thousands of homes and businesses to lower the risk of fires. These power shut offs have proven to be successful in lowering the likelihood of ignitions, making them prudent when there is a significant risk of fire. Nevertheless, they are quite expensive since they force shut-downs of offices and educational institutions, the spoilage of perishable foods due to refrigerators turning off, and the failure of medical equipment. According to one research, a shutdown that occurred in October 2019 might have cost California's economy up to $2.5 billion. Power supply shut offs have mostly been a Californian phenomena up to this point, but in September 2020, Portland General Electric cut power to more than 5,000 Oregonians because of wildfire weather conditions (Wibbenmeyer and McDarris, 2021).

4.2.3.Environmental Impacts

Watersheds

Watersheds can be affected by wildfires in terms of water availability and quality. Soils may be less able to absorb water after fires. Therefore, severe heavy storms that come right after flames can happen. For instance, a storm that hit Montecito, California in January 2018 immediately after the nearby Thomas Fire resulted in landslides that claimed the lives of 23 people. Water quality can decline in burned watersheds, endangering community water sources. Water sources in areas where fires have occurred have become contaminated with hazardous compounds that could harm drinking water for years (Wibbenmeyer and McDarris, 2021).

Ecosystems

Even while many ecosystems depend on fire to exist, the environment may suffer if wildfires become more intense or happen more frequently than in the past. If burns occur too frequently, ecosystems could not have enough time to recover between them. Strong fires can also significantly affect old-growth trees; in 2020, the California Castle Fire destroyed 10% of the world's mature giant sequoias (Wibbenmeyer and McDarris, 2021).

Carbon Emissions

By burning through carbon-rich forests and grasslands, wildfires can emit an enormous amount of carbon dioxide, methane, and carbon monoxide into the atmosphere. Because they emit so much carbon dioxide, wildfires and climate change can enter into a feedback loop; climate change creates more intense wildfires, which then emit more greenhouse gases, which then makes climate change worse (Wibbenmeyer and McDarris, 2021).

4.3.Forest Fire Risk Assessment and Monitoring

The fire risk requires identifying potentially contributing variables, referred to as causative agents, to be assessed which are different in terms of scale or even definition in different countries.

4.3.1.Variables involved

There are numerous possible variables contributing to fire ignition in forests, leading to various methods to group and classify them. Based on the time variability, one method of collection is conceivable. There are some variables whose values fluctuate almost constantly during the day and others whose change is apparent only after a lengthy period of time—a week, a month, or even years. These factors were categorised as short-term variables and long-term variables, respectively. Evapotranspiration, relative humidity, wind and air temperature provide an example of variables clearly unsteady during the day. Fuel type, fire history, amount of population, topography of the territory, soil type and proximity of roads are variables with roughly stable behaviour in a short period (Gabban,A et al, 2008).

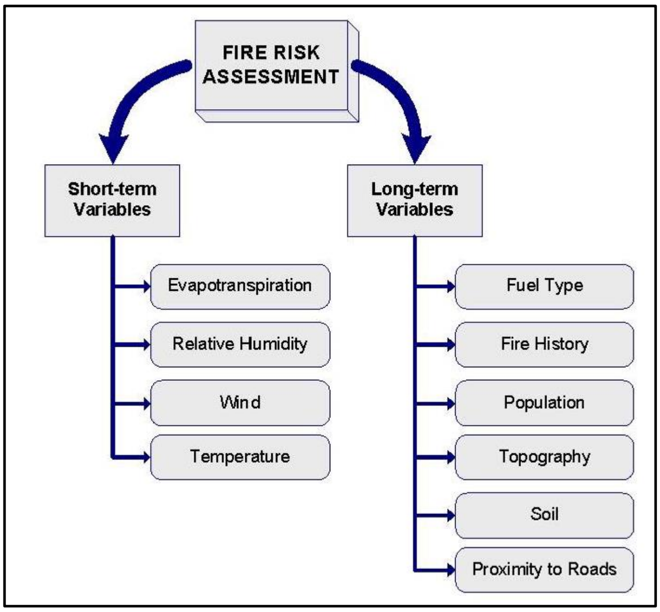


Fig.4-4.Potentially contributing variables for forest fire risk assessment_Source: (Gabban,A et al, 2008)

Meteorological-related variables

The ignition and spread of fire are closely related to specific weather circumstances. Solar radiation, air temperature, relative humidity, precipitation, wind (average speed, turbulence intensity and direction) and vertical structure of the atmosphere are the fundamental meteorological variables involved. Each of these variables plays a relevant role; even though their management becomes difficult (Gabban,A et al, 2008).

Vegetation-related variables

Understanding how water is retained by plants and in soil is essential for predicting the moisture content of vegetation, which is crucial for the initiation and spread of fires. If weather variables are disregarded, the chemical make-up, internal structure, and physical characteristics of the plants will have the greatest impact on how much water is stored and transferred there (Gabban,A et al, 2008).

Human behaviour-related variables

Settlements, agricultural burning, pyromaniacs, barbecues, and cigarettes all increase the chance of unintentional fires. According to the “Assessment Of Forest Fire Risk In The European Mediterranean Region” report(2008), these variables exhibit long-term fluctuation. Therefore, the existence of historical data is urgently required to offer accurate information regarding the occurrence of fires caused by humans.

Meteo-derived indices

Several methods for the evaluation of fire danger based on meteorological data have been developed, referred to as meteorological fire danger indices.These indices depend on different specifics such as fuel moisture content(BEHAVE indice), variations of water content, initial rate of spread for propagation and the quantity of fuel (Canadian Fire Weather index), atmospheric conditions in the proximity of the fuel(the portuguese index) etc.

Vegetation indices derived by remote sensing

Vegetation structure and moisture conditions also influence the ignition and propagation of forest fires. Vegetation indices are derived by remote sensing with the aim to attempt to evaluate the vegetation stress. They are formed from combinations of several spectral values indicating the amount or vigour of the observed vegetation. The simplest form of vegetation index is a ratio between measurements of reflectance in separate portions of the spectrum. The ratios have been defined by applying knowledge of the spectral behaviour of living vegetation. Indices based on the vegetation stress estimate are called vegetation indices and are mainly derived by the simple Vegetation Index, NIR red VI = ρ −ρ , and by the Ratio Vegetation Index (Jordan 1969), RVI= NIR ρ / red ρ (Gabban,A et al, 2008).

Long-term and short term variables

Long term fire risk indices are those based on parameters that do not present high variation in a short period of time. These indices are indicators of stable conditions that, anyhow, could influence fire occurrences.
They are widely used to identify places with a high level of inherent fire risk. Examples of indices falling within this category include the Vulnerability Index and the Fire Probability Index. The Fire Probability Index assesses the likelihood of igniting and is connected to the likelihood of fire incidence. The Likely Damage Index, also known as the Vulnerability Index, assesses the likelihood of potential damages in relation to the area under consideration (Gabban,A et al, 2008).

4.3.2.Registration of forestFire

In order for a forest fire to be registered, a series of specifications need to be clarified which are listed and described as **Date of first alert, Time of first alert, Date of first intervention**, **Time of first intervention, Date on which the fire was Extinguished , Time at which the fire was extinguished, Location of outbreak , Total area burnt, Breakdown of burnt area into wooden and unwooded land , Presumed cause of the forest fire, Commune code(** The European code for the commune in which the fire broke out).

4.4.Wildfires Management Systems

This section discusses the wildfire management system in different scales: the worldwide scale, an international case study_the United States of America, with focus on California state, the European scale, national scale (Italy) and Regional scale (Piedmont). Among the studied factors, we would discuss the institutional frameworks, technologies and regulations, along with their range of covers in order to manage and monitor wildfire events in those areas, using open data sources.

4.4.1.World-Wide Scale

The GEO and the Copernicus Work Programs joined forces to create the **Global Wildfire Information System (GWIS)**. The Global Wildfire Information System (GWIS) aimed to combine existing information sources at the regional and national levels in the new GEO GWIS work program for the years 2020–2022, in order to provide a comprehensive view and evaluation of fire regimes and fire effects at the global level as well as to provide tools to support operational wildfire management from national to global scales (GWIS Website).

The Global Wildfire Information System (GWIS) builds on the ongoing work of the European Forest Fire Information System (EFFIS), the Global Terrestrial Observing System (GTOS), the Global Observation of Forest Cover- Global Observation of Land Dynamics (GOFC-GOLD), the Fire Implementation Team (GOFC Fire IT), and the related Regional Networks, completing the work that is already being done globally to gather information on wildfires. The collaborating companies and space agencies assist the development of GWIS. Support to GWIS is provided by NASA through the medium of its GEO-GWIS activities in the ROSES program (GWIS Website).

GWIS Applications

Current Situation Viewer: This application provides near-real time information on Fire danger forecast up to 10 days in advance on the bases of the Canadian Fire Weather Index (FWI), lightning occurrence, active fire detections from the NASA MODIS and VIIRS sensors, Near-real time burnt area perimeters derived from MODIS and VIIRS, Fire emissions from the Copernicus CAM Service and finally access to a static global Fuel Map (GWIS Website).

Current Statistics Portal: Statistics are provided for the **national level** as well as for specific interest areas like the Arctic Monitoring and Assessment Program and the "Brazilian Legal Amazon" (AMAP). By comparing the current statistics of burnt areas and fire numbers to the average of the last 10 years, the portal gives information on the development of the current fire season. Additionally, the seasonal cumulative trend in burned areas and the number of fires as compared to the average of the previous ten years, as well as the number of thermal anomalies discovered by the MODIS and VIIRS sensors as compared to the average of thermal anomalies discovered during the previous ten years, are provided (GWIS Website).

Country Profile: For the years 2002 to 2019, this application gives a historical overview of fire regimes at the national and subnational levels. Maps of annual/monthly burnt areas, burnt area frequency, and burnt area seasonality are all included. Furthermore, it offers charts for both multi-year and single-year periods that show the number of fires from GlobFire, burnt areas from MODIS MCD64A1, fire regimes (seasonality), monthly fire size distribution per year, damage to land cover, and annual/monthly wildfire emissions (GWIS Website).

Long-term fire weather forecast: Anomalies in temperature and precipitation are predicted on a monthly and seasonal basis throughout the entire earth (GWIS Website).

Data & Services module provides Access to the data utilised in GWIS applications is made available through this application. Web Map Services are used to provide data from the Current Situation Viewer (GWIS Website).

The **Fire Danger Forecast** module offers maps with projected fire danger ratings for the next 1 to 9 days. The Keetch-Byram Drought Index (KBDI), the National Fire Danger Rating System (NFDRS), and the Australian McArthur Forest Fire Danger Index (MARK-5) have all been made available through GWIS in 2019 in response to countries' interest in comparing the performance of the FWI with other pertinent fire danger indices. The European Centre for Medium-Range Weather Forecast(ECMWF) provides daily meteorological forecast data to GWIS (GWIS Website).

1. **Active Fire Detection** is one of the services offered under the Fire Danger Forecast system. Based on the so-called thermal anomalies they cause, active flames are located. The algorithms evaluate a possible fire's temperature to that of the surrounding land cover; if the temperature difference is greater than a certain threshold, the potential fire is confirmed as an active fire or "hot spot." GWIS utilises the NASA FIRMS' active fire detection data (Fire Information for Resource Management System).

2. **MODIS Active fires** is the second service offered by the Fire Danger Forcast package.The MODIS sensor, on board the TERRA and ACQUA satellites, identifies areas on the ground that are distinctly hotter than their surroundings and flags them as active fires. The difference in temperature between the areas that are actively burning with respect to neighbouring areas allows the identification and mapping of active fires. The spatial resolution of the active fire detection pixel from MODIS is 1 km. **VIIRS(Visible Infrared Imaging Radiometer Suite) Active fires** are the third service of this package, which complement the MODIS active fire detection and offer better spatial resolution than MODIS. Moreover, VIIRS is able to detect smaller fires and can help delineate perimeters of ongoing large fires. The mapping of active fires is performed to provide a synoptic view of current fires worldwide and as a means to help the subsequent mapping of burnt fire perimeters.

3. **Burnt Areas** is the forth product of the Fire Danger Service, comprising 4 sub-products namely Modis burnt areas, MODIS & VIIRS NRT, MODIS Active Fires and VIIRS Active Fires. **MODIS burnt areas** Sub-product is used in order to facilitate dispersion and contradiction in wildfire data and information. Global burned area products, which are obtained from satellite images, contain data on the spatial and temporal characteristics of all the areas impacted by flames but not on specific wildfire incidents. Because of this, it is impossible to identify certain wildfire types or analyse their behaviour or occurrence using the dynamics of individual incidents (Artes et al, 2019). The information offered and shown in GWIS is produced using the Globfire technique, which identifies wildfire occurrences and calculates the burnt area of each event using the MODIS burned area product (MCD64A1). Scorched areas are calculated at the national level (or any other administrative level) by aggregating the burnt areas from individual fire incidents (Artes et al, 2019). The MCD64A1 product combines imagery from Terra and Aqua, along with thermal anomalies, and provides burning and quality information on a per-pixel basis.

4. On the other hand, **MODIS & VIIRS NRT** burnt area information is based on the combined use of thermal anomalies from MODIS and VIIRS sensors for delineating single fire perimeters, which are then utilised to estimate the burnt area caused by the fires. GWIS makes use of the active fire detection provided by the NASA FIRMS. Another sub-product is **MODIS Active fires.** The TERRA and ACQUA satellites' MODIS sensors detect hotter spots on the ground than the surroundings and mark those spots as active fires. Active fires can be located and mapped by comparing the temperature differences between burning areas and nearby areas. Active fire detection pixels from MODIS have a 1 km spatial resolution. Finally, **VIIRS(Visible Infrared Imaging Radiometer Suite) Active fires** on board the NASA/NOAA Suomi National Polar-orbiting Partnership (SNPP) uses similar algorithms to those used by MODIS to detect active fires. The VIIRS active fire products

complement the MODIS active fire detection and provides an improved spatial resolution, as compared to MODIS. Additionally, VIIRS is able to detect smaller fires and can help delineate perimeters of ongoing large fires.

5. **Fire Emissions** are the last product for Fire Danger service. The emission plots are derived from the Copernicus Atmosphere Monitoring Service (CAMS) Global Fire Assimilation System (GFAS) operated by the European Centre for Medium-Range Weather Forecast (ECMWF). It produces daily estimates of wildfire and biomass burning emissions by assimilating Fire Radiative Power (FRP) observations from the MODIS instruments onboard the Terra and Aqua satellites (Atmosphere Monitoring Service Website).

The Global Fire Monitoring Center (GFMC)

Following the recommendations of the UNECE/FAO/ILO Seminar Forest, Fire and Global Change (Russia 1996) and a number of international conferences the same year, the UNECE/FAO Team of Specialists on Forest Fire proposed the establishment of an institution which at that time was preliminarily designated as a Global Fire Management Facility. On the basis of these recommendations, the Government of Germany provided initial funding for the establishment of the entity which was designated Global Fire Monitoring Center (GFMC), which initially operated in the 1990s as a contribution to the International Decade for Natural Hazard Reduction (IDNDR) and its successor arrangement, the UN International Strategy for Disaster Reduction (UNISDR). (GMFC Website, 2017).

1.Auspices and main Tasks of the GFMC

Since 2001, GFMC has served as the coordinator and facilitator of the UNDRR Wildland Fire Advisory Group and the Global Wildland Fire Network, a voluntary global network that offers policy recommendations, science and technology transfer, and knowledge advancement to help countries lessen the negative effects of landscape fires on the environment and humanity. It also promotes the understanding of the ecologically and environmentally benign role of natural fire in fire-dependent ecosystems (GFMC, 2017).

Under the UN Office for **Disaster Risk Reduction** (UNDRR) the GWFN provides a Voluntary Commitment to the Implementation of the Sendai Framework for Disaster Risk Reduction.

GFMC provides a **global portal for wildland fire documentation, information and monitoring** and is publicly accessible through the Internet. The regularly updated national to global wildland fire products of the GFMC are generated by a worldwide network of cooperating institutions.

Early warning of fire danger and close to real-time monitoring of fire incidents (at various spatial and administrative scales) are among the web-based information and GFMC services. Other services include interpretation, synthesis, and archiving of global fire data. Supporting the development of long-term plans or policies for wildland fire management, including community-based fire management techniques and advanced wildland fire management training for decision makers, particularly in the prevention and preparedness of wildfire disasters; acting as an advisory body to the UN system through the coordination of the UNISDR Global Wildland Fire Network and the UNISDR Wildland Fire Advisory Group; emerging issues related to wildfire management (GFMC, 2017).

Depending on projects and requests the GFMC services include covering methods of science and technology transfer for application in local fire management (wildland fire prevention, preparedness, suppression, rehabilitation) under different cultural, socio-economic and ecological environments; people-centred participatory fire management (Community-Based Fire Management); development of national strategies and policies for wildland fire management, including legislation; development of standards for international cooperation in wildland fire management (fire management guidelines, common terminology standard procedures for cooperation in wildland fire emergencies), training courses for international wildland fire management specialists global fire assessments and interventions (e.g., for FAO in 2000 and 2006)(GFMC, 2017).

The International Association of Wildland Fire (IAWF)

The International Association of Wildland Fire (IAWF) represents the global wildland fire community and promotes leadership and communication. Its mission is to advance understanding of wildland fire, ensuring effective resource management, firefighter safety, and harmonious coexistence between humans and the environment (IAWF Website) .

4.4.2.United States

In the last ten years, an average of 71,000 wildfires have burned an average of 7 million acres in the United States, posing a significant threat to property, public safety, and natural resources (National Interagency Fire Center, 2021). These fires demand the participation of numerous agencies and organisations at various levels of government in a coordinated effort. In this essay, one of the states most impacted by wildfires, California, will be one of the American states whose organisational and administrative structure will be examined.

4.4.2.1.Federal Level

The U.S. Forest Service manages wildfires on federally owned grasslands and forests at the national level, collaborating with other government organisations like the National Park Service and Bureau of Land Management (U.S. Forest Service, 2022). The National Interagency Fire Center (NIFC), which is run by the Forest Service and is located in Boise, Idaho, coordinates the use of government and state firefighting resources during major wildfires (NIFC, 2022).
The US wildfire management framework involves multiple agencies, including the Forest Service, FEMA, and state and federal organisations, working together to coordinate and implement strategies and disaster response (U.S. Government Accountability Office, 2019).

1.The Nation's Federal Wildland Fire Community(NIFC)

The federal wildland fire community, managed by the Forest Service, includes the Bureau of Land Management, National Park Service, Fish and Wildlife Service, and Bureau of Indian Affairs, covering nearly 700 million acres.

Mobilisation: Three Levels of Response

The three-tier dispatch system includes the local Geographic Area Coordination Center and National Interagency Coordination Center. Nearly 400 local dispatch centres coordinate initial and local response to natural emergencies. Larger incidents may exhaust local teams, crews, equipment, and aircraft.

Fig.4-5.Three-tier system of response in Resource Mobilisation by NIFC_Source: NIFC Website

The wildfire community has established 10 geographic areas to mobilise additional resources and crews after incidents exhaust local capability. These areas can quickly mobilise resources from a broader area (NIFC Website).

The National Interagency Coordination Center (NICC) mobilises response resources across geographic areas and the nation when incident activity exceeds the Geographic Area Coordination Center (GACC)'s capabilities. This includes air tankers, smokejumpers, engines, and large incident management teams, ensuring effective response and assistance (NIFC Website).
The National Multi-Agency Coordinating Group (NMAC) oversees national response efforts during severe fires, coordinating top fire managers from federal and state agencies. It sets priorities for resource mobilisation and coordinates wildfire response across various geographic areas (NIFC Website).The **National Interagency Mobilization Guide** establishes standards for resource **mobilisation** and **demobilisation** in wildland fires and hazard events.

The **NICC** and **GACCs** offer Predictive Services, a decision support for fire forecasting. These services provide critical fire weather, climate, and fire behaviour information to decision-makers. They consist of three primary functions: fire weather and climate analysis, fuels and fire danger predictions, and fire activity and firefighting asset intelligence. Meteorologists analyse weather products and services, Wildland Fire Analysts provide predictions and condition reports, and Intelligence staff access current intelligence on preparedness levels, fire situation, assets, and potential information.

2.US Fish and Wildlife Service

The U.S. Fish and Wildlife Service manages **fire safely** and cost-effectively to improve lands' conditions and **reduce wildfire risks**. With 80% of Service lands relying on fire for wildlife habitat, the service's fire management program **focuses on fuels management**, **wildfire management**, and **wildfire prevention**. Priorities include strategic burn planning, healthy fire application, fuels treatment projects, and leveraging funding sources and partnerships (U.S. Fish & Wildlife Service Website).

3.U.S Department of Interior

The **National Cohesive Wildland Fire Management Plan**, created in 2009, focuses on restoring and maintaining fire-resilient landscapes, establishing fire-adapted communities, and safely and effectively reacting to wildfires. The Office of Wildland Fire (OWF) coordinates the WFM program with federal agencies, tribes, states, and other partners to provide strategic leadership and oversight (National Cohesive Wildland Fire Management Strategy, 2014). The Department of Interior supports the goals through collaboration and coordination, including the preparation of Community Wildfire Protection Plans (CWPPs) and the Wildfire Leadership Council (WFLC). The WFLC aims to implement wildland fire rules, objectives, and management practices consistently. Fuel management ensures forest health by reducing harmful impacts of wildfires, thinning stands, and invasive weed removal.
The Department of Interior also trains veterans and uses emerging technologies like GPS transmitter collars to suppress wildland fires. The Biden-Harris administration has been leading the whole-of-government approach to drought mitigation, working with partners across the federal government. The National Drought Resilience Partnership (NDRP) will be strengthened, and the Bureau of Reclamation has launched a science-based web portal to provide real-time drought-related information and improve public and media understanding of drought conditions (U.S. Department of Interior Website, 2017).

4.National Integrated Drought Information System(NIDIS)

NIDIS is a multi-agency collaboration that organises drought monitoring, forecasts, planning, and information at federal, tribal, state, and local levels. Drought conditions can accelerate wildfires, with unusually warm temperatures causing decreased streamflow, dry soils, and widespread tree kills. To reduce wildfire likelihood, reduce stand density, manage burning, and allow flames to burn without harming people. However, increased wildfire activity may raise suppression costs, changing how fire-prone societies perceive risk and management. The NIDIS Drought and Wildland Fire Nexus (NDAWN) strategy aims to improve drought information use by wildland fire management, air quality managers, fire meteorologists, and fire behaviour analysts (National Integrated Drought Information System Website(NIDIS)).

5.U.S. Department Of Agriculture_Forest Service(USFS)

USFS, the world's largest forestry research organisation, provides financial and technical support to state and private agencies. The USFS researches and develops fire management tools, employs skilled personnel, and provides Incident Management Teams for various emergencies. They also conduct the Burned Area Emergency Response program to detect post-wildfire dangers and assist in fire rehabilitation and restoration. Public platforms like InciWeb provide information on prescribed fires and wildland emergencies, as well as interactive wildfire maps and social media tweets (USFS Website).

Fig.4-6.A map of the United States from InciWeb taken April 14, 2021.Source:(USFS Website)

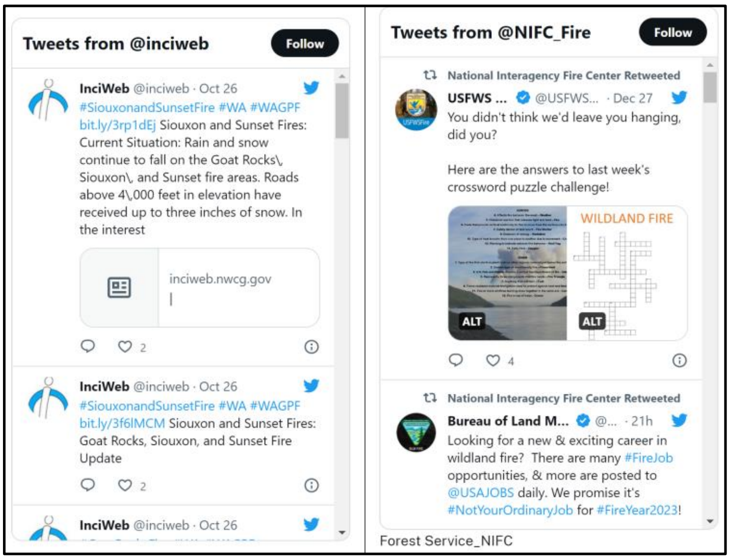


Fig.4-7.Wildfire-related Tweets of NIFC and inciWeb_Source: (USFS Website)

6.National Wildfire Coordination Group(NWCG)

The National Wildfire Coordinating Group provides national **leadership to make integrated wildland fire operations** among federal, state, local, tribal, and territorial partners possible (National Interagency Fire Center Website).

The National Wildfire Coordination Group (NWCG) aims to establish guidelines for interagency national wildland fire operations, establish performance requirements, credentials standards, and wildland fire position competencies. Key objectives include restoring and preserving resilient ecosystems, developing fire-adapted communities, successfully reacting to wildfires, and increasing IT competence. The NWCG offers the Predictive Services Package, which includes the Predictive Services Oversight Group, intelligence section, Weather and Smoke forecast, and Fuels & Fire Danger module (National Wildfire Coordinating Group(NWCG) Website).

4.4.2.2.California

California experienced the highest wildfires and burned acres nationwide, with federal organisations managing 57% of the 33 million acres (California University Website).
California's Department of Forestry and Fire Prevention (CAL FIRE) manages wildfires, assisting local fire departments and providing grants to regional agencies to enhance their response capacity (CAL FIRE, 2022).
California has implemented laws to improve wildfire management, including a Wildfire Safety Advisory Board, increased funding for firefighting equipment, and requiring utilities to upgrade infrastructure (California Legislature, 2019).

1.California Department of Forestry and Fire Protection

California Department of Forestry and Fire Protection (CAL FIRE) safeguards the people of California from fires, responds to emergencies, and protects and extends forest, range, and watershed value catering social, economic, and environmental benefits to rural and urban citizens (CAL Fire Website).
CAL FIRE supports the California Forest Stewardship Program, promoting efficient forest management and community-related issues, while the Wildfire Prevention Grants Program funds projects to protect people, structures, and communities near at-risk areas (Cal Fire Website).

On the other hand, **CalEPA** and its departments assist local, state and federal agencies during and after major wildfires.

2.The California Fire Safe Council (CFSC)

In 1993, CAL FIRE launched the California Fire Safe Council (CFSC), a non-profit organisation educating Californians about wildfire risks and prevention. CFSC collaborates with local fire departments to improve community preparedness and establish strong relationships with decision-makers in Washington, DC, and California (CFSC Website).

3.Evacuation Plans and Public Communication

NIXLE and **CodeRED** mobile applications offer **emergency evacuation notices** to citizens on their phones. Local CalFire Incident Information Page, Office of Emergency Services, sheriff's department, and news stations provide up-to-date information. University of California provides a pre-evacuation order checklist (California University Website).

4.Wildfire Building Construction

Wildfires in California's flammability-prone ecosystems are inevitable, but preventing catastrophic home loss from interface (WUI) fires is crucial. Buildings with older roof coverings and non-fire-retardant roofs can be constructed to reduce ignition risks. The **CAL FIRE website provides information on materials and codes** (CAL FIRE Website).

4.4.2.3.Local Level (General System in United State)

County or city fire departments are responsible for managing wildfires on a local basis. These agencies are in charge of implementing and enforcing fire codes and regulations to avoid wildfires in addition to responding to fires that occur within their purview.

4.4.3.European Union: European Level, National Level and Alpine Area Level

In the European Union (EU), wildfires are a frequent natural catastrophe that present a serious risk to both human lives and the environment. A number of variables, including climate change and changes in land use, have contributed to an increase in the frequency and severity of wildfires in recent years. This section discusses the system for managing wildfires while taking into account administrative and operational aspects at various levels, including the European Union level, national levels (for the member states), and ultimately the level of the Alpine region.

4.4.3.1.Administrational & Operational Aspects of Wildfire Management in European Union and at the national level for the Nation States

In the European Union, a variety of regulatory frameworks and policies in Europe regulate how wildfires are managed. The European Forest Fire Information System (EFFIS), which offers a thorough system for tracking and evaluating the risk of forest fires throughout Europe, is the most significant legal framework for wildfire management at the level of the European Union.(San-Miguel-Ayanz et al., 2013). In addition, EFFIS is in charge of offering fire management services to assist national and local authorities in preventing and fighting forest fires. Through its **Rural Development Policy**, which includes actions like the establishment of firebreaks, the creation of buffer zones around settlements, and the provision of firefighting tools and training, the EU additionally funds wildfire prevention and management (European Commission, 2014).
From an **Administrational** point of view,The EU has created a thorough policy framework for managing wildfires that covers the stages of prevention, preparedness, response/combat, and recovery (European Commission, 2018). A multi-level governance structure that includes national, regional, and local authorities is used to implement this policy (Bachmann et al., 2013). Through financing initiatives like the European Solidarity Fund, which can provide financial aid in the wake of a wildfire, the EU supports Member States (European Commission, 2021).
From an **Operational** perspective, Several actors, including fire brigades, civil protection agencies, forestry authorities, and other emergency responders, are involved in managing wildfires in the EU (Bachmann et al., 2013). These parties share responsibility for managing wildfires, and cooperation between them is essential to a successful reaction (Ganteaume et al., 2013).
In terms of **operational technologies**, In order to manage wildfires, a variety of cutting-edge systems are used throughout Europe, including geographic information systems (GIS), modelling, and simulation tools (San-Miguel-Ayanz et al., 2013). For instance, the Copernicus Emergency Management Service (EMS) offers real-time fire detection and mapping services, and the European Space Agency's (ESA) Sentinel satellite series provides high-resolution imagery for watching and assessing forest fires (San-Miguel-Ayanz et al., 2013).
At the **national level**, Numerous European nations have their own regulatory frameworks for controlling wildfires. For instance, the **National Forest Fire Plan** in Spain regulates the management of wildfires and includes measures like fire prevention programmes, the implementation of firebreaks, and the use of early warning systems (Moreno et al., 2015). **The Forest Code**, which governs wildfire management in France, calls for actions like building firebreaks, implementing fire prevention programmes, and creating an integrated network of fire observation and response systems (Ganteaume et al., 2013).

4.4.3.2.Wildfire Management in Alpine Regions

The **Alpine region**, which includes eight nations and covers about 200,000 square kilometres, includes Austria, France, Germany, Italy, Liechtenstein, Monaco, Slovenia, and Switzerland (WWF, 2021). With forests covering about 35% of the land, the area has a sizable amount of forested territory (FAO, 2020). As a result, wildfires pose a serious danger to the ecosystems of the area and may have serious economic and social repercussions. Similar to other regions of Europe, wildfire control in alpine areas involves some specific adaptations because of the terrain's special characteristics. Due to the elevated danger of wildfires in this area, a number of specialised legal and administrative frameworks have been created. For instance, the development of firebreaks, the implementation of early warning systems, and the construction of a system for real-time fire risk monitoring are all part of **Italy's National Plan for the Prevention of Forest Fires (Piano Nazionale Prevenzione Incendi)** (Lombardi et al., 2019). The **Federal Forest Fire Protection Act (FFPA)**, which governs wildfire management in Switzerland, includes measures like building firebreaks, putting early notification systems in place, and establishing a coordinated network of firefighting resources (Marzolini et al., 2019).

Preventive measures, early detection, and quick action are all used in conjunction to manage wildfires in the Alpine area. The administration of the forests themselves, which includes routine upkeep and fuel reduction techniques like thinning, pruning, and clearing of forest floors, is a crucial component of prevention. These actions lessen the amount of fuel that is readily accessible and aid in containing the spread of any fires that may occur (EEA, 2020). **Awareness campaigns for the public** and restrictions on practices like camping and smoking in forested regions during dry seasons are additional prevention measures.

The management of wildfires in the Alpine area is also influenced by **legal bodies.** The eight Alpine nations signed the **Alpine Convention**, which serves as a **framework for regional collaboration** on environmental protection and sustainable development. A number of forest protection protocols have been created by the **Convention,** such as the **Protocol on Forest Fire Protection,** which mandates that signatory nations take action to prevent and suppress forest fires(Alpine Convention, 2021).

In the Alpine region, **early detection** is another essential component of wildfire control. In order to quickly identify and pinpoint wildfires, several nations have established **early warning systems** that combine remote sensing technologies, weather information, and ground-based observations. Using a satellite-based system, the Swiss Federal Institute for Forest, Snow and Landscape Research, for instance, can quickly identify fires and notify officials(Swissinfo.ch, 2020).

The effect of a wildfire must be reduced as soon as it starts, so quick action is essential. The challenging terrain and severe weather that firefighters in the Alpine area frequently deal with can make their jobs more difficult. To get a bird's eye view of the scene, drop water or fire-retardant chemicals, or carry equipment and firefighters to remote areas, helicopters and other aircraft are frequently used. Additionally, some areas have created specialised wildfire response teams that are educated specifically to work in mountainous environments (Alpine Convention, 2021).

4.4.3.3.European Forest Fire Information System (EFFIS)

Since 1998, the ***Expert Group on Forest Fires***, a group of experts from several nations registered with the *Secretariat General of the European Commission*, has provided EFFIS with support. Experts from 43 European, Middle Eastern, and North African nations currently make up this organisation. EFFIS joined the EU Copernicus program's Emergency Management Services as a component in 2015 (EFFIS Website). In the EU, legal entities and organisations are crucial to the control of wildfires. The **European Commission's Joint Research Centre** manages the **European Forest Fire Information System (EFFIS)**, which gives real-time data on wildfire events (San-Miguel-Ayanz et al., 2013). The Wildfire Prevention and Management Regulation is one of the legal tools the EU has created to support wildfire management(European Parliament and Council, 2019).

The European Commission services and the European Parliament receive up-to-date and accurate and precise information on wildland fires in Europe from the EFFIS, or European Forest Fire Information System, assisting the services in charge of protecting forests against fires in the EU and neighbouring countries (EFFIS Website).

Applications in EFFIS platform include **"Current Situation Viewer"** which provides the current knowledge about the Mediterranean region's and Europe's current fire season. This comprises daily updated maps of hot spots and fire perimeters, today's meteorological fire danger maps, and forecasts out to six days (EFFIS Website), **"Current Statistics Portal"** which comprises of Statistics are supplied at the country level as well as for three groups of nations: the Middle East and North Africa, European Non-EU Countries, and the EU. The portal provides information on the evolution of the current fire season through the provision of *Current statistics of burnt areas and number of fires, Seasonal cumulative trend in burnt areas and number of fires, Number of thermal anomalies detected by the VIIRS sensor* and finally *Number of thermal anomalies detected by the MODIS sensor. "***Wildfire Risk Viewer"** is one of other main services on EFFIS which is basically the Index of wildfire risk on the European Scale. By taking into account the fire threat (or hazard) and the susceptibility in three categories—people, ecological, and economic values exposed in sensitive areas—this contains two primary groupings of components (EFFIS Website).

"Fire News" which provides news about wildfires, categorised by geographical location of the areas**, "long-term fire weather forecast", "Data Request form"** that provides the possibility to request for data not directly available via the EFFIS web services, and "Data and Services" section which provides the totals for each nation (in terms of burned land and fires per year), as reported in the Forest Fires in Europe, North Africa, and the Middle East reports are other products offered by EFFIS (EFFIS Website).

4.4.4.Wildfire in Italy: Monitoring & Management, Institutional Processes & Technologies

The forest fire events in the past few years has proved quite well that forest fires are also an urgent issue in the Alpine region which can lead to the destruction of protected forests, increasing vulnerability to natural hazards and resulting in high costs up to millions of euros for one fire. Forest fire frequency and severity will likely increase in the future due to climate change, more recreational use of forests and changing forest management. Especially protection forests **dominated by coniferous tree species** on southern slopes are at risk. The impacts of forest fires can lead to **new avalanche-prone slopes**, a higher risk of **rockfall**, mudslides or soil erosion. Furthermore, costs of firefighting, restoration of forests and necessary protective measures can seriously rise (Wanger et al, 2020).

The identification of good practice solutions in tackling climate change is one of the major activities. In this context, the Austrian Federal Ministry of Agriculture, Regions and Tourism (BMLRT) has launched the **project "Forest fires in the Alps**: State of knowledge and future challenges" in cooperation with the University of Natural Resources and Life Sciences, Vienna (BOKU), and the members of Action Group 8. For this project, Scientists, authorities and members of action forces of all EUSALP member states (Austria, France, Germany, **Italy**, Liechtenstein, Slovenia and Switzerland) contributed to the survey. In June 2019, a forest fire workshop was held in Vienna in order to identify success stories on fire management and to discuss the major elements of an integrated fire management for the Alpine region that for each version (based on language and country), would be adapted to the context of that country (Wanger et al, 2020).

In italy, the **Department of Civil Protection**, through the **Centro Operativo Aereo Unificato(COAU)**[1], is entrusted with the coordination of the means of the **State fire-fighting air fleet**, which is made up of Canadair CL-415 vehicles and S-64 helicopters owned by the **Fire Brigade Department Fire, public aid and civil defence**, as well as other types of military helicopters owned by the defence sector. In the forest firefighting activity, the COAU is in constant contact with the **Sala Operativa Unificata Permanente(SOUP)**[2] from which it receives the request for a state aerial competition when the regional forces in the field (teams and helicopters) are unable to deal with the fire (Dipartimento della Protezione Civile Website).

[1] Unified Air Operations Center

[2] Permanent Unified Operations Room

The forecasting activity, but more generally the warning system, makes use of the forecasts of the dangerous conditions of possible forest fires and the consequent risk scenarios not only in wooded and rural areas, but above all in the peri-urban areas. These activities, implemented by the Department and the regions through the network of functional centres, are therefore fundamental in view of the activation of the interventions that take place on the basis of the needs expressed by the individual territories (Dipartimento della Protezione Civile Website).

The forecasting activity consists in identifying the areas and periods at risk of forest fire, as well as the danger indexes elaborated on the basis of climatic and vegetational variables, the application of which is decisive for the planning of prevention and extinguishing interventions. The **management of the warning system** is ensured by the Department of Civil Protection through the **Centro Funzionale Centrale**[3] and the **Servizio Rischio incendi boschivi**[4] and interface, which issues a **daily bulletin of susceptibility to the triggering of forest fires throughout the national territory**, identifying for each province three levels of danger (low-medium-high).

The **forecasts** are prepared not only on the basis of the weather and climatic conditions, but also on the basis of the vegetation, the physical state and use of the land, as well as the morphology and organisation of the territory. The bulletin is limited to a forecast on a provincial scale, estimating the average value of the susceptibility to triggering over a period of time useful for the next 24 hours and trending for the next 48. The bulletin is made **available to Regions and Autonomous Provinces**, Prefectures, Forestry Carabinieri and Fire Brigades. The decentralised functional centres, in the Regions where the alert system is active, can in turn issue a **fire susceptibility bulletin** (Dipartimento della Protezione Civile Website).

As far as **prevention activities** are concerned, these fall under the **responsibility of the Regions** which therefore also deal with this sector, involving the subjects entitled to the effective execution of the interventions, such as for example the Municipalities for cleaning the edges of municipal roads (Dipartimento della Protezione Civile Website).

The *Direzione per la Protezione della Natura e del Mare del Ministero dell'Ambiente e della Tutela del Territorio e del Mare (DPNM/MATTM)*[5] is directly interested in the issue of forest fires in implementation of art.8 of Law 21 November 2000, n.353 "FRAME LAW REGARDING FOREST FIRE". In particular, it is dealt with by the Forest Fire Sector of Division II of the aforementioned Directorate. The DPNM/MATTM, starting from the general indications contained in the Civil Protection Guidelines for the drafting of the regional forest fire **prevention plans (or AIB plans)**, prepared in 2002 an AIB Plan Scheme for the state protected natural areas to which the managing bodies adhere to in drafting their own Plan (Dipartimento della Protezione Civile Website).

Moreover, every year, as required by law 152/2005, the Prime Minister defines the times for carrying out the winter and summer Aib forest fighting campaign and issues the **operational guidelines** for adopting all the necessary initiatives to prevent and deal with forest and interface fires. The indications, contained in two separate documents, are addressed to the Regions and the Ministries of the Interior, of Defence, of Agricultural Policies, of the Environment, of Infrastructure and Transport and to that for relations with the Regions. Again on an annual basis, the Civil Protection Department, which coordinates the state's air fleet, defines the procedures for requesting the air competition by the Regions and Autonomous Provinces (Dipartimento della Protezione Civile Website).

In addition, the DPNM/MATTM **supervises and supports** the work of the managing bodies in the drafting, approval and implementation of the AIB plans, systematically activates and **coordinates** the process necessary **to reach an agreement with the regions** concerned for the inclusion of the AIB plans of the state protected areas in the corresponding regional AIB plans, upon request and obtaining the favourable opinion of the State Forestry Corps, until the publication of the Decree adopting the AIB plans (Dipartimento della Protezione Civile Website).

[3] Centralised Functional Centre

[4] Forest Fire Risk Service

[5] The Directorate for the Protection of Nature and the Sea of the Ministry of the Environment and the Protection of the Territory and the Sea

The website of the *Ministero dell'Ambiente e della Sicurezza Energetica*[6] has provided categories of activities that would be performed by the Directorate in order to manage wildfires, namely Supporting Activities for the managers of the disaster including manuals and bibliographies related to wildfire, Information including news, presentations, statistics etc and A|B plans and Cartography including plans and maps for national parks, state parks, scientific support and research for GIS and satellite outputs, working on biodiversity and recovery after the fire (Ministero dell'Ambiente e della Sicurezza Energetica, 2021).

The AIB thematic cartography of the national parks, available at the MATTM, constitutes a concrete contribution to the better **drafting and management of forest fire prevention plans**, as this cartographic information can be superimposed both on each other and with the other themes, the basic cartography and the orthophotos of various years; In particular, the managing bodies of state protected areas (National Parks and State Nature Reserves) have the information elements necessary for the preparation of their own AIB plan and for subsequent annual updates (Ministero dell'Ambiente e della Sicurezza Energetica, 2021).

The resulting cartography derives from previous project initiatives regarding to forest fires include some projects such as first project, which carried out in two phases, by the Italian Botanical Society and the Interuniversity Research Center for Biodiversity, Phytosociology and Landscape Ecology (C.R.I.B.F.E.P.), an activity was launched to support the AIB planning of National Parks (PN) and Nature Reserves Government (RNS), from which the first **"Scheme plan for the planning of forecasting, prevention and active fight against forest fires in state protected natural areas"** of the DPNM/MATTM was derived and subsequently a special "portal help desk” to provide the National Parks online with various elements of documentary and cartographic knowledge useful for their AIB planning activities (Geoportale Nazionale Website).

Among the latter, the State Forestry Corps detects every year - with a GPS tool - the polygons of forest fires; therefore, after correlating these polygons with the fire information resulting from the "News Sheet" (AIB_FN) of the same CFS, the DPNM/MATTT selects the fire polygons present in the National Parks and reports them in this cartographic project (Geoportale Nazionale Website).

Fire polygons are presented in two forms; each fire (possibly overflowing beyond the National Park boundary) is represented by an integer polygon and Each fire is represented with a group of adjacent polygons having different land uses: **"Forest"** or **"Non-Forest"** (which only affect the areas covered by the fire within the Park). Therefore, in this cartographic project, the polygons of the fires that have occurred since 2010 are systematically inserted, as soon as they are available (Geoportale Nazionale Website).

There are also some more independent organisations working on wildfires. For example at a national level, the CIMA Foundation collaborates with the Civil Protection Department to support the **forecasting of the danger** from forest fires on a national and regional scale, and with the National Fire Brigade to support the management of the intervention through simulation of event scenarios. Furthermore, in the context of the ARISTOTLE-ENHSP project, the researchers in the field are partners of the team of experts who provide the European Union's Emergency Response Coordination Center (ERCC) with the pan-European scale fire danger forecast bulletin. One of the main activities of the foundations has been through The Forest Fires and Conservation of Forest Biodiversity area which specialises in research on the prediction and prevention of fire risk and aims at the continuous improvement of the ability to accurately discriminate when and where a trigger can generate an uncontrollable fire (CIMA Foundation Website).

[6] Environment and Energy Security Minister

Organisation/Body	Level	Technology/Operational body	Functionality
Austrian Federal Ministry of Agriculture, Regions and Tourism (BMLRT) +6 other EUSALP countries	International	Forest fire in the Alps	Scientific efforts for the integrated fire management for the Alpine region that for each version (based on language and country), would be adapted to the context of that country
Department of Civil Protection (DPC)	National	Centro Operativo Aereo Unificato(COAU)	entrusted with the coordination of the means of the State fire-fighting air fleet, which is owned by the Fire Brigade Department Fire, public aid and civil defence, as well as other types of military helicopters owned by the defence sector.
	National	Centro Funzionale Centrale[7] and the Servizio Rischio incendi boschivi[8]	management of the warning system through publication of fire susceptibility bulletin covering the whole national territory
	Regional	Sala Operativa Unificata Permanente(SOUP)	In contact with COAU to request for forces in case the regional resources are not enough. composed of various agencies involved in emergency management, including firefighting, civil protection, and health services.
CIMA foundation in collaboration with Civil Protection	National	Simulation of the event scenarios	Forecasting the danger and support the management of the intervention
Direzione per la Protezione della Natura e del Mare del Ministero dell'Ambiente e della Tutela del Territorio e del Mare (DPNM/MATTM)	National	AIB Plan	• Drafting of the regional forest fire prevention plans (or AIB plans) • Issues the operational guidelines • supervises and supports the work of the managing bodies in the drafting, approval and implementation of the AIB plans

Table 4-2.Summary of the Institutional technologies and operative/legal bodies for Antifire activities in different levels_ Source: (Author).

4.4.4.1. Wildfire Management and Regional Level

As envisaged by the framework law on forest fires, the regions have the task of implementing - on the basis of the guidelines defined by the Ministerial Decree of 20 December 2001- the regional plans for forecasting, preventing and actively fighting forest fires. The plans are triennial and are updated annually. The primary objective of the regional plans is to reduce the wooded areas affected by the fire. In addition, as envisaged by the regional plans, intervention teams are located throughout the territory for onshore shutdowns made up of specialised personnel. The priority objectives to be defended and the territorial area pertaining to each team are indicated on a special map. If necessary, the teams can also be deployed in other areas. An operations coordinator is identified for each territorial area. The teams on the ground, always in direct contact with the operations centres, can also be employed in the reconnaissance-sighting-surveillance phases. Outside of periods at risk, team personnel can be engaged in forest fire risk prevention activities (Dipartimento della Protezione Civile Website).
Extinguishing can be conducted from the ground or by aerial means in conjunction with a ground intervention. In the event of a fire, the first to intervene are the ground teams coordinated by the Regions and made up of regional personnel or, on the basis of specific program agreements indicated in the regional plans, by personnel of the State Forestry Corps, the National Fire Brigade , the Armed Forces, the State Police Forces and forest fire volunteers. If the fire is too extensive and the work of the teams on the ground is not sufficient, whoever directs the extinguishing operations can request the intervention of the air means supplied to the Regions (above all helicopters) and if not sufficient, also of the coordinated State air fleet from the -Centro Operativo Aereo Unificato(Coau)[9](Dipartimento della Protezione Civile Website).

[7] Centralised Functional Centre
[8] Forest Fire Risk Service
[9] Unified Air Operations Center

The Civil Protection Department ensures and coordinates on the national territory, through the Coau - Unified Air Operations Center, the **aerial firefighting activities** with the State firefighting air fleet.
The Coau is active continuously within 24 hours throughout the year. Command and control centre for all aircraft made available for competition in civil protection activities, the Coau plans and coordinates flight activities both nationally and internationally. In forest firefighting activities, it is in constant contact with the *Centro Operativo Regionale*(COR)[10] and the *Sale Operative Unificate Permanenti(SOUP)*[11] of all the Regions (Dipartimento della Protezione Civile Website).

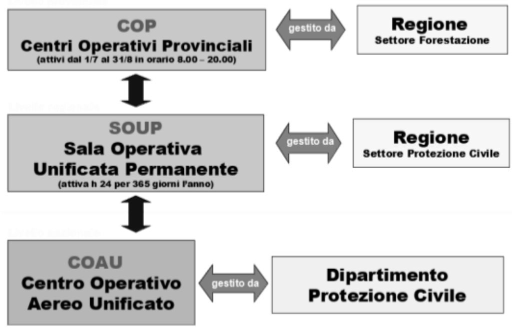


Fig.4-8.Anti wildfire Operating Rooms (Sale Operative AIB)_Source: (Tuscany Region Website)

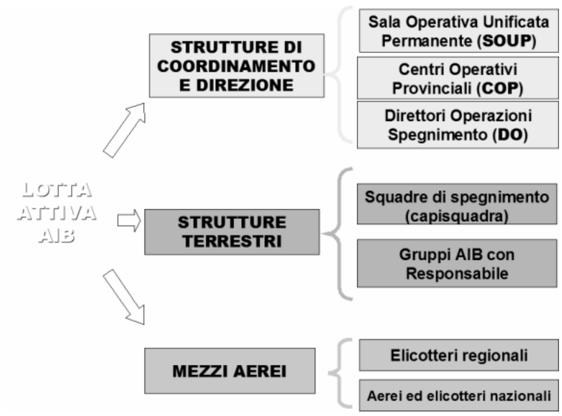


Fig.4-9.Active Wildfire Fight Administrational Structure_Source:(Tuscany Region Website)

4.4.4.2.The Regional Level:Piedmont

The specific regional organisation on forest fire prevention began in **1997**, when the Forest Fire Prevention Sector and Relations with the State Forestry Corps was established, as part of the Mountain and Forest Economy Directorate. Subsequently, following the regional reorganisation, provided for by L.r. 23/2008, and with the aim of improving the efficiency and effectiveness of the Piedmont emergency intervention system, all the competences in the field and, consequently, the organisation of the Piedmont forest fire prevention operating system, have been placed within the regional Civil Protection (Ricaldone, C, del Negro,L, Murru, A et al, 2021).
The Civil Protection Sector and Forest Fire Prevention System was also born in Piedmont, to bring together and coordinate the action of the two operating systems. Two parallel worlds that, in the past, rarely met, started a common path that could lead to sharing and optimising the daily and the extraordinary, i.e. emergencies of various nature and risk, regional and national (Ricaldone, C, del Negro,L, Murru, A et al, 2021).

[10] Regional Operative Centres
[11] Permanent unified operations rooms

The regulatory changes of recent years certainly influenced the choice, which - following the entry into force of Legislative Decree 177/2016 - led to the suppression of the State Forestry Corps, to the review, among others, of the regional operating system Piedmont and the largest forest fire emergency in Piedmont (Autumn 2017). In fact, however, the two systems, civil protection and forest fire prevention, continued to operate side by side, even in the same location, sharing work and supporting each other, especially during emergencies. Regardless of the organisational location, however, attention to forest fire risk has also grown following the emergency that affected Piedmont in **autumn 2017**, the aftermath of which some important organisational changes were recorded:

− the "de facto" **creation of the SOUP** (at the SOR VVF), with the presence of all the operational components of the forest fire prevention system ;

− the recognition of the **figure of the Co.AIB**: territorial subject, belonging to the **Piedmont AIB Volunteer Corps**, in charge of coordinating its personnel in the field - alongside the DOS VVF - and of the possibility, in its temporary absence, to request regional aircraft from the SOUP ;

− a **new regional law**, adapted to the regulatory changes that have occurred;

− the signing of the three-year agreement with the **fire brigade**;

− the updating of some aspects of the operating procedures, in force since 2012, through the approval of the document Technical operating guidelines for the management of activities to combat forest fires of the Piedmont AIB System;

− the approval of guidelines for the implementation of direct forest fire prevention interventions, with the use of forest fire prevention and civil protection volunteering, through the organisation of exercises: an important document for forest fire prevention activities , i.e. guide sheets for the correct implementation of exercises by the Volunteer Forest Fire Fighting Corps of Piedmont, aimed at producing interventions, of limited size, but numerous, punctual and constant, for the maintenance and care of the territory;

− a new contract for the helicopter service, with greater guarantees of immediate intervention (Ricaldone, C, del Negro,L, Murru, A et al, 2021).

All this until autumn 2019, when the partial reorganisation of the regional structures (DGR n. 4-439 of 29 October 2019) divided the two systems again, with the intention of giving greater prominence and room for growth to **forest fire risk** .

The Piedmont Region, in compliance with the national legislation L. 353/2000 and the regional L.r. 15/2018 coordinates all AIB activities, promotes actions aimed at reducing the risk of forest fires, draws up the planning tools (Regional Plan for forecasting, prevention and active fight against forest fires) required by the regulations, establishes and coordinates the forest fire prevention operating system, through the stipulation of specific Agreements, Conventions and contracts; promotes information and dissemination on fire prevention, promotes studies and research on AIB (Regione Piemonte Website).

This prevention planning activity has uninterruptedly involved the Piedmont Region since the second half of the 1970s with the enactment of the aforementioned national legislation considering the fact that in Piedmont, forest fires have always been a serious problem and are still today one of the main causes of forest degradation (Regione Piemonte Website, 2021).

The **regional provision** is the direct consequence of the current and expected meteorological evolution and of the consequent risk forecast bulletin, issued by the ***Centro funzionale di Arpa Piemonte***[12]. In fact the official website of the Piedmont region informed the citizens on August 2022 that even though at the moment the extreme risk conditions that had led to the emanation of the maximum danger no longer existed, considering that the general problem of the drought that has affected the Piedmont area along with a vast part of the rest of Italy, cannot be considered solved, the population is invited to maintain an adequate level of attention in carrying out those actions that can contribute to triggering fires (Regione Piemonte Website, 2022)

Following a specific agreement, the Piedmont Region has specifically entrusted the National Fire Brigade with:

[12] Functional Center of Arpa Piemonte

a) the management and technical-operational coordination of the Permanent Unified Operations Room (hereinafter SOUP), provided for in art. 7 of the Framework Law on forest fires (Law 21 November 2000, n. 353), through the *Sale Operative Regionale(SOR)*[13] (Regione Piemonte Website);
b) the coordination of operations to extinguish forest fires on land, in compliance with the organisational and operational autonomy of the Piedmont Forest Fire Volunteer Corps, on the basis of regional operating procedures (Regione Piemonte Website);
c) the direction of aerial forest fire extinguishing operations, through the use of state and regional means, carried out through the use of DOS - VV.F. specially formed (Regione Piemonte Website).
Following the Convention, specifically on forest fires, the Carabinieri Forestale are required, among other things, to provide data relating to the perimeters of the surfaces covered by the fire, pursuant to Law no. 353 of 2000; to carry out surveillance activities on regional territories at risk of forest fires and to prevent dangerous behaviour, to conduct investigative activities, sending, when possible, a representative to the theatre of firefighting operations who verifies compliance with the laws and provides, where necessary, information on the vegetational and orographic characteristics of the same (Regione Piemonte Website).
The AIB Volunteer Corps of Piedmont - following a special agreement with the Piedmont Region - actively intervenes in the prevention and in all phases of surveillance and active fight against forest fires. It supplies the Co.AIB, highly specialised figures, recognized by the Region, suitable for the operational coordination of AIB volunteers in the fight against forest fires. Participate in preventive awareness initiatives on fire risk (Regione Piemonte Website).
The Regional plan for the planning of forecasting, prevention and active fight against forest fires 2021-2025 (consisting of a main document and an annex document) describes the technical, organisational and administrative processes necessary for the protection of the forest area from fires.
It contains the analysis of the characteristics of the Piedmont area (forest heritage); Analysis of forest fires in Piedmont: risk zoning and definition of basic areas with reference to risk classes; Fire forecasting system and direct and indirect prevention actions; Active fight: description of the forest fire fighting operating system of Piedmont, intervention operating procedures, helicopter service; Education/training; Study and research activities; Economic framework of needs (Regione Piemonte Website, 2021).
The annexes to the main document - conceived as a dynamic work tool, constantly evolving according to needs - constitute and will constitute, with their continuous updating, the documentary support of studies, experiments, insights and updates generated by the application of the provisions or proposed in the Plan itself. Furthermore, these Annexes contain documents (e.g. risk analysis) which can refer to the previous operating system as they were approved before the reform referred to in Legislative Decree 177/2016. As these documents are reviewed, the Plan will be updated annually, as required by the relevant legislation (Regione Piemonte Website, 2021).

[13] Regional Operation Rooms

5.The Role of Remote Sensing in Wildfires Management

Introduction

In order to better understand an object, place, or phenomenon under study, the science and art of remote sensing entails the interpretation of data gathered by a device that is not in close proximity to it. One of the most successful uses of satellite remote sensing is the mapping of burned regions and evaluation of wildfire consequences. Satellite remote sensing offers a low-cost method for gathering thorough and coordinated data on the effects of wildfires for vast areas.

This section goes through the different components and processes and features related to remote sensing, including the different types of remote sensing, sensors and their different uses and categories. It continues with diving deep into remote sensing application for wildfire, in all its phases with different methodologies and tools. And finally, the chapter is concluded by a review on european services covering wildfire events.

5.1.Remote Sensing Definitions

5.1.1.Remote Sensing

The science and art of remote sensing involves the interpretation of data collected by a device that is not in direct contact with the object, location, or phenomena being studied in order to learn more about it (GeographyNotes Website). Data-informed decision-making based on the present and potential future status of our planet is made possible by remote sensors, which offer a global perspective and a plethora of information about Earth systems (EarthData Website of NASA).

5.1.2.Remote Sensing Components

Remote sensing components include the Source, Platform, the sensor and ground-based receiving station. This section tries to summarise these components in the following paragraphs.

Electromagnetic radiation(EMR), is the essential element in the remote sensing process and is viewed as **the source**. When electromagnetic radiation strikes an object's surface, it may be absorbed, transmitted, reflected, or sometimes the object may even emit radiation (for example in the form of heat). Satellites and spacecraft are always packed with a range of sensors to detect and record radiation which is emitted or reflected (StudyProbe Website, 2020).

A **Platform** is described as the carrier for remote sensing sensors. There are three main remote sensing platforms: ground-level platform (such as towers and cranes), aerial platforms (i.e. Helicopters, low altitude aircraft, high altitude aircraft), and spaceborne platforms (i.e. space shuttles, polar-orbiting satellites and geostationary satellites) (The constructor Website).

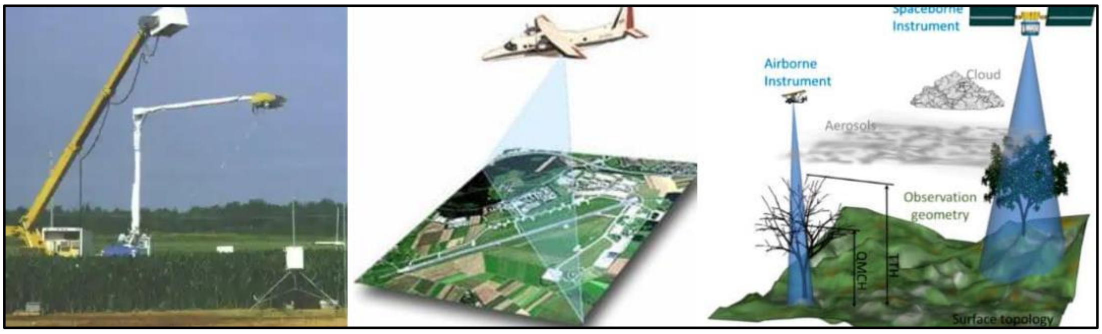


Fig.5-1.(From Left to Right) Ground-Based Platform, Airborne Platform,Space-Based Platform_Source: (The Constructor Website)

Sensors are the apparatus that take in electromagnetic radiation and transform it into a signal that can be stored and shown as either numerical data or an image (The Constructor Website). Sensors are employed in a variety of daily items, including touch-sensitive elevator buttons and lamps, in addition to satellites(GISRSStudy Website, 2022).
Finally, **Ground based receiving stations** are Communications equipment for receiving and transmitting signals to and from satellites such as Landsat (Esri Website, 2020).

5.1.3.Sensor Classification

1.Sensor Classification Based on the signal Source

There exist two main types of sensors, classified according to the source of signal they use to explore the object, active vs. passive.
Active remote sensing instruments operate with their own source of emission or light, and its sensor measures reflected or backscattered energy. The energy is generated and sent from the Remote Sensing platform towards the targets (Kogut, 2020). Active sensors can typically pass through the atmosphere, since they work mostly in the microwave section of the electromagnetic spectrum. These kinds of sensors are important for determining the vertical profiles of aerosols, the topography of the sea's surface, the structure of forests, precipitation and winds, and ice, among other things (EarthData Website of NASA). Active remote sensing is used by several ranging equipment, including Radar, Lidar, Sounder, Laser altimeter, Ranging instruments, and Scatterometer. The location, speed, and direction of an object are determined by measuring the time delay between emission and return, as in the case of RADAR and LiDAR. Elevation is measured using a laser altimeter and lidar. In remote sensing, each active sensor sends its signal in the direction of the item, then measures the response to determine the quantity received. Since they are largely resistant to weather, microwaves are used by most gadgets. Active remote sensing techniques differ by what they transmit (light or waves) and what they determine (e.g., distance, height, atmospheric conditions, etc.) (Kogut, 2020).
Passive sensors, on the other hand, rely on solar energy that bounces off the object. Most of the passive sensors use solar energy as the source of EMR, otherwise there will be nothing to reflect. In passive remote sensing, various band combinations are used to measure the obtained quantity through multispectral or hyperspectral sensors. The number of channels used in these combinations varies (two wavelengths and more)(Kogut, 2020). The majority of passive systems used in remote sensing applications operate in the electromagnetic spectrum's visible, infrared, thermal infrared, and microwave ranges. These sensors track physical characteristics like vegetation characteristics, cloud and aerosol characteristics, land and sea surface temperatures, and more. Most passive sensors are limited in their ability to observe regions like the tropics where substantial cloud cover is common because they cannot penetrate it (EarthData Website of NASA).
Passive sensors include varieties of radiometers (instruments that quantitatively measure the intensity of electromagnetic radiation in select bands) and spectrometers (devices that are designed to detect, measure,

and analyse the spectral content of reflected electromagnetic radiation) (EarthData Website of NASA). Spectroradiometer, Hyperspectral radiometer, Imaging radiometer and Accelerometer are some other examples of passive remote sensing(GISRSStudy Website, 2022). Examples of passive remote sensors include film photography, infrared, charge-coupled devices, and radiometers (Kogut, 2020).

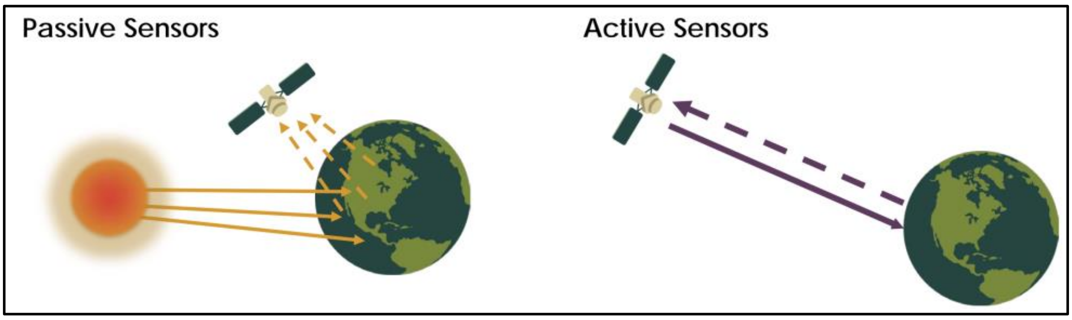


Fig.5-2.Diagram of a passive sensor versus an active sensor. Credit: NASA Applied Sciences Remote Sensing Training Program_ Source:(Kogut, 2020)

2.Sensor Classification based on The Output Type

Remote sensing sensors can be classified based on the output type into imaging sensors and non-imaging sensors (Zhu et al, 2017).The electrons emitted by an imaging sensor are used to ionise or excite a substance, such as silver in film, or to power an image-producing apparatus, such as a TV, computer monitor, cathode ray tube, oscilloscope, or battery of electronic detectors. Non-imaging An electrical signal strength or other quantitative feature, such as radiance, is reported by the sensor as a result of integrating the radiation received from all places in the sensed object. The output of non-imaging sensors is linear (Kogut, 2020) and includes microwave radiometers, microwave altimeters, magnetic sensors, gravimeters, Fourier spectrometers, laser rangefinders, and laser altimeters. The imaging sensors, on the other hand, include optical imaging sensors, thermal imaging sensors, and radar imaging sensors based on their spectral properties. In terms of image sensors and non-imaging sensors, Figure(5-3) depicts the category (Zhu et al, 2017).

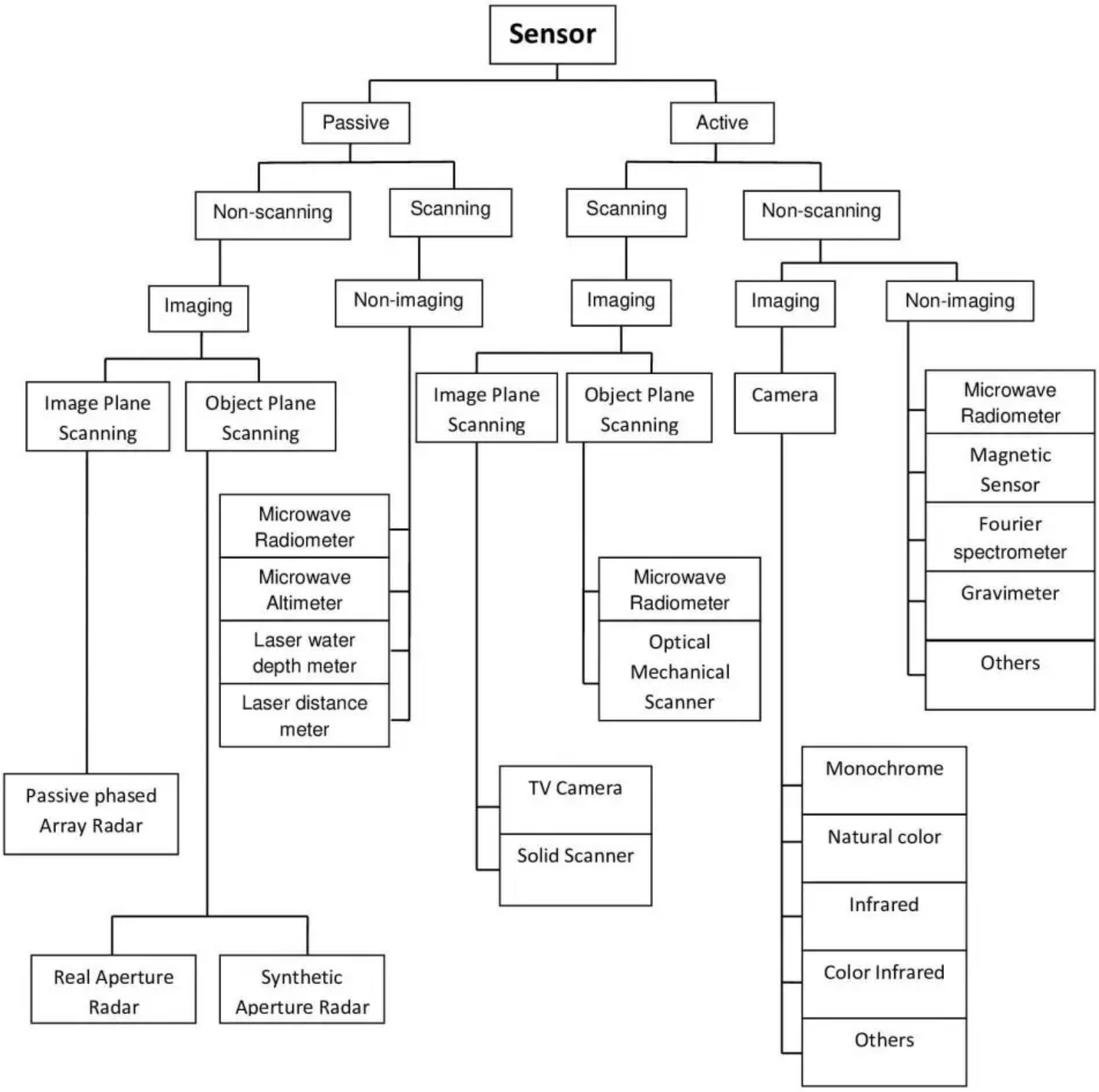


Fig.5-3.Imagine and Non-Imaging Sensors_ Source:(GISStudy,2022)

3.Sensor Classification based on Resolution

Resolution is commonly used to describe the number of pixels displayed on a display device, or area on the ground that a pixel represents in an image file. Resolution plays a role in how data from a sensor can be used. Resolution can vary depending on the satellite's orbit and sensor design (EarthData Website of NASA). The resolution of a sensor with a digital output is usually the numerical resolution of the digital output. A sensor's accuracy may be considerably worse than its resolution (GISStudy Website, 2022). There are four types of resolution to consider for any dataset—radiometric, spatial, spectral, and temporal which are discussed in this section. However, It is difficult to combine all of the desirable features into one remote sensor. For example, to acquire observations with high spatial resolution (like OLI, aboard Landsat 8) a narrower swath is required, which requires more time between observations of a given area resulting in a lower temporal resolution. Therefore, Researchers have to make trade-offs. This is why it is very important that when researching seasonal vegetation changes, a high temporal resolution may be sacrificed for a higher spectral or spatial resolution (EarthData Website of NASA). The four types of resolutions include

Spectral resolution, Spatial Resolution, Radiometric Resolution and Temporal Resolution which are respectively discussed in the following paragraphs.

A sensor's ability to record particular wavelength intervals is referred to as **spectral resolution**. In actuality, it is a sensor's capacity to distinguish finer wavelengths, or having more and narrower bands. Numerous sensors are categorised as multispectral, which means they have 3–10 bands. Some sensors, which are referred to as hyperspectral, have hundreds or thousands of bands. The spectral resolution is finer when the wavelength range for a given band is more narrow. The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), for instance, collects data over 224 spectral channels(EarthData Website of NASA).
Researchers and scientists are now studying hyperspectral remote sensing, also known as imaging spectroscopy, with reference to the detection and identification of minerals, terrestrial plants, and man-made materials and backgrounds. Individual absorption features caused by certain chemical bonds in a solid, liquid, or gas can be found using spectroscopy. With recent technological advancements, imaging spectroscopy has started to concentrate on the Earth. Imaging and spectroscopy are combined in a single device for hyperspectral remote sensing, which frequently involves massive data sets and calls for innovative processing techniques. Multispectral data sets often consist of 5 to 10 bands with very high bandwidths, whereas hyperspectral data sets typically consist of 100 to 200 spectral bands with relatively tiny bandwidths (5-10 nm) (70-400 nm). Typically, spatial information is collected in the X-Y plane of hyperspectral images, while spectral information is displayed in the Z-direction of the data cube (The University of Texas Website).

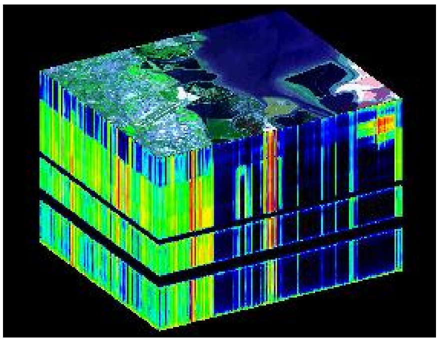


Fig.5-4.AVIRIS hyperspectral data cube over Moffett Field, CA_Source: (The University of Texas Website)

The size of each pixel in a digital image and the area on Earth's surface that each pixel represents can be used to define **spatial resolution**, which refers to the area on the ground that each pixel represents. For instance, the Moderate Resolution Imaging Spectroradiometer (MODIS) observes most bands with a spatial resolution of 1 km; each pixel corresponds to a 1 km x 1 km region on the ground. Bands from MODIS also have a 250 m or 500 m spatial resolution. You can see more information when the resolution is finer (lower number). You can notice the difference in pixelation between a 30 m/pixel image on the left, a 100 m/pixel image in the middle, and a 300 m/pixel image on the right in the image below (right image) (EarthData Website of NASA).

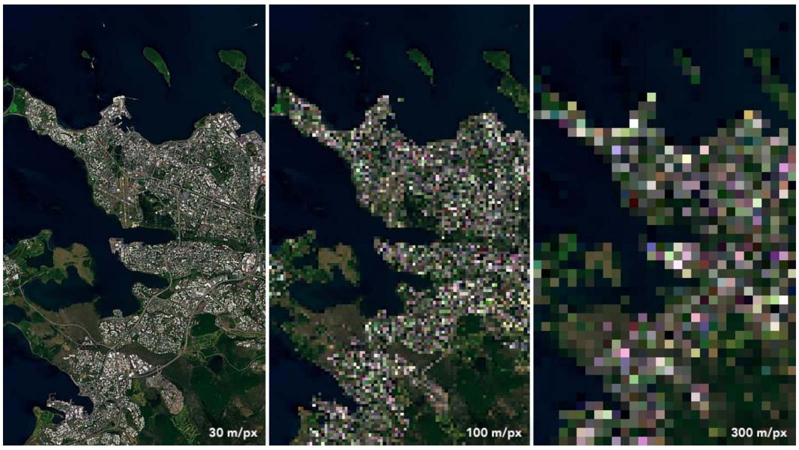


Fig.5-5.Landsat 8 image of Reykjavik, Iceland, acquired July 7, 2019, illustrating the difference in pixel resolution. Credit: NASA Earth Observatory_Source: (EarthData Website of NASA)

Radiometric resolution refers to the number of possible data file values in each band and can be described as the amount of information in each pixel, that is, the number of bits representing the energy recorded. It is an indicator of how sensitive the instrument is to small variations in the EM energy. Each bit is said to record an exponent of power 2. For example, an 8 bit resolution is 28, which indicates that the sensor has 256 potential digital values (0-255) to store information. Thus, the higher the radiometric resolution, the more values are available to store information, providing better discrimination between even the most subtle differences in the energy. For example, when assessing water quality, radiometric resolution is necessary to distinguish between small differences in ocean colour. Thus, sensors with high radiometric resolution can distinguish greater detail and variation in light (EarthData Website of NASA).

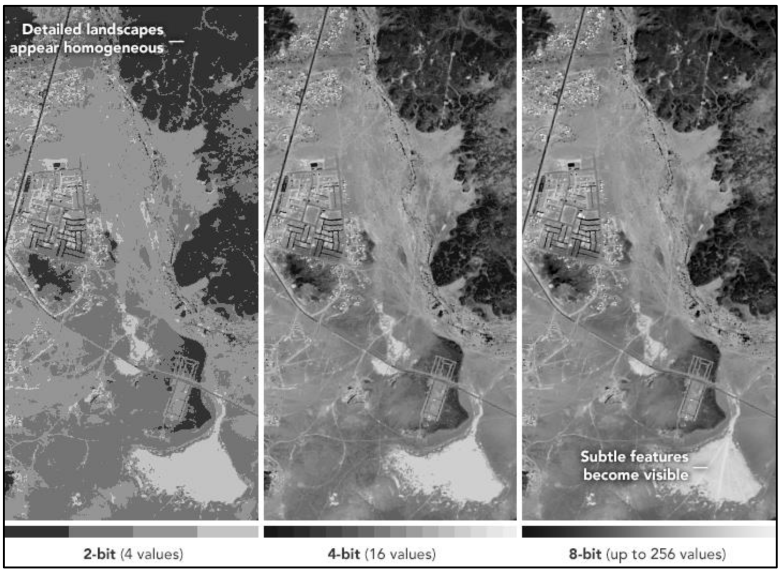


Fig.5-6.Radiometric Resolution_ Credit: NASA Earth Observatory images by Joshua Stevens, using Landsat data from the U.S. Geological Survey_ Source: (EarthData Website of NASA)

Temporal resolution is described as the time it takes for a sensor/satellite to complete an orbit and revisit the same observation area.This resolution is influenced by the orbit, the features of the sensor, and the swath size. The temporal resolution is substantially higher for geostationary satellites since they rotate at the same speed as the planet. The temporal resolution of polar orbiting satellites, however, might range from one day to sixteen days. As an illustration, the MODIS sensor on NASA's Terra and Aqua satellites has a temporal resolution of 1-2 days, enabling the sensor to see how the Earth changes throughout the day. The Operational Land Imager (OLI) aboard the joint NASA/USGS Landsat 8 satellite, however, has a narrower swath width and a temporal resolution of 16 days; showing not daily changes but bi-monthly changes (EarthData Website of NASA).

5.1.4.Process of Remote Sensing

Energy Source or Illumination (A), Radiation and the Atmosphere (B), Interaction with the Object(C), Recording of Energy by the Sensor (D), Data acquisition (energy propagation, platforms), Transmission, Reception and Processing (E), Processing (conversion of energy pattern to images), Interpretation and Analysis(F), Analysis (quantitative and qualitative analysis), Accuracy assessment (radiometric and geometric correction), Application(G) and Information distribution to users are the main components in the remote sensing process, which are illustrated in figure (5-7) .

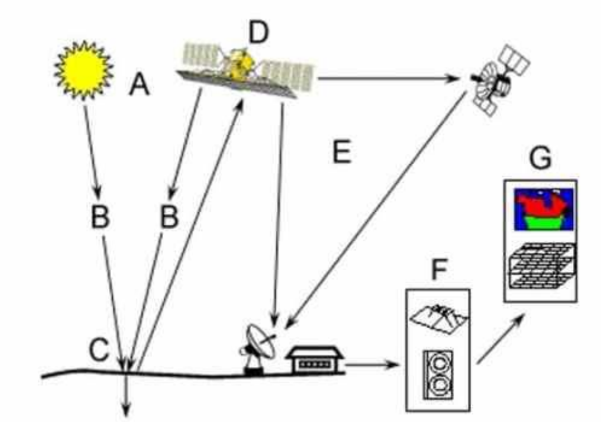


Fig.5-7.Elements Involved in Remote Sensing_Source: (gissstudy Website)

The Sun is the main source of electromagnetic energy that satellites can detect. The amount of energy, which varies by wavelength, is reflected, absorbed, or transmitted by everything on Earth. It depends on the surface's abrasiveness and albedo, or how well a surface reflects light as opposed to absorbing it. Energy is frequently reemitted after being absorbed, notably at longer wavelengths. For instance, the energy that the ocean absorbs is reemitted as infrared light. Everything on Earth has a distinct spectral fingerprint, just like we each have one. This knowledge can be used by researchers to distinguish between various Earth features and various kinds of rocks and minerals. The degree of material difference that a researcher can discover depends on the number of spectral bands that a particular instrument can detect, or its spectral resolution (EarthData Website of NASA).

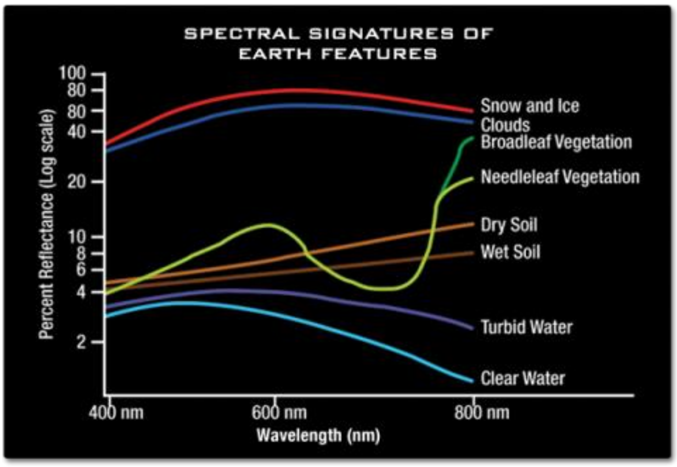


Fig.5-8.Spectral signatures of different Earth features within the visible light spectrum. Credit: Jeannie Allen_ source: (EarthData Website of NASA)

Processing is required before the bulk of researchers and users in applied science may utilise remote sensing data from instrumentation onboard satellites. Users typically need to use numerous sensors and data products to address their topic because of the limitations of the data supplied by different spectral, geographical, and temporal resolutions. Pictures of the data that reveal various landscape characteristics can be made by combining bands. Images of data are routinely used to define a study region or to identify characteristics of an area under investigation. True colour is used to represent Earth, just as the human eye does. When data is transformed into imagery using different band combinations, the imagery can help with disaster assessment and resource management decisions. Knowing the scale and using the knowledge of the resolution at its best, looking for patterns, shapes and textures(for identifying features), using colours to distinguish different phenomena, and having knowledge of the local area are the (EarthData Website of NASA).

Other methods of image analysis include classification algorithms. Different land cover types can be discriminated more readily by using image classification algorithms. Image classification uses the spectral information of individual image pixels. A program using image classification algorithms can automatically group the pixels in what is called an unsupervised classification. The user can also indicate areas of known land cover type to "train" the program to group like pixels; this is called a supervised classification. Satellites also often carry a variety of sensors measuring biogeophysical parameters, such as sea surface temperature, nitrogen dioxide or other atmospheric pollutants, winds, aerosols, and biomass. These parameters can be evaluated through statistical and spectral analysis techniques (EarthData Website of NASA).

Fig.5-9.Fire scars reflect strongly in Landsat's Band 7, which acquires data in the shortwave infrared range. The fire scar is not visible in the left image, which is a standard true-colour image. The fire scar stands out clearly in red in the right image, which is a false-colour infrared image. Credit: NASA_ Source: (EarthData Website of NASA)

5.1.5.Commonly Used Remote Sensing Satellites

So far, more than 1000 remote sensing satellites have been launched. These satellites have been updated with new generation satellites. The few spectral sensors from the earliest missions have been upgraded to hyperspectral sensors with hundreds of spectral bands. The spatial and spectral resolutions have been improved on the order of 100-fold. Revisit times have been shortened from months to daily. In addition, more and more remote sensing data are available as open data sources. Table (5-1) gives an overview of the commonly used remote sensing satellites and their parameters (Zhu et al, 2017).

Mission	Country	Launch year	Sensors	Height of orbit (km)	Swath (km)	Revisit (day)	Channels	Spatial resolution
Landsat	USA	1972, 1975, 1978,1982, 1984,1993, 1999,2013, 2020	Panchromatic and multispectral sensor	705	185, 183	16	7–11	120 m, 100 m, 60 m, 30 m, 15 m
SPOT	USA	1986, 1990, 1993, 1998, 2002, 2012	Imaging spectroradiometer	694	60	1–3	Panchromatic, B, G, R, NIR	2.5 m, 5 m, 10 m, 20 m
ERS	ESA	1991, 1995	IR radiometer, microwave sounder, Radiometer, SAR	782–785	5–100 km (AMI) - 500 km (ATSR)	3, 35, 336	SAR	26 m across track and 6–30 m along track
RADARSAT	Canada	1995, 2007, 2018	SAR	793–821, 798, 592.7	45–100, 18–500, 5–500	1	SAR	8–100 m, 3–100 m, 3–100 m
MODIS	USA	1999, 2002	Imaging spectroradiometer	705	2330	1	36	1000 m, 500 m, 250 m
IKONOS	USA	1999	Imaging spectroradiometer	681	11.3	3	Panchromatic, B, G, R, NIR	Panchromatic:80 cm B, G, R, NIR:3.2 m
QuickBird	USA	2000, 2001	Imaging spectroradiometer	482, 450	16.8–18	2.4–5.9	Panchromatic, B, G, R, NIR	Panchromatic:65 cm/61 cm B, G, R, NIR:2.62 m/2.44 m
Envisat	ESA	2002	ASAR, MERIS, AATSR, RA-2, MWR, GOMOS, MIPAS, SCIAMACHY, DORIS, LRR	790	1150 km, 100 km, 400 km	35 days	15 bands (VIS, NIR), C-band	300 m, 30–150 m
GeoEye	USA	2008	Imaging spectroradiometer	681	15.2	8.3	Panchromatic, B, G, R, NIR	Panchromatic:41 cm B, G, R, NIR: 1.65 m
WorldView	USA	2007 2009 2014 2016.9	Imaging spectroradiometer, Laser altimeter	496, 770, 617, 681	17.6 km 16.4 km 13.1 km 14.5 km	1.7 1.1 <1 3	Panchromatic; Panchromatic and eight multispectrum; Panchromatic and eight multispectrum; Panchromatic, B, G, R, NIR	Panchromatic 0.5 m; Panchromatic and stereo images:0.46 m multispectral: 1.84 m; Panchromatic 0.34 m and multispectral 1.36 m
Sentinel 1–6	ESA	2014, 2015, 2016, 2017, 2021	Radar and super-spectral imaging	693, 786, 814	250 km 290 km, 250 km,	12, 10, 27	C-SAR, 12 bands (VIS, NIR, SWIR), 21 bands (VIS, NIR), S-band & X-band	5–20 m, 5–40 m, 10 m & 20 m & 60 m

Table 5-1.Commonly-used Remote Sensing Satellites_ Source: (Zhu et al, 2017)

5.1.6.Remote Sensing Applications

The longest-running Earth-observing mission, Landsat, stands out among passive sensor examples used in remote sensing (Kogut, 2020).

Remote sensing data can be used to track changes over time and obtain the most recent land use trends for huge areas at any one time. It can be used to update wetland delineation, asphalt conditions, and road maps. Regional planners and administrators utilise this data to frame policy decisions for the region's overall development. In India, weather forecasting makes heavy use of remote sensing technology. It is also employed to inform people of approaching cyclones. Remote sensing is used in the environmental sector to monitor deforestation, the degradation of fertile land, air pollution, desertification, eutrophication of big water bodies, and oil spills from oil tankers. Last but not least, damage brought on by earthquakes, volcanoes, landslides, floods, wildfires and melting polar ice can be studied via remote sensing. Remote sensing can frequently be used to anticipate the occurrence of natural dangers (The Constructor Website).

5.2. Remote Sensing for Wildfire

The benefits of satellite imaging include wide regional coverage, uninterrupted viewing, and the capacity to reliably and affordably collect data in inaccessible regions. One of the various pre-fire conditions that may be seen by remote sensing is the status of the fuel type, which can be mapped using high spatial resolution optical or radar imaging. A wildfire threat analysis system can then connect these maps to other pre-fire situation elements, such as topography, proximity to roads and urban centres, etc. Another pre-fire parameter that can be calculated via remote sensing is the fuel moisture status (Leblon, B. et al, 2012).

5.2.1.Types of Remote Sensing Systems for Wildfire Detection

Finding flames as soon as they begin and acting promptly to control their spread before they cause substantial damage are the keys to lowering wildfire risks and damages today. To monitor and detect wildfire outbreaks, many authorities and industries regularly use **IoT-based solutions**, **terrestrial**, **aerial**, and **satellite remote sensing systems** (Bedolla, 2022). This section tries to summarise the various systems available for detecting wildfire.

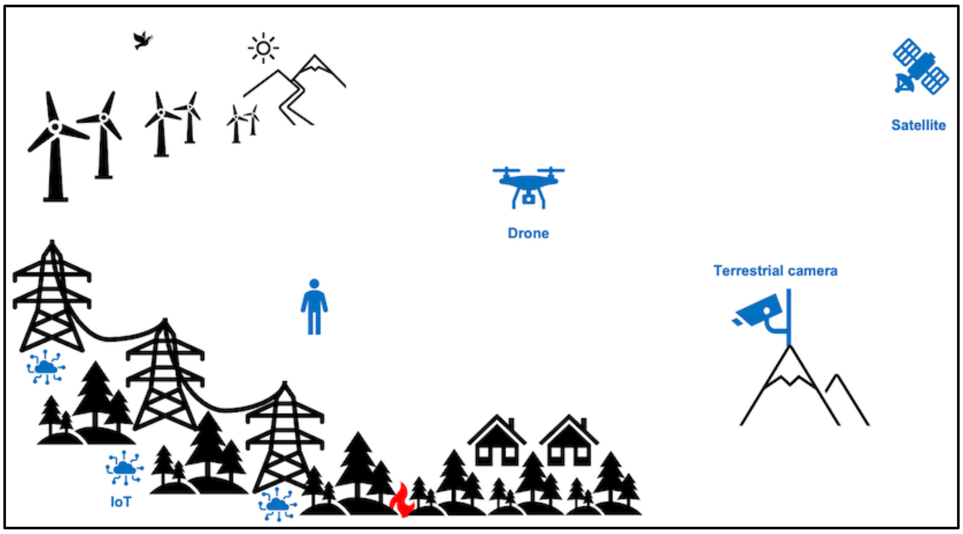


Fig.5-10.diagram showing common wildfire detection technologies_Source:(Bedolla, 2022)

In many areas, **Terrestrial Camera Systems (Visual & Infrared Sensors)** have been used to actively scan the environment for new fires. They have near-infrared and/or thermal sensors that allow them to collect information about distant objects. Optical cameras may record images in both colour and black & white/Monochrome. Visual sensors can record red, blue, and green light to record colour information. In this way, it is simple to see if there is smoke or fire during the day. The capacity to collect thermal information on the heat emission from nearby objects is one benefit of integrating infrared sensors into these camera systems. When infrared and visible sensors are coupled, false alarm rates for fire detection are reduced, and the dependability of camera systems for wildfire detection is raised (Bedolla, 2022).
Utilising cameras is the most sophisticated and popular method of early wildfire detection. Optical zoom functions are also provided, giving fire managers access to more situational information. Visual camera systems can detect flames up to 60 kilometres distant in good weather. The best distance to detect minor, early-stage flames is 15 kilometres. Thermal cameras with line-of-sight and long-wave infrared (LWIR) technology can detect 2 m2 fires at a distance of 5 km and 9 m2 burning surfaces at an 8 km (Bedolla, 2022).

The NASA Suomi NPP satellite, NASA-Terra NOAA and Aqua satellites, as well as other **satellites**, provide detailed pictures of smoke and fire throughout the globe approximately twice every day. Information about forest fires is now accessible from ISRO. FSI receives the forest information from ISRO (Subha, 2020). Satellites have been used in firefighting to locate hotspots, active flames, and to track the movement of smoke. Geostationary satellites are positioned 35,785 kilometres above the planet's equator. These satellites provide a consistent view of the same significant area as they orbit at the same speed as Earth. Every 15 minutes, they continuously produce coarse, low resolution imagery of clouds, fire, and smoke. On the other hand, polar orbiting satellites like NASA's Terra and Aqua can record incredibly detailed photos of energy radiation, smoke, and aerosol properties, all of which are connected to the fire phenomenon (Bedolla, 2022).
The geostationary and polar orbiting spacecraft might have any of these three types of sensors—VIIRS, MODIS, and AVHRR—which all provide visual data on fire, hotspots, and smoke. The VIIRS sensor is commonly used for wildfire detection since it gathers data from both visible and infrared light. Every one to

two days, the Terra and Aqua satellites' MODIS sensors will scan the entire planet. They collect more atmospheric data than VIIRS and have a greater range of infrared light detection. During the day, visible imaging is helpful for locating hotspots and clear smoke, but at night or when visibility is poor, it is useless.Data on smoke may be comparable to data on other phenomena, such as clouds and haze, which presents issues. The Earth's surface is scanned by MODIS' thermal detectors for abnormal temperatures. Hotspots and other heat sources' precise positions are never known, just estimated. The polar-orbiting satellite technology of NOAA helps AVHRR sensors create images with a 1 km resolution. This spatial resolution, which is equivalent to a resolution of 700 m, does not provide enough detail to distinguish between fires in the early stages of commencement(Bedolla, 2022).

Another tool being utilised to enhance fire management activities are **Airborne Remote Sensing/ Unmanned Automated Vehicles (UAV)**. They have been used in place of crewed aircraft to observe and put out flames in low visibility. Similar to terrestrial camera systems, drones with infrared and optical sensors can be used to map out active fires and hotspots that might be hidden by smoke (Bedolla, 2022). Drones are able to fly up and down the terrain, taking pictures in places where there are steep slopes. In addition to being extensively used to monitor areas and locate hotspots or firebreaks, drones are also frequently used to battle flames by restricting their spread using fire-dropping techniques. Technologies for detecting wildfires using drones are being developed by companies including Northrop Grumman and Robotto (Bedolla, 2022).

Drones exist in these two forms of rotary winged and fixed winged drones and both of these categories may be deployed with ease. The automated vehicle's rotors rotate at high speeds, allowing it to remain still for extended periods of time—some for as long as three hours and others for more than eight. Rotating wing drones can only survey and examine the area for a shorter period of time than fixed wing drones, which may fly for up to 16 hours, due to their limited endurance. One disadvantage of some rotary winged drones is that they may not be able to carry big thermal and visual cameras or other sensors due to their small payload(Bedolla, 2022).

Through networked devices and software, data can now be gathered, processed, and shared in almost real-time thanks to the **Internet of Things (IoT)**. **IoT devices** are being used to keep an eye on and safeguard social and biological ecosystems. Environmental characteristics such as temperature, air pressure, moisture levels, and radiation, smoke, CO2, and other particulate matter are all detected by the sensors that are currently in use.

Heat, smoke, and abnormal CO2 readings can all be signs of the beginning of a potential fire. The weather features of a region are crucial information because they affect how a fire starts, grows, and spreads. Front-line users, including fire managers, can receive alerts from IoT-based systems. Because the devices are frequently inexpensive and compact, numerous sensors can be put to cover huge regions in both accessible and inaccessible locations. Sensors are constructed with both heat- and weather-resistant materials to survive high temperatures and severe weather. The resilience and endurance of these sensor devices are increased by the employment of heavy metals. The only drawback is that weathering could cause these metals to end up in our drinking water and other areas of the ecosystem (Bedolla, 2022).

Hotspots may be identified by a group of sensor nodes in some IoT-based systems, which may subsequently cause a drone to fly over the area to observe and collect more information. Information gathered by sensors, drones, and other detection devices is analysed and delivered to the internet or to a data centre through interconnected networks. The network transmits detections to the relevant authorities and other network users, who can subsequently act and decide how to manage fires (Bedolla, 2022). **EUREKA**, and **Dryad** are **IoT-based systems** that are being used to alert various communities of any detected wildfires.

Sensor	Technology description	Detection: range & fire size	Strength	Weakness	Best Use considerations
Terrestrial camera (visual/near IR)	Detects monochrome or color information (visual light)	Detects wildfires up to 60 km away in optimal conditions, Detects early stage wildfires 15 km away	Detects fires at a distance of 5 km up to 60 km, situational awareness for operations	Poor performance in low light/hazy conditions and requires assistance from cameras including near IR capabilities, limited by field of view	To detect smoke during daylight hours, situational awareness of active fires
Terrestrial camera (thermal)	Detects temperature anomalies and heat radiated by objects (infrared light)	Infrared light can be detected on building surfaces of 9 m^2 at a distance of 8 km, fires as small as 2 m^2 may be detected at ranges up to 6 km	Detects heat that may come before smoke is visible	Limited range, uses line of sight	To detect flames (heat) and smoke during night time hours or in low visibility conditions
Drones	Unmanned automated vehicles may be equipped with visual/thermal sensors	Detects hotspots and small fires	Maneuverability, potential for long endurance times, scans wide landscapes, access to remote or dangerous areas	Small payload, must take into account battery capacity	Monitoring and inspecting inaccessible landscapes for hotspots, close range observations
Terrestrial IoT	Sensors gather data on forest parameters and weather conditions (eg. C02, smoke, heat radiation, humidity, temperature, air pressure)	Depends on cluster of sensor nodes	Remote monitoring, tracks patterns and movement based on data, battery/solar powered	Without installing clusters of sensors, coverage and data transmission remains limited	Forests and remote areas
Satellite	Orbit around the Earth to provide large scale coverage of smoke, fire, clouds, etc. Equip thermal detectors	Observes large fires and heavy smoke	Global coverage, may equip sensors to detect and monitor fire spread and smoke movement, detects nighttime fires	long revisit times, does not provide near real time data, deployment is often regulated	Large-scale observations, monitoring weather conditions, to track and monitor the spread of wildfires and smoke

Table 5-2.Remote Sensing Technologies comparison_Source :(Bedolla, 2022)

5.2.2.Indexes Ordinarily Used for Wildfires Analysis (NDVI, FWI, etc.)

Using remote sensing methods, a lot of work is put into locating, tracking, and mapping the burned-out forest. This approach saves time and money. On satellite images, we may spot active fires using direct visual approaches. Active fires can be identified by the visible light they produce; however, only at night it is possible to distinguish between different fire-emitted lights. The majority of fires start and reach their peak intensity during the day, hence operational fire management does not place a great priority on nighttime fire detection. As an alternative, fires can be located by the plume of smoke plum they release. This detection method is widely used at local scale, as an alternative to visual detection by human operators. Image processing algorithms can be used to single out this smoke plume in contrast to its background, and associate it to a fire. Although these systems eliminate false alarms produced by overheating of ground areas, they also present some limitations (Leblon,B et al, 2012).

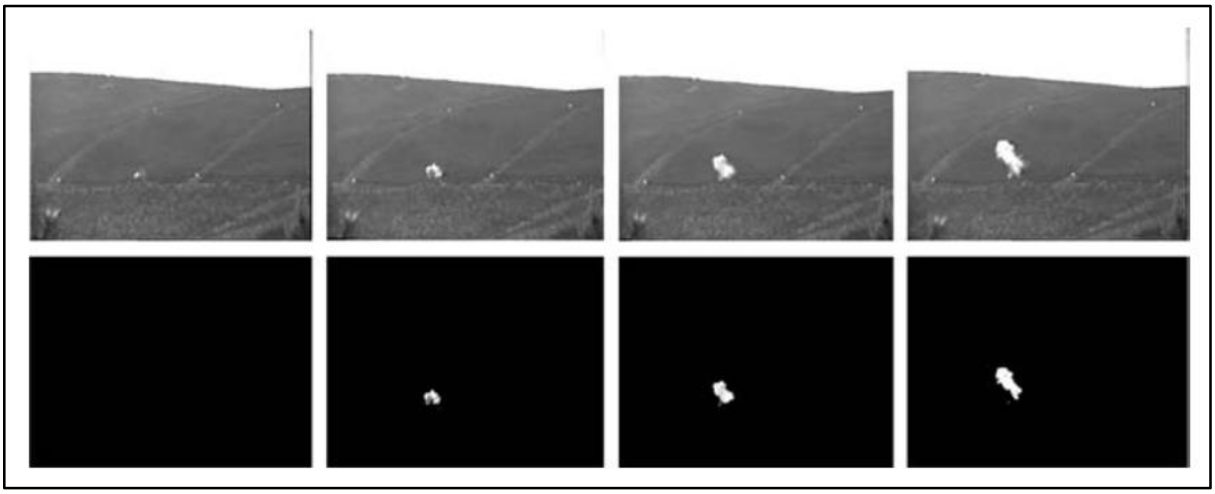


Fig.5-11.Smoke plume identification for fire detection with optical cameras_Source:(Leblon,B et al, 2012)

Last but not least, fires are most usually found because of the specific high temperature they produce, which results in a high reflection signal in the thermal electromagnetic and mid-infrared spectra. Temperatures from active fires normally vary from 800 K to 1200 K, though they can exceed 1800 K. These temperatures are easily visible in the mid-infrared part of the spectrum. This mid-infrared spectral window is suitable for fire detection since it is far from the Earth's and the Sun's respective radiation peaks at 0.5 and 9.7 m (see Fig. 5-12). However, the maximum radiation at these wavelengths is 300 K, which is the average ambient temperature. The heat area of the spectrum, which is between 8 and 12 m, is where fires also emerge. The mid-infrared and thermal spectra can be used to locate fires either locally or at their absolute maximum(Leblon,B et al, 2012).

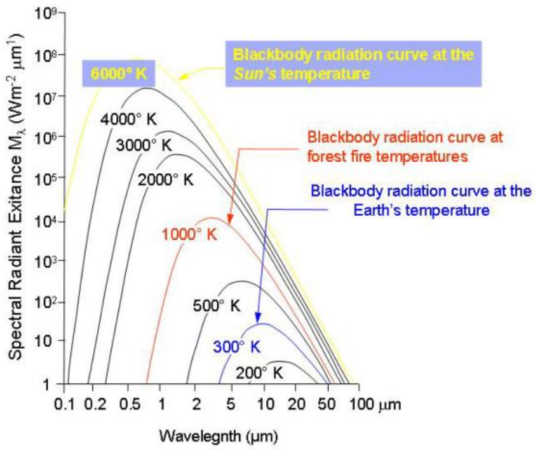


Fig.5-12.Existence of spectral radiants in relation to the black body's temperature. The graph demonstrates that forest fires, which are hotter than the surface of the Earth, have a peak in their spectral exitance at a shorter wavelength than the surface of the Earth. Source: (Leblon,B et al, 2011)

To locate and map burned areas, **infrared bands** are highly helpful. The distinctions between burned and unburned landscapes are immediately apparent. Each earthly feature has its own reflectance value. By examining their reflectance values, we can locate forest fires. **The Burn Area Index (BAI)**, **Normalised Burn Ratio (NBR)**, **Mid-Infrared Burn Index (MIRBI)**, and other metrics are used to evaluate forest fires and burned regions. Using the segmentation tools in ENVI for ArcGIS software, which also supports supervised and unsupervised classifications, it is possible to analyse the map and identify the burned region. Using the map of forest cover, we can determine what kind of forest fires were there. Satellite images are used to make these maps. The forest cover map includes shrubs, non-forest, open forest, dense forest, moderately dense forest, and extremely dense corset (Subha, 2020).This section tries to summarise the indexes used in order to detect the burnt area.

Normalised Difference Vegetation Index (NDVI) index, is basically a normalised statistic that highlights the differences between how vegetation's chlorophyll and cell structure respond to the red (R) and near-infrared (NIR) bands of light. High NDVI levels are produced by the chlorophyll in healthy, green plants absorbing visible (R) light and the cell structure reflecting NIR light. Low NDVI values are caused by increasing fire damage to vegetation and/or seasonal vegetation senescence. NDVI is calculated for each pre-fire and post-fire scene as:

$$NDVI = (NIR - R) \div (NIR + R)$$

When the pre-fire NDVI is subtracted from the post-fire NDVI, a new NDVI image called Differenced Normalised Difference Vegetation Index (dNDVI) is produced. Similar to how the dNBR can be used to distinguish between burned and unburned areas, the dNDVI can be used to classify vegetation burn intensity.The dNDVI is calculated as:

$$dNDVI = NDVI\ pre\text{-}fire - NDVI\ post\text{-}fire$$

The **Emissivity Difference Vegetation Index (EDVI)** index, a drought indicator, is used to track the condition of the flora and water availability. "Enhanced Vegetation Index Drought Index" is what EDVI

stands for. It computes the ratio of near-infrared (NIR) to visible (VIS) reflectance values from satellite imagery to quantify the vegetation reaction to drought stress.
The EDVI index can be used as a tool to pinpoint areas at risk for wildfires because of dry conditions and stressed vegetation in the context of wildfire control. Drought-stressed vegetation is more prone to ignition and can ignite more easily, which raises the possibility of wildfires. Monitoring EDVI values can therefore serve as a helpful wildfire early warning method.

The **Normalised Burn Ratio (NBR)** is an index designed to highlight burnt areas in large fire zones. The formula is similar to NDVI, except that the formula combines the use of both near infrared (NIR) and shortwave infrared (SWIR) wavelengths. It leverages the contrast in response by the near-infrared (NIR) and short-wave infrared (SWIR) bands to leaf area, plant productivity and moisture. High NBR values are produced by healthy, green vegetation because it significantly absorbs SWIR light and substantially reflects NIR light. Low NBR values are caused by increasing fire damage to vegetation as well as the exposing of dry, rocky soils (United Nations Website).
Healthy vegetation shows a very high reflectance in the NIR, and low reflectance in the SWIR portion of the spectrum (Fig. …) - the opposite of what is seen in areas devastated by fire. Recently burnt areas demonstrate low reflectance in the NIR and high reflectance in the SWIR, i.e. the difference between the spectral responses of healthy vegetation and burnt areas reach their peak in the NIR and the SWIR regions of the spectrum (United Nations Website). NBR is calculated for each pre-fire and post-fire scene as:

NBR = (NIR - SWIR) ÷ (NIR + SWIR)

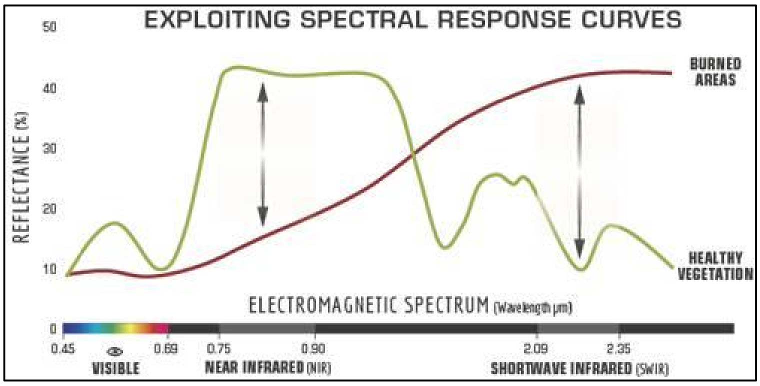


Fig.5-13.Comparison of the spectral response of healthy vegetation and burned areas. Source: U.S. Forest service.

To benefit from the magnitude of spectral difference, NBR uses the ratio between NIR and SWIR bands, according to the formula shown below. A high NBR value indicates healthy vegetation while a low value indicates bare ground and recently burnt areas. Non-burnt areas are normally attributed to values close to zero (United Nations Website).

$$NBR = \frac{NIR-SWIR}{NIR+SWIR}$$

Burn severity data and maps can aid in developing emergency rehabilitation and restoration plans - post-fire. They can be used to estimate not only the soil burn severity, but the likelihood of future downstream impacts due to flooding, landslides, and soil erosion (United Nations Website).
A **Differenced Normalised Burn Ratio (dNBR)/Burn Severity** image, also known as a change image, is produced by deducting the post-fire NBR from the pre-fire NBR. The dNBR can be used to distinguish between burned and unburned areas and to determine the severity levels of vegetation burns(United Nations Website). The dNBR is calculated as:

dNBR = NBR pre-fire – NBR post-fire

The delta NBR (dNBR or NBR), which can be used to evaluate the burn severity, is calculated from the difference between the pre-fire and post-fire NBR derived from the photos. Greater damage is indicated by a larger dNBR value, while regeneration after a fire may be seen in places with negative dNBR values (United Nations Website). The formula used to calculate dNBR is illustrated below:

$$dNBR \text{ or } \Delta NBR = PrefireNBR - PostfireNBR$$

Since dNBR readings can differ from case to case, it is best to interpret particular circumstances through field evaluation in order to get the best results. However, in order to understand the burn intensity, the United States Geological Survey (USGS) produced a classification table, which can be seen below (Table 5-3).

Severity Level	dNBR Range (scaled by 10^3)	dNBR Range (not scaled)
Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.99
Low Severity	+100 to +269	+0.100 to +0.269
Moderate-low Severity	+270 to +439	+0.270 to +0.439
Miderate-high Severity	+440 to +659	+0.440 to +0.659
High Severity	+660 to +1300	+0.660 to +1.300

Table 5-3.Burn severity levels obtained by calculating dNBR, proposed by USGS_Source: (United Nations Website)

It should be noted that the Fire Intensity is not the same as Burn Severity. The amount of energy released from organic materials during burning is represented by the intensity of the fires. It also describes the fire's intensity when it is burning. On the other side, burn severity shows how the intensity of the fire impacts how the ecosystem in the burned area functions. Within a given location and amongst various ecosystems, the reported impacts frequently vary. The degree to which a space has been changed or disrupted by the fire can also be used to indicate the severity of a burn. An illustration of the difference between fire intensity and burn severity is shown in Figure (5-14) (United Nations Website).

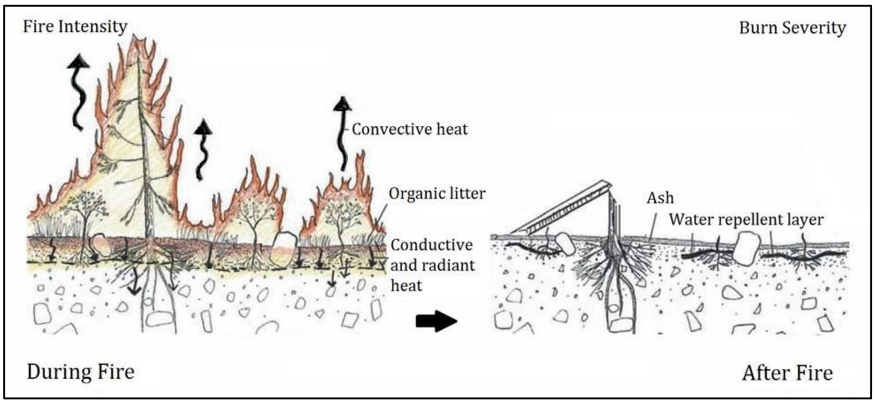


Fig.5-14.Illustration of fire intensity versus burn severity_(Source: U.S. Forest Service).

In places with little vegetative cover, **Landsat Soil Adjusted Vegetation Index(SAVI)** is used to adjust the Normalised Difference Vegetation Index (NDVI) for the impact of soil brightness. In order to account for the majority of land cover types, the SAVI produced from Landsat Surface Reflectance is calculated as a ratio between the R and NIR values(USGS Website).

$$((NIR - R) / (NIR + R + L)) * (1 + L)$$

By highlighting the charcoal signal in photos taken after a fire, the **Burnt Area Index (BAI)** index emphasises burned terrain in the red to near-infrared spectrum. The spectral distance between each pixel and a reference spectral point, where recently burned areas converge, is used to calculate the index. Burned areas are indicated by brighter pixels.

$$BAI = \frac{1}{(0.1 - Red)^2 + (0.06 - NIR)^2}$$

Using **Burned Area Index for Sentinel-2 (BAIS2)**, more spectrum data captured in the red-edge spectral region is carried by the new MSI sensor on Sentinel-2 satellites, paving the path for the creation of new indices for burned area mapping. The vegetation characteristics indicated in the red-edge spectral domains and the radiometric response in the SWIR spectral domain, which are universally acknowledged to be effective in identifying burned areas, improve BAIS2. Based on the mathematical difference between pre-fire BAIS2 and post-fire BAIS2 estimates, the derived dBAIS2 index (Difference Burned Area Index for Sentinel-2) measures burned area (Filipponi, 2018).

Finally, the **Fire Weather Index (FWI)** is an international index that measures fire hazard, and is based on meteorology. It is made up of various parts that take wind and fuel moisture impacts on fire behaviour and spread into account. The likelihood of a wildfire starting increases with the FWI, which measures the favorableness of the weather. The European Forest Fire Information System (EFFIS) categorization is used by the Fire Weather Index (FWI) system to determine the fire danger(European Commission Website).

5.4.Existing European Services

In times of natural disasters, man-made emergencies, and humanitarian crises around the world, the Copernicus Emergency Management Service (CEMS) leverages satellite images and other geospatial data to provide free mapping services. It specifically addresses tsunamis, landslides, severe storms, fires, technological disasters, volcanic eruptions, and floods (Copernicus EMS Website, 2023).

5.4.1.CEMS Instruments for Information on Wildfires

Maps from Copernicus EMS are available at all stages of the emergency management cycle. Rapid Mapping and Risk and Recovery Mapping are the two temporal modalities in which the maps are produced. The **European Forest Fire Information System (EFFIS)** and the **mapping services (EMS)** that make up CEMS provide complementary solutions in the form of spatial data and maps that can help users of the services deal with crisis situations related to, among other things, forest fires throughout the entire disaster management cycle. For instance, the always-on EFFIS service provides rapid damage assessment following a forest fire while continuously monitoring the fire hazard throughout Europe and the Mediterranean basin.RM is an on-demand service that provides geospatial data from extremely high-resolution satellite images for the quick response to an incident, hours after activation, covering all regions of the world. RRM is an on-demand service that provides post-event thorough effect assessments and recovery monitoring for all regions of the world along with pre-disaster fire risk assessments (Copernicus EMS Website, 2023).

The **European Forest Fire Information System (EFFIS)** is one of the main features of CEMS. The Copernicus EMS Early Warning and Monitoring component's EFFIS is an always-on, fully functional system that manages the entire cycle of managing forest fires, from prevention and readiness through post-fire damage analysis. It keeps an eye on forest fire activity in almost real-time, assisting national and regional wildfire management for EU member states as well as in the Middle East and North Africa. The activity provides funding for organisations in the EU member states tasked with preventing forest fires. Additionally, it delivers accurate and up-to-date information on wildland fires in Europe to the European Commission services and the European Parliament (Copernicus EMS Website, 2023).

The following comprehensive modules are part of EFFIS, starting from the pre-fire state: Fire Danger Assessment, Rapid Damage Assessment, which includes Active fire detection, Fire severity assessment, and Land cover damage assessment; Emissions Assessment and Smoke Dispersion Potential; Soil Loss Assessment and Vegetation Regeneration; and Fire News, which compiles all fire-related news posted on the internet (Copernicus EMS Website, 2023).

Providing geospatial data within hours or days of a service request, **The Copernicus Rapid Mapping service for forest fires (CEMS RM)** is a module of the On-demand Mapping service that supports emergency management tasks in the immediate wake of a disaster. The RM is capable of delivering four different kinds of products, including a Reference product to determine the situation prior to the event, a First Estimate product to roughly identify and assess the most affected areas, a Delineation product to determine the geographic extent of the fire event, and a Grading product to assess the severity and scope of the damage caused by the fire event.
Since EFFIS is an always-on service that continuously monitors the fire hazard and charred areas, EFFIS and Rapid Mapping are complementing services. Additionally, RM works as an on-demand service that uses higher spatial resolution satellite imagery to offer precise wildfire estimates, delineations, and grading over a user-defined area of interest. The **On-Demand Mapping service's RRM** module, which offers on-demand geospatial data in support of Disaster Management operations related to prevention, preparation, disaster risk reduction, and recovery, is the second module (Copernicus EMS Website, 2023).
The Copernicus Mapping Service, includes 6 main products namely **Wildfire delineation and grading(P07), Impact Assessment on Assets and Population(P14), Detailed Impact Assessment on Selected Aspects(P15), Soil Erosion Risk Assessment (P16), Landslide risk assessment(P17) and finally Risk and Recovery Mapping Portfolio(RRM FLEX).**
P07 Wildfire delineation and grading(P07), which is essentially information extracted straight from the image data received as soon as the emergency event occurred on the extent and severity of the burnt region, is one of the first outputs of the RRM service. evaluation of a wildfire event's spatial spread, size, and severity. The P07 consists of a group of burnt regions and information about the degree of damage. Four classes—Destroyed, High Damage, Moderate Damage, and Negligible to Slight Damage—represent the different damage levels. This item could be utilised throughout the disaster management cycle's recovery stage (Copernicus EMS Website, 2023).

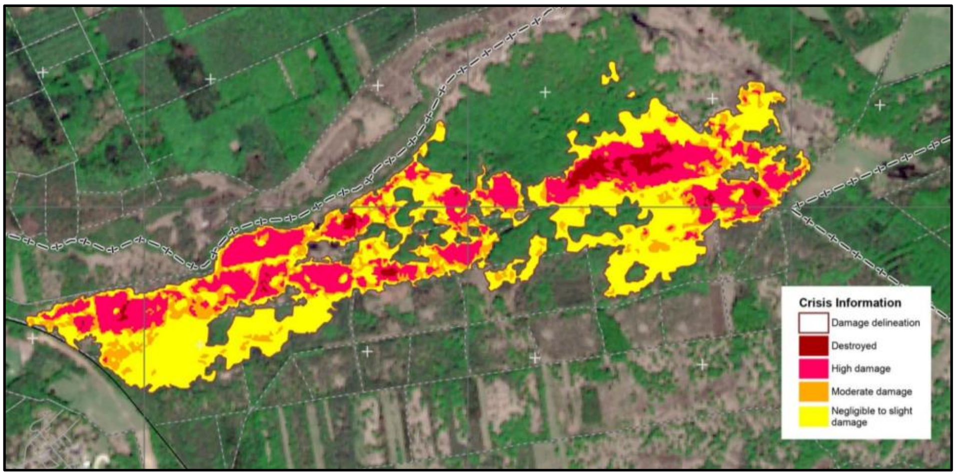


Fig.5-15.Wildfire Delineation And Grading product (P07)_Source: (Copernicus EMS Website, 2023)

As far as it concerns the **Impact Assessment on Assets and Population(P14)**, the Information on the affected assets and infrastructure makes up P14's impact assessment on assets and population. When a disaster's magnitude is known, it gives an impact assessment analysis on assets and population, or when an event is expected or modelled, it delivers an exposure analysis on assets and population. On the basis of reference datasets and/or LULC data, the analyses are carried out. General statistical data on the population and assets that are exposed to or affected by an incident are the key outputs of this product.

Tabular format is used to provide the summary statistics. The disaster management cycle's phases of preparation and recovery might both make use of this product (Copernicus EMS Website, 2023).

Consequences within the AOI		Unit of measurement	Total affected	Total in AOI
Flooded area		ha	2354.71	
Estimated population		Number of inhabitants	9282	66545
Settlements	Residential Buildings	No.	3909	37518
Transportation	Highways	km	0.05	6.68
	Primary Road	km	16.23	126.46
	Secondary Road	km	9.54	74.32
	Local Road	km	35.31	432.56
	Cart Track	km	74.63	1058.68
	Long-distance railways	km	5.84	57.78
Land Cover	Discontinuous urban fabric	ha	259.73	2230.24
	Industrial or commercial units	ha	3.23	199.03
	Sport and leisure facilities	ha	1.22	46.64
	Non-irrigated arable land	ha	226.90	6783.45
	Fruit trees and berry plantations	ha	4.60	241.13
	Pastures	ha	1683.05	4734.57
	Complex cultivation patterns	ha	3.07	66.01
	Land principally occupied by agriculture	ha	13.04	106.01
	Broad-leaved forest	ha	144.48	4828
	Coniferous forest	ha	15.14	651.99
	Transitional woodland shrub	ha	0.24	10.18

Fig.5-16.Impact Assessment on Assets and Population product(P14)_Source: (Copernicus EMS Website, 2023)

Regarding the **Detailed Impact Assessment on Selected Aspects(P15)**, the solution, like P14, tries to give two different types of assessments on impact or exposure, but it depends on user-provided information on particular assets (i.e., agriculture production and crop, forest stand information, economic values). This product's principal outputs are in-depth (customised) statistics reports on a chosen asset that has been exposed to or impacted by an event. Tabular format is used to provide the summary statistics. The disaster management cycle's phases of preparation and recovery might both make use of this product (Copernicus EMS Website, 2023).

The **Soil erosion risk assessment (P16)** Product can be used to analyse how the decrease in vegetation cover brought on by a forest fire may increase the danger of erosion and/or landslides. The product's objective is to disseminate knowledge regarding the soil's vulnerability to the risk of erosion. For instance, the lack of vegetation cover over a burned region may raise the danger of soil erosion (Copernicus EMS Website, 2023). The following soil erosion risk assessment classes are defined as the image below:

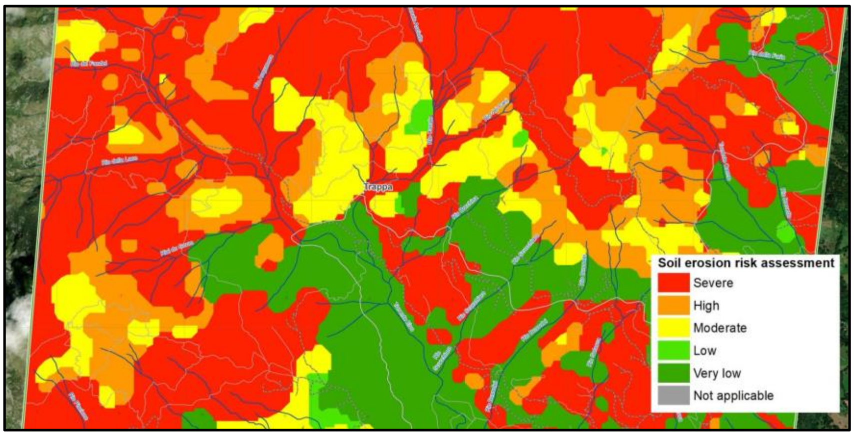


Fig.5-17.Soil Erosion Risk Assessment product(P16)_Source: (Copernicus EMS Website, 2023)

The **Landslide risk assessment(P17)** product aids decision-makers in identifying vulnerable locations and developing anti-landslide strategies. This item could be utilised throughout the disaster management cycle's recovery stage (Copernicus EMS Website, 2023).

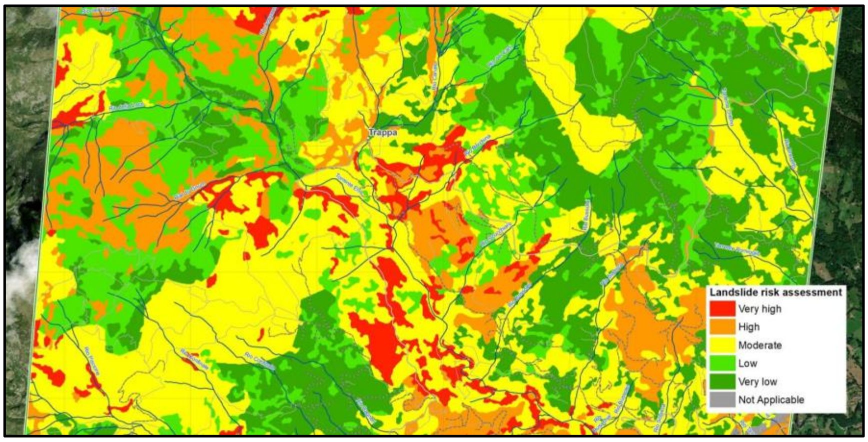


Fig.5-18.Landslide risk assessment product(P17)_Source: (Copernicus EMS Website, 2023)

Finally, products from the **Risk and Recovery Mapping Portfolio (RRM FLEX)** can be activated to produce more complicated products, such as research on wildfire hazards and preparedness or recovery plans and monitoring after wildfires. Since RRM is an on-demand mapping service that can give precise information on the risk readiness for wildfires as well as post-wildfire effect assessment and recovery utilising extremely high-resolution satellite imagery and other ancillary information, it is a supplement to EFFIS and RM. For recent fires that are still recovering or for older fires that are outside the purview of RM, it can also provide comprehensive information on fire demarcation and grading. Floods, forest fires and wildfires, humanitarian crises, soil erosion and landslide risk, ground deformation, damage assessment, and rebuilding monitoring are among the portfolio's standard product packages (Copernicus EMS Website, 2023).

The Copernicus Emergency Management Service (CEMS), in particular the early warning systems for flood and fire threat, benefits from the work of the **European Centre for Medium-Range Weather Forecasts(ECMWF)**. End of 2017 saw ECMWF take over as the Copernicus Emergency Management Service - Fire's computational hub. Daily fire danger estimates are provided by ECMWF using high-resolution ensemble forecasts out to 15 days. The European Forest Fire Information System receives the data (EFFIS). We also report temperature and precipitation anomalies from the extended-range and seasonal system twice a week and once a month (ECMWF Website).

6.Case study on the Italian Alps: the Susa Valley

Introduction

Current chapter elaborates on the geographic and environmental overview of the research area _ Susa Valley, where different features such as Climatic conditions namely precipitation, temperature and wind, morphological and topographical features, human settlements, hydrological systems, wildlife and biodiversity and forest resources are discussed. The chapter then continues on discussing the historical analysis of wildfire in the area, taking help from the statistics and provisional maps focusing on the principal documentation provided by the regional entity such as the Regional Antifire plan for Piedmont (Piano AIB Regione Piemonte), Regional Forestry Plan, Carta dei tipi Forestali, thematic reports of Arpa Piemonte with regards to climate and wind etc and continues to discuss the major fire event in 2017, using the public news websites, Copernicus delineation plan and public reports. Finally, the fire-fighting administrational structure and technologies in different levels of national and regional and in specific the Piedmont region have been explained.

6.1.Geographic and environmental overview of the area

The Val di Susa (Valsusa in Piedmontese) is an Alpine valley located in the western part of Piedmont, west of Turin, bordering on France to the west: although it belongs entirely to the hydrographic basin of the Po, and therefore to the Italian geographical region, portions of some of its high side valleys are politically part of the French Republic following the peace treaties of 1947 (surrounding area and hill of Moncenisio in the Department of Savoy; Valle Stretta, Po valley side of the Scala and Monginevro passes, summit of Mount Chaberton in the Department of the High Alps).
80 km long and with over 90,000 inhabitants, it is the largest and most populated valley in Piedmont. It takes its name from the ancient city of Susa, located in a central position, even if its largest centre today is Avigliana. The westernmost point of Italy is located in the upper valley (the summit of Rocca Bernauda, in the municipality of Bardonecchia, 45°06′15″N 6°37′32″E).

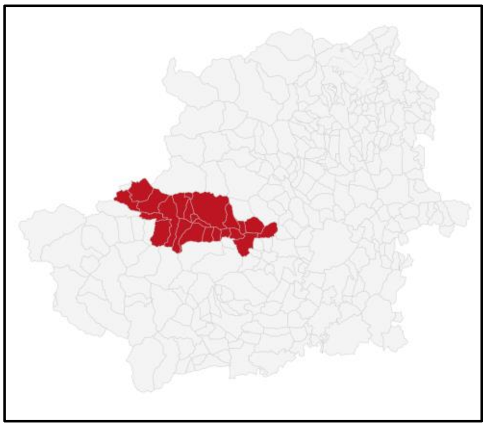


Fig.6-1.The Susa Valley Area demonstrated in the Piedmont Map.

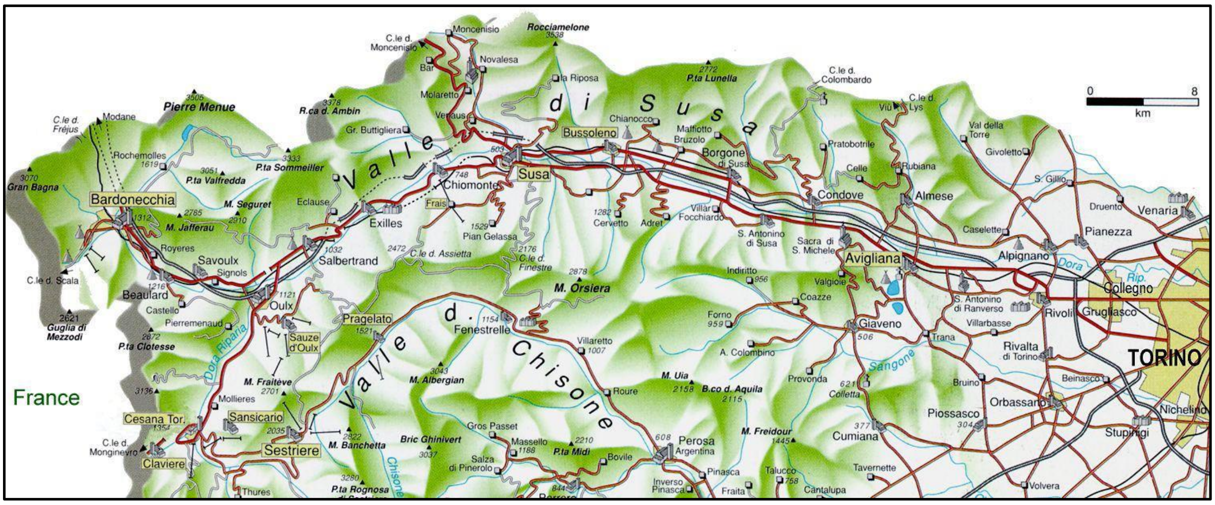


Fig.6-2.Susa Valley_Source:(Invalsusa Website)

6.1.1.Climatic Conditions

The climate of Piedmont is strongly conditioned by the presence of the Alps and the Apennines, which not only defend the territory from the arrival of cold air currents from northern Europe, but also prevent the direct flow of warm Mediterranean air. Thus, a **typically alpine climate** is observed in the mountain areas, with strong diurnal temperature ranges and maximum rainfall in autumn and spring. Instead, the climate of the plain is mostly continental, with very hot summers and chilly winters. The hilly terrain, on the other hand, is prone to the circulation of breezes and enjoys less harsh climate conditions than both the mountains and the plains(AIB Plan Piedmont Region 2021-2025).

Susa Valley is situated in the Piedmont region which has a typically temperate climate, which on the Alps becomes progressively temperate-cold and colder as the altitude increases. In areas located at low altitudes, winters are relatively cold but not very rainy and often sunny, with the possibility of snowfall, sometimes abundant. On the other hand, in north-east areas, snowfall is less frequent and occasional. Summers are hot with local possibilities of strong thunderstorms.

6.1.1.1. Precipitation

The spatial distribution of the cumulative rainfall shows that the most rainy area is located in the northern sector of the region with peaks even higher than 1700 mm/year. The absolute maximum precipitation occurs at the interface between the mountainous areas and the flat areas where the humid currents meet the barrage of the Alpine foothills, while the precipitation values decrease as one enters the innermost areas of the Alpine valleys, particularly in the west-east oriented valleys. The least rainy area coincides with the Asti and Alessandria plains with quantities of less than 700 mm/year (Piano AIB Regione Piemonte 2021-2025). As it can be observed(Fig.6-3), the area for this study, considered Susa Valley, situated in the western side of the region, is among the less rainy areas, mostly having less than 700 mm/year of rain at its peak.

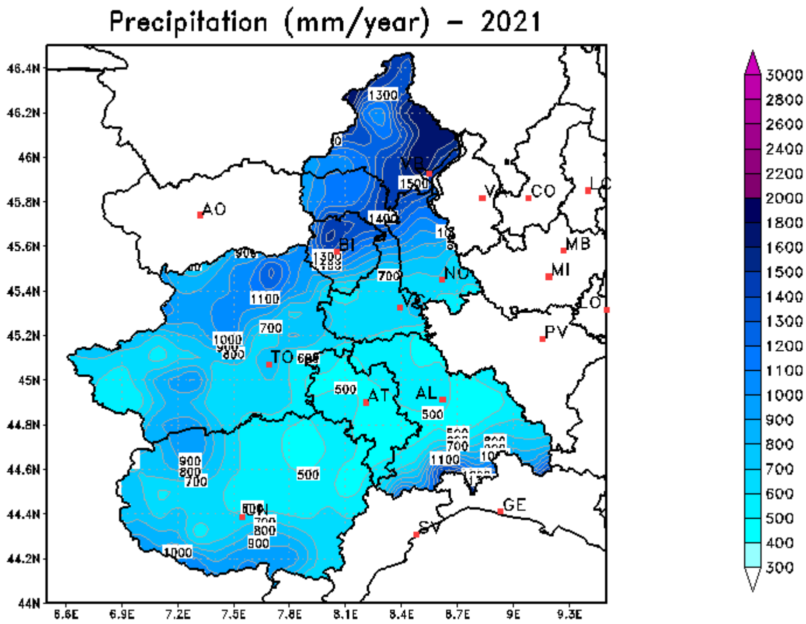


Fig.6-3.Total precipitation in the year 2021 in Piedmont_ Source(Dipartimento Rischi Naturali e Ambientali-Arpa Piemonte, 2020)

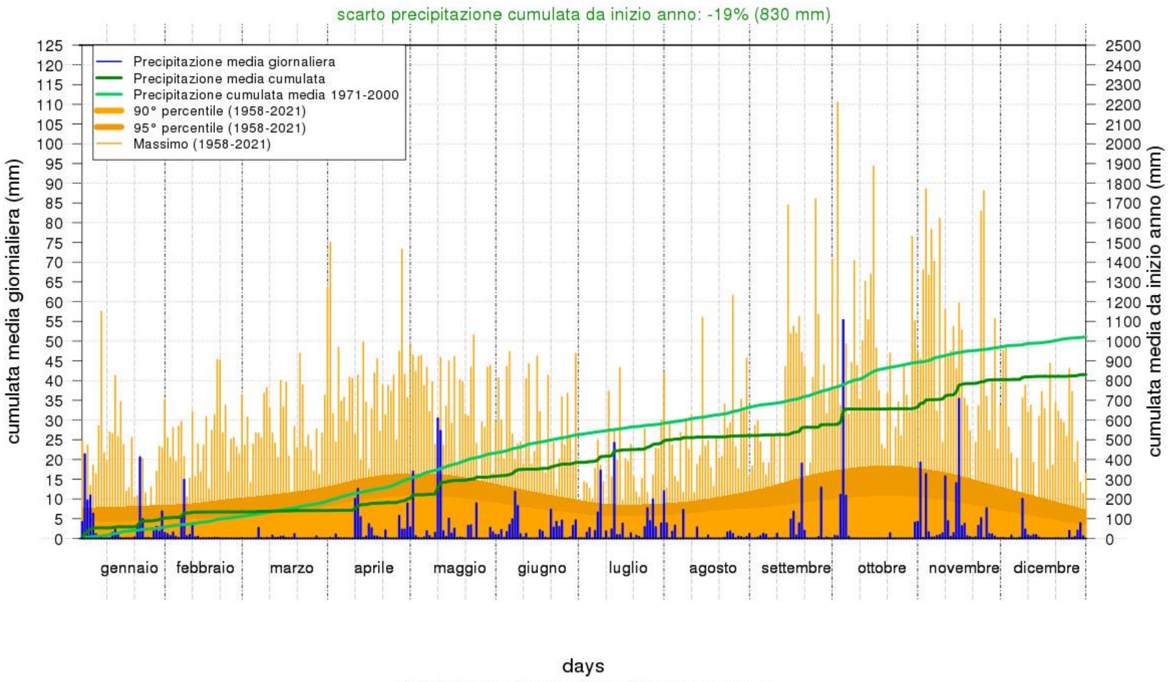


Fig.6-4.Trend of average daily cumulative precipitation in Piedmont for the year 2021 (values referred to a midpoint located at an altitude of 900 m)_Source:(Dipartimento Rischi Naturali e Ambientali- Arpa Piemonte, 2020)

In Piedmont as the trends show, the contribution of **total annual rainfall** was 858.4 mm, with a **deficit of 192.1 mm** (equal to 18%) compared to the norm for the thirty-year period 1971-2000, making 2021 the **16th driest year since 1958**. In this year, however, there was the flood event of 3-5 October, in which some stations of the Ligurian-Piedmont meteorological network set Italian records (Dipartimento Rischi Naturali e Ambientali - Arpa Piemonte, 2020).

Precipitazione	Anomalia pluviometrica (°%)	Posizione nella distribuzione storica	Valore medio (mm)	Percentuale record pluviometrici in 24 ore stabiliti
Gennaio 2021	+78	8° più piovoso	106.0	0
Febbraio 2021	-40	25° meno piovoso	33.6	0
Marzo 2021	-90	5° meno piovoso	8.4	0
Aprile 2021	-46	18° meno piovoso	63.7	1
Maggio 2021	-12	29° più piovoso	115.3	4
Giugno 2021	-24	22° meno piovoso	72.7	1
Luglio 2021	+85	5° più piovoso	112.6	8
Agosto 2021	**-65**	**3° meno piovoso**	**29.1**	**0**
Settembre 2021	-42	26° meno piovoso	57.2	0
Ottobre 2021	-32	27° meno piovoso	89.6	2
Novembre 2021	+81	23° più piovoso	142.3	0
Dicembre 2021	-50	22° meno piovoso	28.5	2
Anno 2021	-11	16° meno piovoso	858.4	1

Table 6-1.Monthly average cumulative rainfall in Piedmont. The percentage anomaly is reported for each month from the 1971-2000 standard, the percentage of weather stations that reported their cumulative precipitation record daily the relative position with respect to the corresponding driest or wettest month of the entire historical series. In orange (dry) or blue (rainy) the months in the top 10 historical positions, in bold those among the first Three. Only stations active for at least 5 years are taken into consideration. _ Source(Natural and Environmental Risks Department- Source:(Dipartimento Rischi Naturali e Ambientali - Arpa Piemonte, 2020)

Figure 6-5 demonstrates that the area related to Susa Valley not only experienced one of the lowest annual cumulative precipitation(between 50 mm to 200 mm deficit) in 2021, but also it experienced one of the lowest number of rainy days (well over 15-35 days less than normal) compared to the reference period.

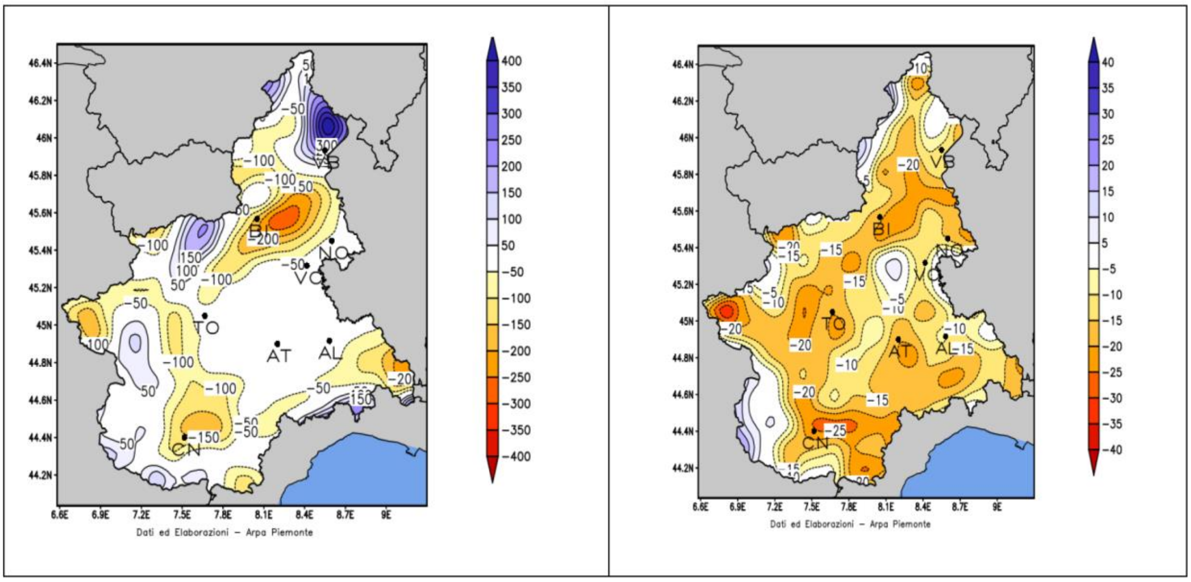


Fig.6-5.Difference between the cumulative annual precipitation (left) and the number of rainy days (right) of the period 2002-2019 compared to the reference period 1971-2000_ Source:(Piano AIB Regione Piemonte 2021-2025 derived from Arpa Piemonte Report)

6.1.1.2.Temperature and Drought

According to the ARPA Piemonte website, the year 2021 in Piedmont was the **15th warmest** in the last 64 years, with an average temperature of around 9.9°C and an average thermal anomaly around +0.8°C compared to the climatology of the period 1971-2000. In 2021, for the first time since 2014, there was a season with temperatures below normal. in fact, spring 2021 interrupted a sequence of 26 warmest seasons in climatology, from autumn 2014 to winter 2021(Dipartimento Rischi Naturali e Ambientali - Arpa Piemonte, 2020).

As regards the analysis of the maximum length of the dry periods, there is an increasing trend over the years, in particular for the lower altitudes.The driest years in the new millennium also involve mountainous areas, while in the last century drought is particularly evident in the plains.
The annual maximum and minimum temperature maps of the period 1981-2010 (Figure 4) highlight the orographic influences on this variable, which dominate with respect to other variations (latitude, exposure...) (Piano AIB Regione Piemonte 2021-2025). As it can be highlighted on the maps, for the interested area (Susa Valley), it seems that eastern areas along the Dora river have suffered more from higher temperatures and as we move on the western side of the valley (From Novalesa to the west), the minimum and maximum temperature decrease.

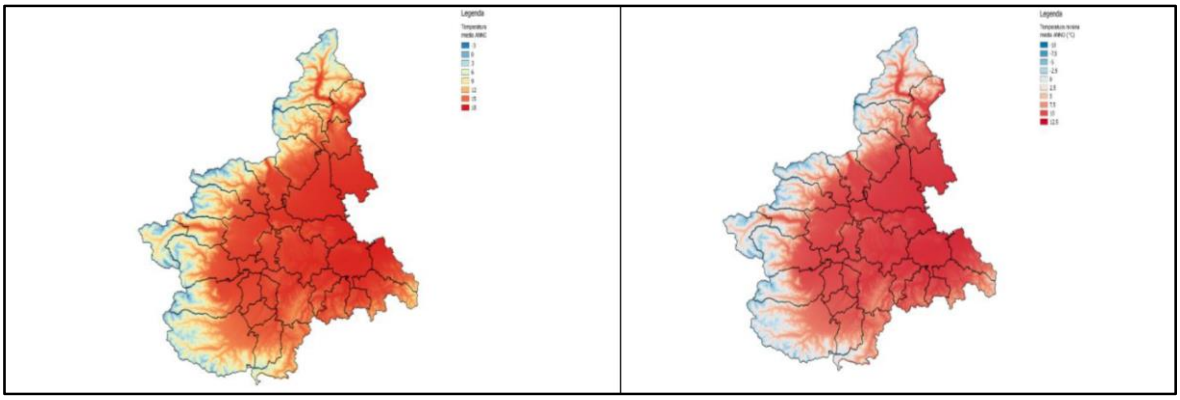


Fig.6-6.Maximum (left) and minimum (right) annual average temperatures over the period 1981-2010 (Piano AIB Regione Piemonte 2021-2025)

The most important aspect regarding the temperature, however, is related to its positive trend over the years, which is statistically significant on a general level for the entire region (Fig.6-7)(Piano AIB Regione Piemonte 2021-2025).

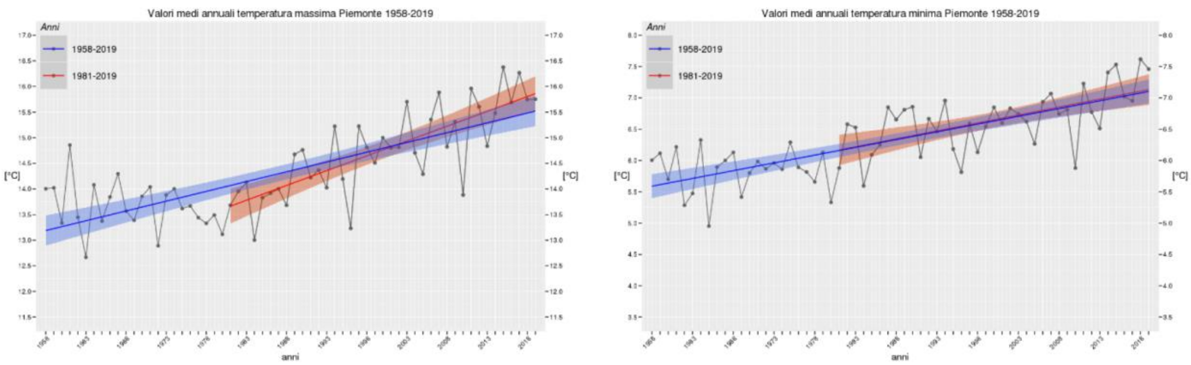


Fig.6-7.Trend of the maximum (left) and minimum (right) annual average temperature from 1958 to 2019 over the entire region. In blue the linear trend over the entire period, in red the trend in the more recent period 1981-2019. The coloured areas represent the statistical uncertainty of the trend- Source:(Piano AIB Regione Piemonte 2021-2025).

Both the maximum and minimum temperatures show a positive trend, statistically significant, whether we consider the entire time period (1958-2019) or the most recent period (1981-2019).
Table (6-2) summarises the values of the trends expressed as a change in degrees Celsius in 10 years, averaged over the entire regional territory. It can be seen that the variations are more important as regards the **maximum temperatures** to the **minimums** and how, in the most recent period, the maximum temperature trend is almost double that which occurs considering the entire time series. This confirms the accelerating warming trend in recent years for positive thermal extremes. For the minimum temperature, the trends in the two periods are similar. In the 1981-2019 period, the average annual minimum temperature in Piedmont increased by about 1.5°C, with a slightly lower statistical variability than that of the maximum temperature (AIB Plan Piedmont Region 2021-2025).

1958 - 2018		1981 - 2018	
T MAX	T MIN	T MAX	T MIN
0,38 °C /10y	0,24 °C /10y	0,58 °C /10y	0,24 °C /10y

Table6-2.Ten-year temperature variations in degrees Celsius_ (Piano AIB Regione Piemonte 2021-2025).

The increases of temperature are greater in all the mountainous, Alpine and pre-Alpine areas, in particular in the western and northern regions and in the lower Alessandria area. Lower values in the northern border areas. The seasons where the increases are greatest are winter and spring at the regional level, while along the pre-Alpine belt autumn also records significant increases (AIB Plan for the Piedmont Region 2021-2025).

6.1.1.3.Wind

The presence of the **Alpine arc** is also the cause of the **formation of favonio or foehn**, a typical **dry and hot wind** which constitutes a very important predisposing factor for the development and **propagation of fires**. The foehn is generated by the **pressure difference** between the two sides of the Alps. When a mass of humid air has to overcome a mountain range, a process is triggered which leads, on the windward side, to meteorological conditions characterised by high humidity and abundant rainfall.
On the leeward side(the side sheltered from the wind/downwind-side), on the other hand, there is the presence of dry and often hot downwind, accompanied by strong gusts of **wind on the peaks and in the valleys**.

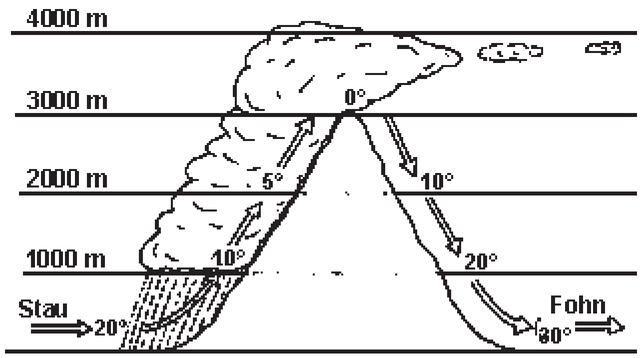


Fig.6-8.Fohn Wind_Source:(Arpa Piemonte Report for the Wind in Piedmont, 2007)

In the event of a very strong flow, the wind also reaches the lowland areas, resulting in clear and sunny days. In most cases of foehn affecting Piedmont, these are winds coming from the **north**, **north-west** or **west** and therefore the windward side corresponds to the **northern side of the Pennine** and **Lepontine Alps** or to **the western side of the Graian** and **Cozie Alps**. Due to the thermodynamic process involving the air masses that make up the foehn, this wind is characterised by **higher temperatures** than the same air masses originally had, and this generally leads to an **increase in temperatures** also in the leeward areas which can be sudden and significant. However, the recorded temperature depends on the initial temperature of the air masses, while there is always a decrease in relative humidity (Piedmont Region AIB Plan 2021-2025). The figure below shows the prevailing wind directions over the Piedmont area.

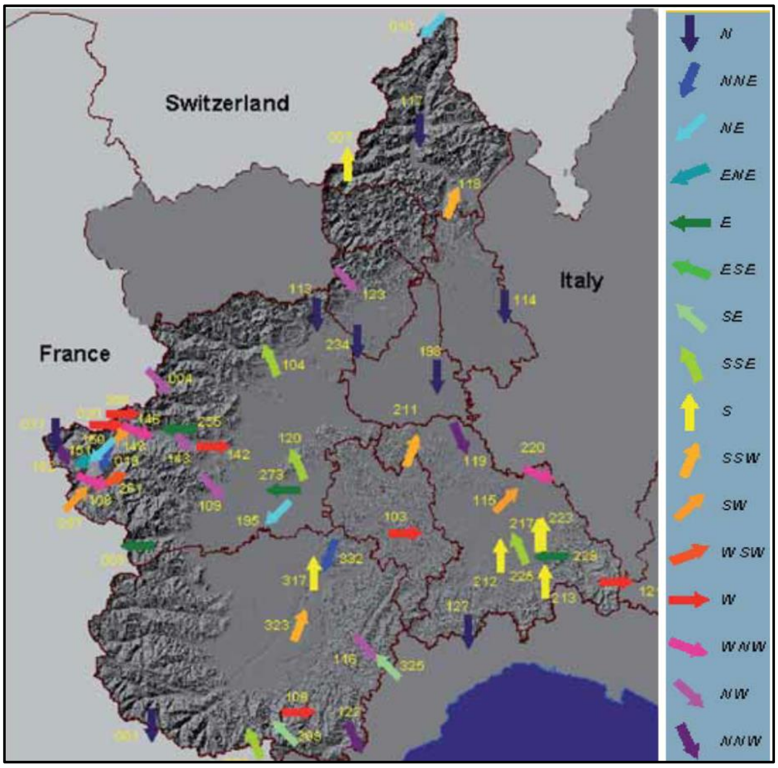


Fig.6-9.Prevailing wind direction per year, in autumn, spring, summer and winter_Source: (Arpa Piemonte Report for the Wind in Piedmont, 2007)

Even if each area of the Alps has its own favonio climatology, it can be said that the foehn can affect all the Piedmontese Alpine valleys, even if it comes from the south, albeit to a much less extent. The valleys that are particularly subject to this wind are the **Val di Susa** and the **Val d'Ossola**. The foehn is not always able to reach the plains, therefore its effect is greater in areas near the hills and in the valley floors, where the wind undergoes a further acceleration. In fact, in the period 2000-2020 (Figure 6-10) the foehn occurred with an average frequency of about 66 days a year; mainly, but not exclusively, in the winter, late autumn and early spring seasons. The months where the cases are most numerous are January and March, followed by December. In recent years, there has been an increase in events lasting longer than one day. Figure(06-10) demonstrates this trend in which the number of foehn events is also increasing, although marked interannual variability is observed.In 2021 in fact, the annual 84 **foehn days** have been the second highest value of the new millennium after the 86 daily episodes in 2019 (Piano AIB Regione Piemonte 2021-2025).

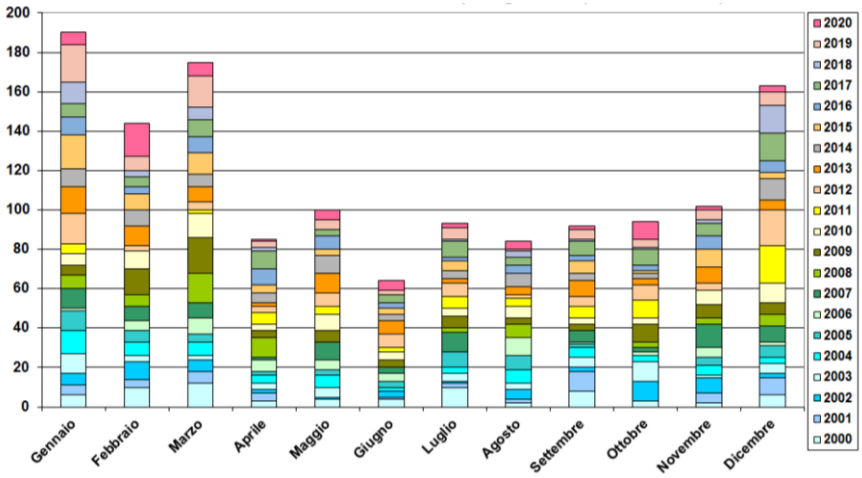


Fig.6-10.Number of foehn events from 2000 to 2020 in Piedmont, for each month. Source:(Piano AIB Regione Piemonte 2021-2025)

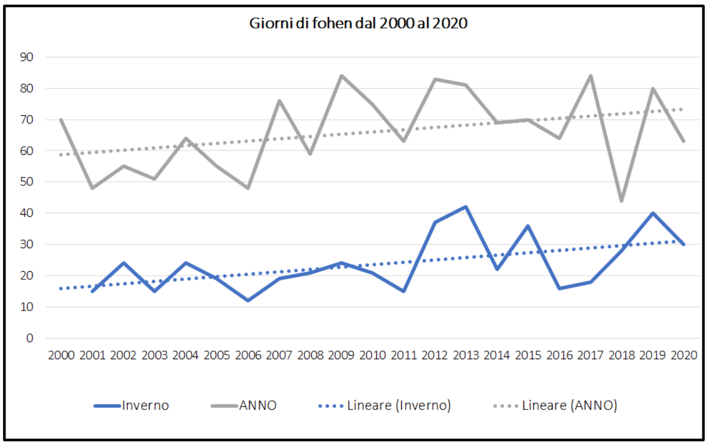


Fig.6-11.Trend in the number of annual foehn days from 2000 to 2020, dashed trend line_ Source: (Piano AIB Regione Piemonte 2021-2025)

6.1.2.Vegetation and Morphology

Many peaks in the valley exceed 3,000 metres: Mount Rocciamelone, with its 3,537 metres, is erroneously considered the highest peak which, instead, is la Roncia (3,612 m), in French territory.
The Regional Forestry Plan identifies areas of homogeneous territory from a vegetational and morphological point of view on which the studies for the Territorial Forestry Plans have been drawn up. These areas, called Forest Areas, are used in this document to describe the impact of the forest fire phenomenon on the vegetation component. For the research, the areas of interest are Lower Susa Valley and Cenischia Valley(29) and Upper Susa Valley(30) **(The Regional Forestry Plan,2016).**
Piedmont occupies an area of 2,539,983 ha, of which 1,098,677 is in a mountain area, 769,848 in the hilly area and 671,458 in the lowland area (ISTAT, 2001). As for the **forest area**, based on recent inventory and planning studies of territorial forestry, it amounts to 922,866 ha, equal to **36% of its total extension**. Within the scope of the sub.forestry the forests amount to approx 874,000 ha, while the remainder (about 48,000 ha) is **wood arboriculture** (**poplar groves** and cycle plants medium long). The **tall trunk** trees occupy about **24%** of the wooded area and consists mainly of **larch trees**; the populations historically governed by **coppice**, mainly of **beech** and **chestnut**, they extend over approx 528,500 ha, equivalent to **62%** of the surface overall; while for the remaining **14%** (126,000 ha) these are pioneer or **invasion formations**, not subject to active management **(betuleti, alneti e arbusteti)** (Carta dei tipi Forestali di Piemonte, 2017-2027). The following map(Fig.6-12) demonstrates the vegetational categories covering the region. As it can be observed, the area for this research is mostly covered with Querco-carpinetti and Querceti di roverella on the north-east side, while on the south-eastern side, we can see mostly coverage with Castagneti and Faggete. The more we go towards the west, the coverage transforms into Abetine and Larch Trees and Stone Pine(Cembrete).

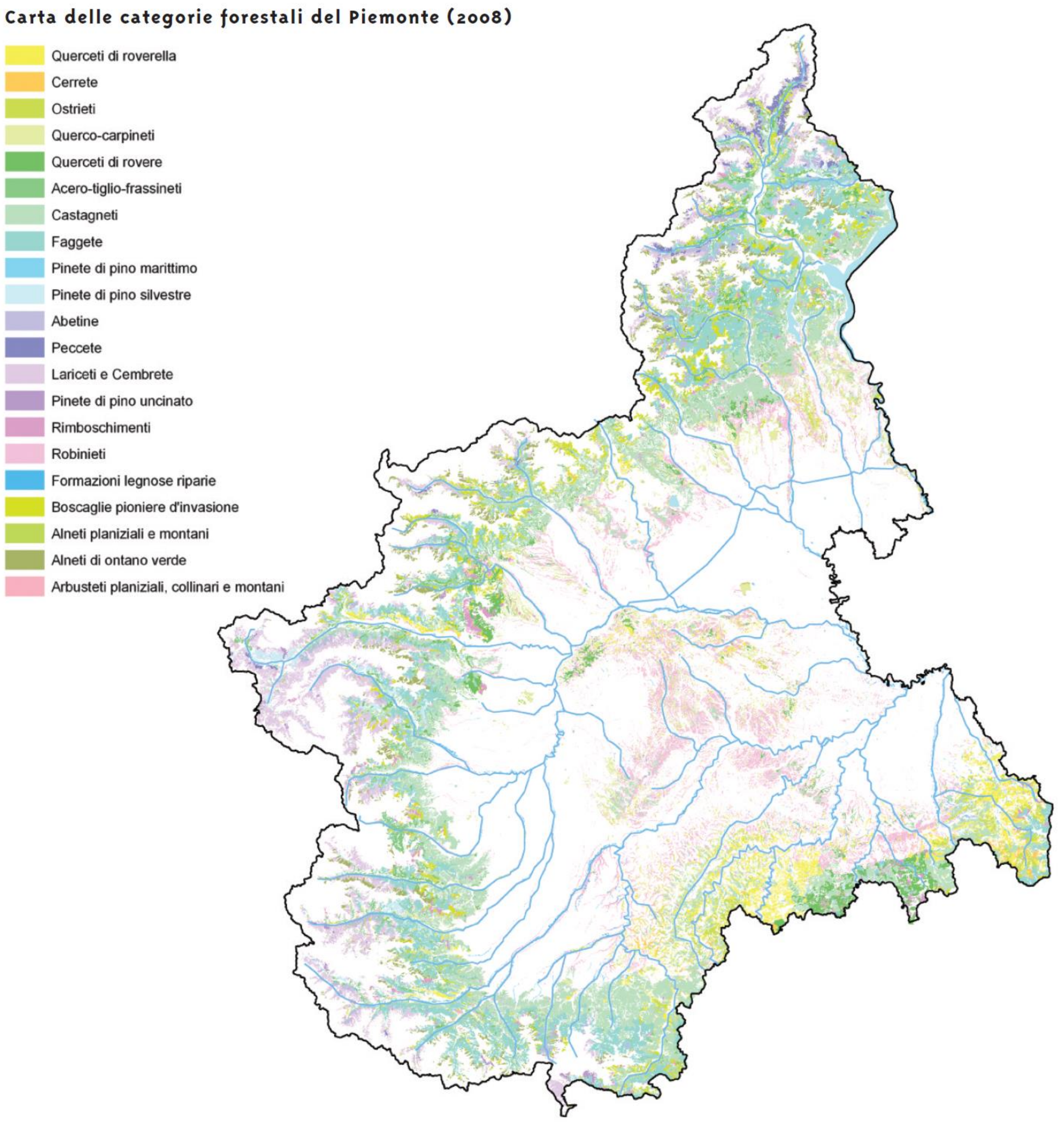


Fig.6-12.Map of the Forestry Categories of Piedmont_Source:(Carta dei Tipi Forestali, 2008)

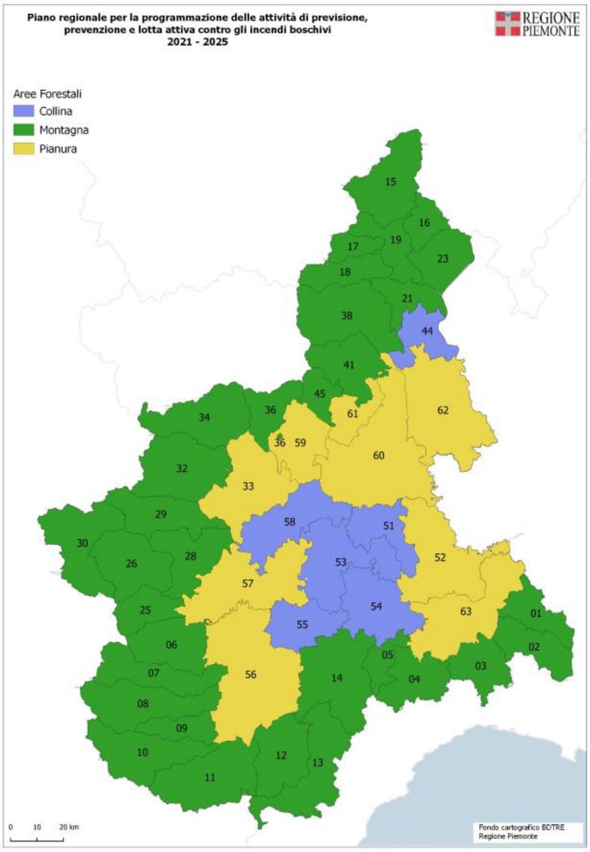


Fig.6-13.Homogeneous forest areas of Piedmont. The areas of interest for this research(Susa Valley area) are the segments number 29 and 30-Source(Piano Forestale Regionale 2017-2027)

Fig(6-14) demonstrates the main forest categories of each province/metropolitan city in Piedmont. According to the graph, it can be observed that overall, most of the forested area in Turin province consists of newly-formed forests, followed by **Larch Trees** and **Cembrete(Stone Pine?)**.

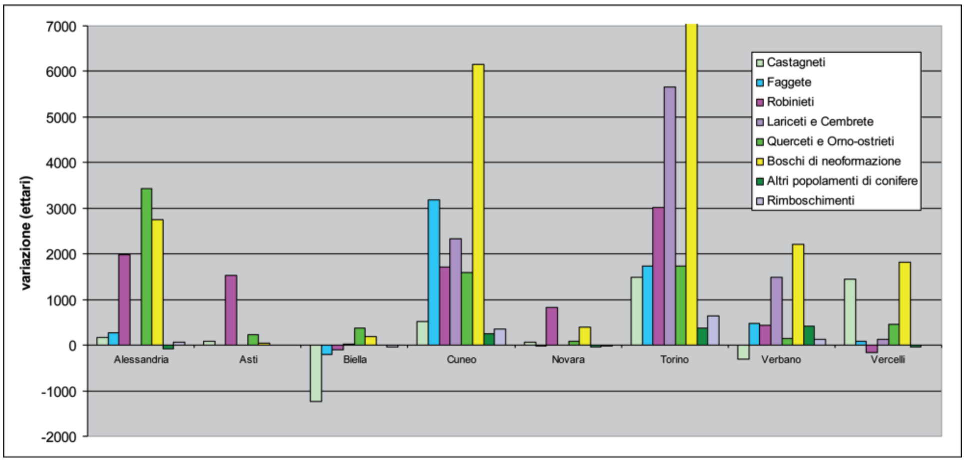


Fig.6-14.Variations of forest surface by forest macro-categories and provinces/metropolitan cities _ Source:(La Carta Forestale del Piemonte, 2017)

6.1.3.Human Settlements and Population Data

The geographical location of the Susa Valley Valley has marked its history and social and economic evolution, with an urban and infrastructural development which, especially after the Second World War, has progressively moved from the mountain slopes to the valley floor, marked by the **routes of the Dora Riparia**, the **railway**, the **two state roads** and, in more recent years, also the international **motorway**.

Departing from Torino, the first town to cross in order to enter Susa Valley Casellette is Almese, which is just 25 km from Turin. Susa Valley covers **420** km² of area in the Piedmont region and Bardonecchia is the most western comune of Susa Valley. According to “Unione Montana Valle Susa”, it comprises of 22 Comune, namely Comune di Almese , Comune di Avigliana, Borgone Susa, Bruzolo, Bussoleno, Caprie, Caselette, Chianocco, Chiusa di San Michele ,Condove ,Mattie , Mompantero ,Novalesa ,San Didero, San Giorio di Susa, Sant'Ambrogio di Torino ,Sant'Antonino di Susa ,Comune di Susa ,Vaie ,Venaus ,Villar Dora ,Villar Focchiardo. Among these comune, most famous places are Avigliana, Bardonecchia, Bussoleno, Cesana, Sauze d'Oulx, Sestriere, Susa, the latter also known as the "key to Italy" due to its strategic position. Overall population in Susa Valley is **67.289** persons. Figures (6-15) and (6-16) illustrate the distribution of the settlements along the river Dora Riparia in Susa Valley and also the municipalities forming the Susa Valley area.

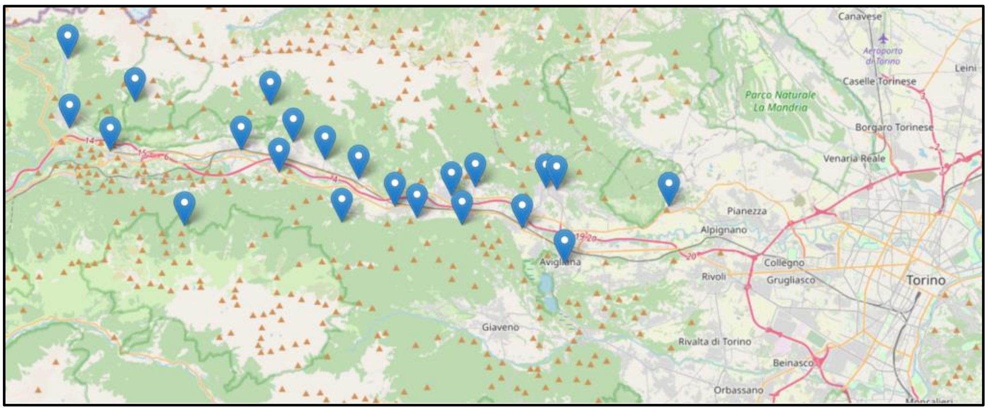


Fig.6-15.Susa Valley area and human settlements with proximity to Turin- Source:(amministrazionicomunali Website)

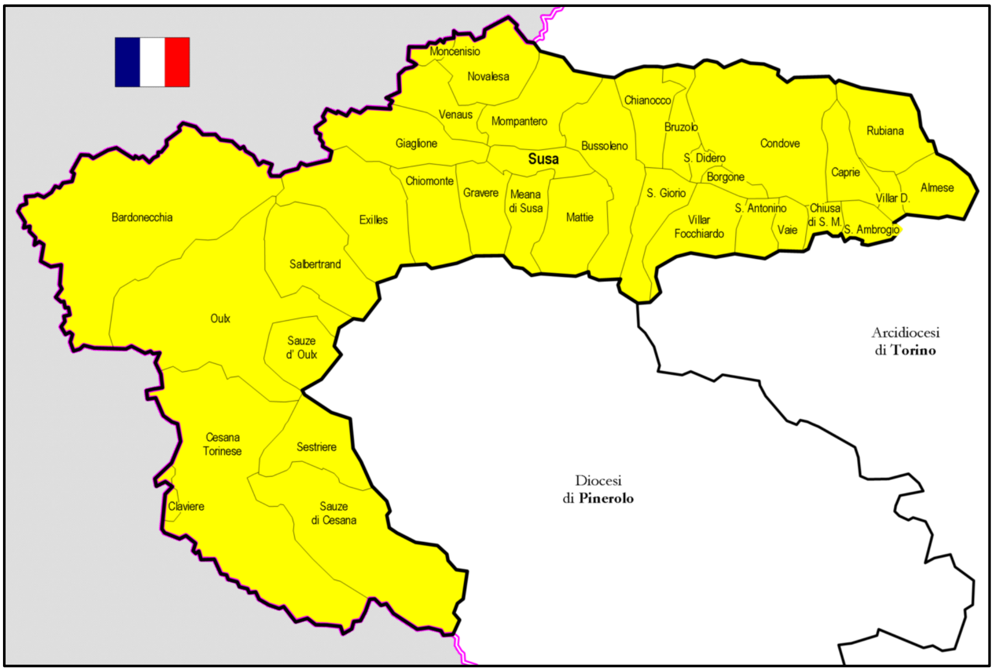


Fig.6-16.The Municipalities(Human Settlements) of Susa Valley-Source: (Internet)

6.1.4.Hydrological System

Wildfires can have an impact on both the quantity and quality of water available, just as they do on air quality. Water resources may be negatively impacted both while a wildfire is actively burning and for years afterward. Ash and its accompanying toxins settle on streams, lakes, and water reservoirs during active burning. Burning vegetation destroys vegetation that stabilises soil and captures water. Rainstorms sweep enormous amounts of ash, sediment, nutrients, and toxins into streams, rivers, and reservoirs downwind of a huge wildfire. Lack of vegetation in the watershed can make conditions for erosion and even flooding more likely, and both naturally occurring and man-made pollutants can affect the quality of drinking water, change the appearance of recreational waters, and possibly even cause toxic algal blooms (EPA Website).Water quality can be harmed by wildfires both while they are actively burning and for months or even years after they have been put out. Burned watersheds are more likely to experience increased floods and erosion, which can have a detrimental impact on water supply reservoirs, water quality, and the methods used to purify drinking water (USGS Website).

The Susa Valley area includes a rich hydrological system including rivers and lakes. The main river of the valley is the **Dora Riparia**, 125 km long with a basin of 1,251 km², a left tributary of the Po. The Dora Riparia originates in **Colle del Monginevro**, in the French Cottian Alps, with the name of Piccolo Dora which is replaced with Dora It repairs after the influx of the Ripa and Thuras streams. The tributaries of the Dora Riparia consist of **Cenischia** (starts at Moncenisio and ends in the Dora Riparia at Susa), **Dora di Bardonecchia** (born in the confluence between the Rio di Valle Stretta and the Torrente di Rochemolles in Bardonecchia and ends in Oulx), **Rio Gerardo** (the source at Colle del Sabbione and flows into the Dora Riparia at Bussoleno), **Torrente Gravio** (the source on Punta Cristalliera and ends at Villar Focchiardo), **Torrente Gravio di Condove** (the source on Punta Sbaron and ends in Condove), **Torrente Messa** (originates on Monte Civrari, west of Colle del Lys and ends in Avigliana), **Rio Prebec** (the source on the Grand'Uia and reaching the Dora Riparia in the Vernetto di Chianocco hamlet), **Torrente Ripa** (starts on Monte Gran Queyron, in the Argentera Valley and ends in the Torrente Thuras in Bousson, a hamlet of Cesana), **Rio Scaglione** (born in the Vallone degli Adretti in the Orsiera - Rocciavrè Natural Park), **Torrenti Sessi** (starts on Monte Civrari, east of Colombardo, and ends in Caprie) and **Torrente Thuras** (it starts on Colle di Thuras and ends in the Torrente Ripa in Bousson, a hamlet of Cesana). Other streams in Susa Valley are Torrente Rochemolles (began on Punta Sommeiller and ends in Rio di Valle Stretta in Bardonecchia) and Rio Valle Stretta (born on Mount Thabor and flows into the Rochemolles stream in Bardonecchia).

On the other hand, there are some lakes also such as Alpe Laune lake above Sauze d'Oulx, Lake of the 7 Colors (Cesana), Rochemolles lake (Bardonecchia), Lake of Moncenisio (totally in French territory even if from one side it stands on the Val di Susa), Black Lake (Cesana), Black Lake (Sauze d'Oulx), Lake Paradiso delle Rane (1075 metres, San Giorio di Susa), Lago Verde (totally in French territory even if from one side it stands on the Val di Susa) and Lakes of Ferrera Cenisio(Lago Piccolo, Lago Grande) and Lago Piccolo(Avigliana) and LagoGrande(Avigliana) are the existing lakes in the area. Figure(6-17) depicts the main waterways in Susa Valley.

Fig.6-17.Dora Riparia Basin Area, the main hydraulic system for Susa Valley_Source:(Piano di Tutela delle Aque, 2007)

Figure (6-18) demonstrates the classification of the surface waterways and water-bodies for the Dora Riparia river that is the main hydrological network in the Susa Valley area. The map highlights irrigation districts, lakes, hydrological areas, river basin closure sections(small red squares).

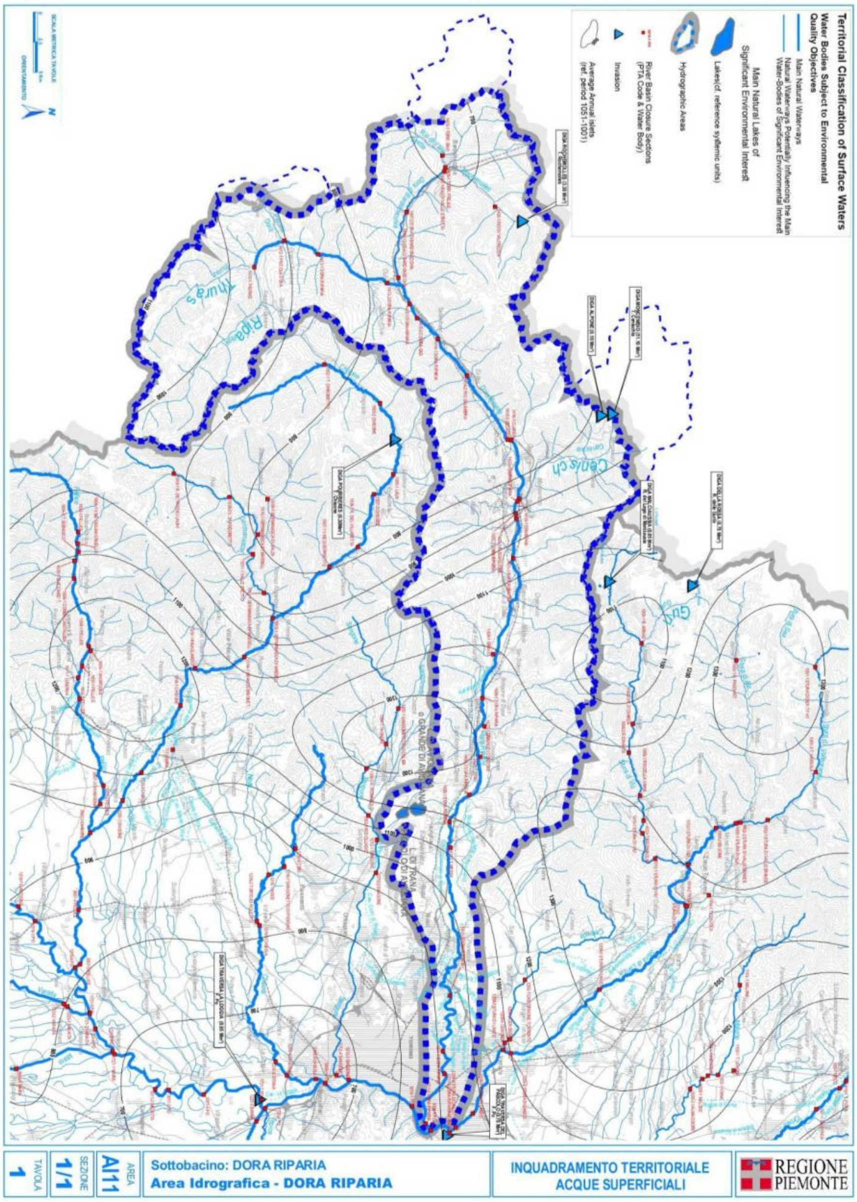


Fig.6-18.Territorial Classification of surface Waters for Dora Riparia river _ Source:(Regione Piemonte - Direzione Pianificazione Delle Risorse Idriche, Piano Di Tutela Delle Acque, 2007)

On the other hand, figure(6-19) demonstrates the Environmental MonitoringNetwork and quality state of waterbodies in the interested area. As it can be noticed, chemical-physical and biological sections are set all along the Dora Riparia , and the monitoring along the river is mostly done using the automatic hydrometric sensors. The summarised results can be observed also in the table (6-3).

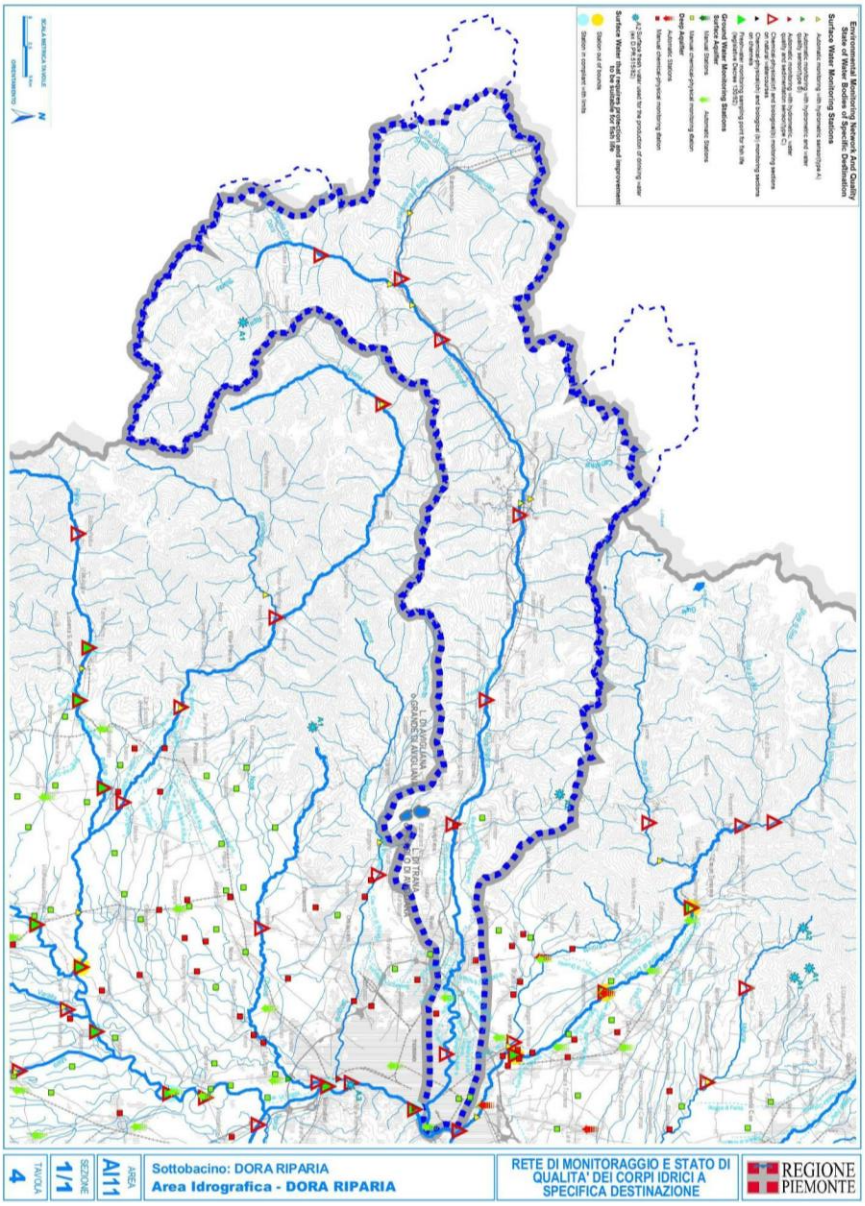


Fig.6-19.Environmental monitoring network and quality state of water bodies in the interested area_Source:(Regione Piemonte - Direzione Pianificazione Delle Risorse Idriche, Piano Di Tutela Delle Acque, 2007)

Water Body	Number of Stations
Natural waterways (manual monitoring)	7
Natural waterways (automatic monitoring)	5
Lakes (monitoring pursuant to Legislative Decree 152/99)	2
Channels	0
Groundwater (manual monitoring)	6
Groundwater (automatic monitoring)	2

Table 6-3.Environmental monitoring networks_Source:(Regione Piemonte - Direzione Pianificazione Delle Risorse Idriche, Piano Di Tutela Delle Acque, 2007)

6.1.6.Wildlife/Biodiversity

The Susa Valley is home to a rich variety of animal life. Mammals are of the **Middle European** type and consist mainly of **micromammals**. Among these are various species of **shrews** and **mice**, **dormouse**, and

voles. The **Western European hedgehog** and the **European molehill** are also present. **Lagomorphs** include the **European hare** and, at higher altitudes, the **Alpine** or **white hare**. **Rodents** are represented by the **squirrel**, the **marmot** and the **dormouse**. There are six species of wild **ungulates**: the **red deer** or **European deer**, the **roe deer**, the Alpine chamois, the ibex or Alpine ibex, the mouflon and the wild boar. In the Valley there are numerous species of Carnivores. Among the Mustelidae, in the medium altitude areas live the common marten or Eurasian marten, the stone marten, the weasel and the badger while at higher altitudes you can meet the ermine. Among the Canids there are the fox and the wolf. In recent years, signs of the presence of the lynx have been found both in Val Chisone and in the Upper Valle di Susa.
The deer is present in limited areas, where it generally has a significant impact on the vegetation of many forest species. The chamois interacts locally and with limited damage. The wild boar largely finds shelter and food in the woods, however it is really harmful in the forest only in young reforestation and artificial thickening, which are less and less widespread. The relationship between forest management and pastoral activities is also becoming topical and relevant again following the promotion of cattle grazing in mountainous areas, in the context of the Rural Development programme; at the moment there are still no integrated silvo-pastoral planning experiences (Piano Forestale Regionale 2017-2027).

6.1.7.Forest Resources

The forest area occupies more than 1/3 of the regional territory, with an average forest index of 36% (34% woodland and 2% wood arboriculture). Out of all the forest areas, 30% is Public and 70% is Private forest (Piano Forestale Regionale, 2021-2027). Table (6-4) summarises Forest areas by category.

Areas		Hectares	Percentage
Regional Territorial Area		2,538,297	100%
Forest Areas	Forests	874660	34%
	Arboriculture	48,206	2%
	Total	922,866	36%
Public Forested Areas		262,398	30%
Private Forested Areas		612,262	70%

Table 6-4.Overview of forest areas_Source : (Piano Forestale Regionale 2017-2027)

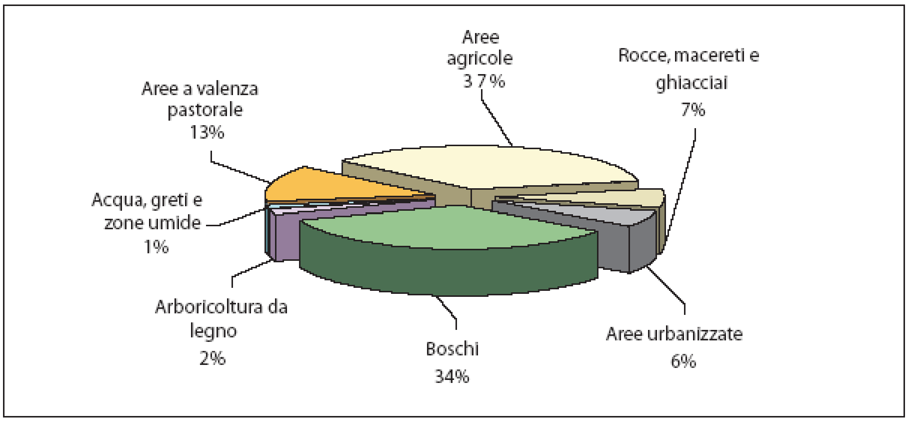


Fig.6-20.Percentage subdivision of the main categories of land coverage_Source: (Piano Forestale Regionale, 2021-2027)

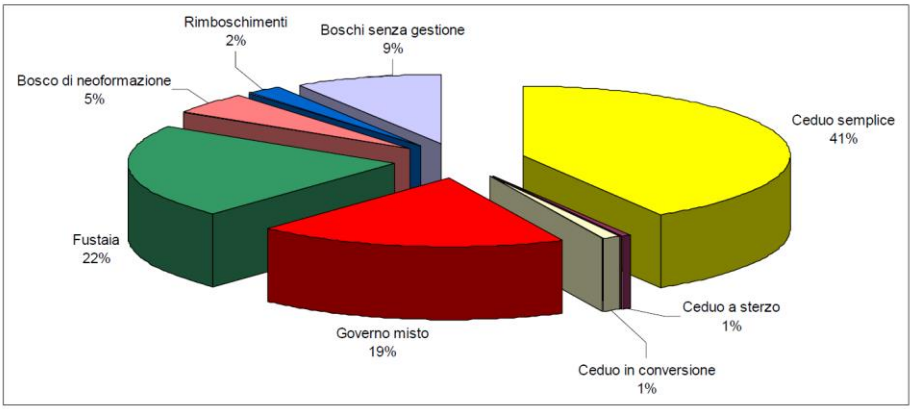


Fig.6-21.Forests in Piedmont: breakdown by evolutionary-cultural arrangements_Source: (Piano Forestale Regionale, 2021-2027)

The territory of Piedmont is also affected by a vast **ecological network** consisting mainly of three types of areas with different protection objectives, peculiarities and constraints: **a) the regional system of protected areas** consists of **2 National Parks**, Gran Paradiso and Val Grande and **77 regional parks** and **natural reserves**, to which are added 7 special reserves to protect the Sacri Monti of Piedmont. In total, these areas occupy a territory of approximately 203,735 ha, equal to 8% of the regional territory. **b) the Natura 2000 Network** of Piedmont, established in implementation of the European Directives "Habitats" (92/43/EEC) and "Birds" (2009/147/EC), consists of 122 Special Areas of Conservation (ZSC), 11 Sites of Community Importance (SIC) and 51 Special Protection Areas for avifauna (SPA). In total, the Natura 2000 network in Piedmont occupies approximately 403,946 ha, equal to almost 16% of the regional area. c) other areas with different degrees of protection are often placed as **"buffer areas"** on the borders of the protected natural areas: 10 Contiguous Areas and 13 Natural Safeguard Areas for a total of 55,169 ha. The protected natural areas and the sites of the Natura 2000 network are placed to protect the main environmental and naturalistic emergencies of Piedmont and, often, the two types of protection institutes overlap in consideration of the peculiarities present in terms of habitat and species. In total, therefore, the territory protected for biodiversity in Piedmont, including points a), b) and c) is 461,587 ha, equal to just over 18% of the regional area. Out of these protected areas, Parco Naturale Orsiera Rocciavrè and Riserva naturale dell'Orrido di Foresto in Bussoleno, and Parco naturale Laghi di Avigliana, Granbosco di Salbertrand,Stagno di Oulx, Champlas Colle Sestriere are among the main protected areas and ecosystem services in Susa Valley (Piano AIB Regione Piemonte 2021-2025).

		Number	Surface Area (ha)
Protected Areas	**Regional**	84	155,208
	National	2	48,527
	Total		203,735
Natura 2000 Network	**SIC e ZSC**	152	289,756
	ZPS		308,061

Table 6-5.Piedmont area subject to protection (Protected Areas and Natura 2000 Network)_Source: (Carta Tipi Forestali, 2016)

6.2.Historical Analysis of the Wildfires occurred in the SusaValley (For period of 2000 – 2019)

6.2.1.Vegetation cover data related to wildfire

According to the Piano AIB Regione Piemonte, the Castagneto acidofilo a Teucrium scorodonia delle Alpi (CA30X), the Betuleto montano (BS20X), and the Faggeta oligotrofica (FA60X) are the forest types in Piedmont that are most impacted by fire in terms of the area covered. Due to their extensive surface area, southern exposure, poor soil fertility, and high flammability of the undergrowth, these forest types are particularly vulnerable to the start and spread of fires. A key factor in the occurrence of forest fires is also the presence of human activity in these places. These elements work together to lower the combustibles' average humidity, which makes these kinds of forests much more prone to fires (Piano AIB Regione Piemonte 2021-2025)..

6.2.2.Forest Categories And Types Influenced By Fire In Piedmont (Time series 2000 – 2019)

As regards the forest-fire coverage of the territory, the Forest Map (2016 edition) in 1:25,000 scale created by IPLA on behalf of the Piedmont Region was taken into consideration. The total area covered by the perimeter fires, which occurred in the period 2001-2019, is equal to 43,253.45 ha, of which 27,274.72 ha in wooded areas.The remaining 15,978.73 has concerned non-wooded areas. It should be noted that part of the areas delimited by the perimeters were retracted by fire several times during the historical series considered. Analysing the historical series 2000 - 2019, which counts a total of 3,074 events (See table 6-6), there have been 1,541 (50.1%) that report the classification of the voluntary cause, and 22,2% of the fires were caused involuntarily. Only 3,3% of the fires have been caused by natural causes. The specific processings are reported in the following tables and graphs:

period	Natural Fires	Involuntary causes	voluntary causes	Doubtful or unclassifiable causes	Total Fires
2000-2019	100	682	1.541	751	3.074
	3,3%	22,2%	50,1%	24,4%	

Table 6-6.Causes of forest fires_Source: (Piano AIB Regione Piemonte 2021-2025)

Some surfaces were repeatedly covered during the period under consideration and for which the cartographic perimeters are available (2001-2019). In the following maps, which show areas that are often not wooded, covered up to 8 times in 19 years, they make it clear that some archaic and non-rational cultivation practices are still used above all for the presumed renewal of pastures. The recurrences of the same territory, albeit with limited intensity but with short time intervals, evidently have a significant effect on the stability of the vegetation and on the hydrogeological instability that can potentially be activated.

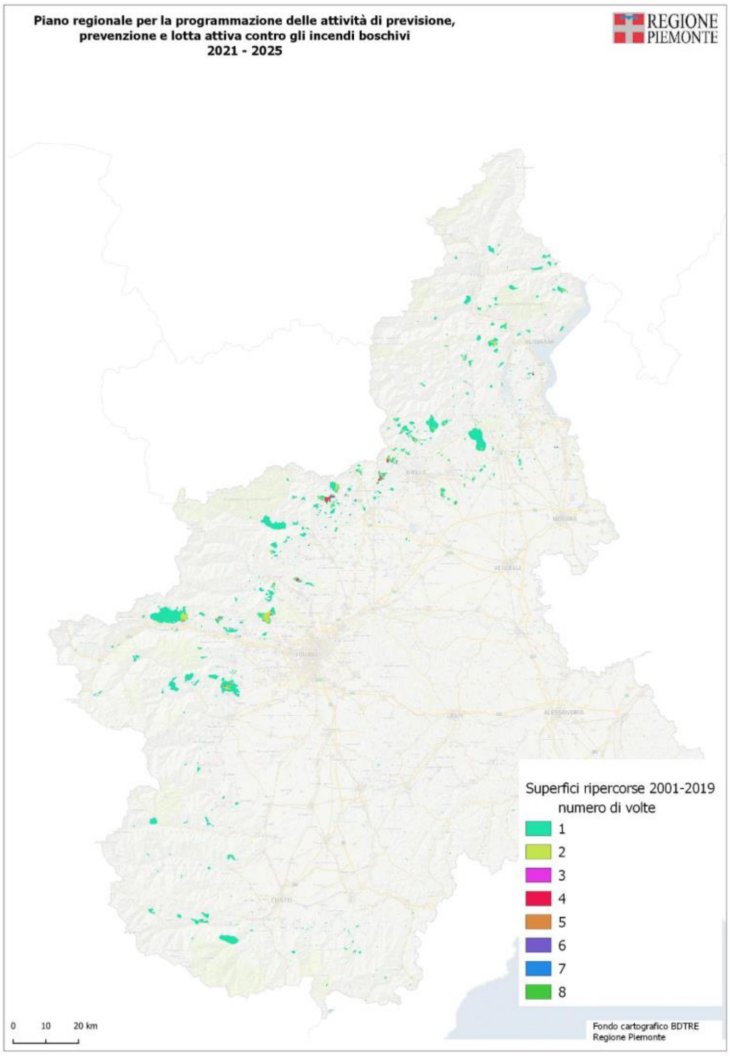


Fig.6-22.Recovered Surfaces after the fire_Source: (Piano AIB Regione Piemonte 2021-2025)

The HRL Forest 2018 change product Tree Cover Change Mask (TCCM) 2015-2018 has been created in frame of the tender "EEA/IDM/R0/18/009 - High Resolution land cover characteristics for the 2018 reference year" as part of the EEA Copernicus Land Monitoring Service (CLMS, https://land.copernicus.eu). The TCCM raster product provides information on the change between the reference years 2015 and 2018 and consists of thematic classes demonstrating tree cover loss (area in red) and unchanged areas (in grey) at 20m spatial resolution and covers the full of EEA39 area (Fig.6-23) (Copernicus Land Monitoring Service Website).

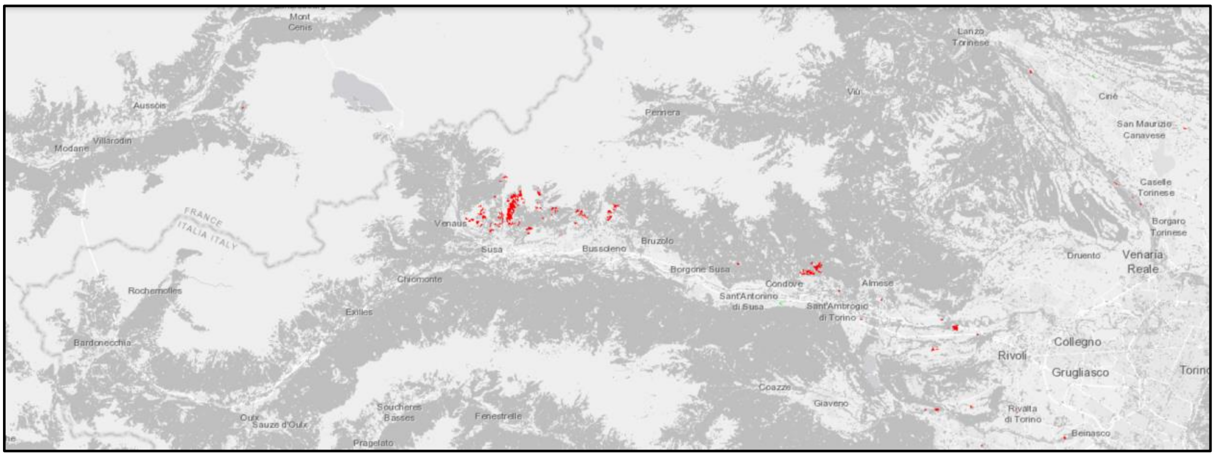


Fig.6-23.Tree Cover Change Mask 2015-2018 tree cover loss areas in red and the unchanged areas in grey_Source: (Copernicus TCCM)

6.2.3.Wildfire Statistics

6.2.3.1.Statistics of Wildfire Numbers and Burnt Areas

The average annual number of fires in the Piedmont area, for the historical series considered, is equal to 229. The annual number of fires decreased significantly in the period analysed, as can be seen from the histogram in Figure (6-24) representing the frequency distribution by all fires of an area equal to or greater than 0.5 ha. However, the trend of the surfaces shows a high variability strongly influenced by events of extraordinary dimension (e.g. 2017 season) without a clear trend (Piano AIB Regione Piemonte 2021-2025).

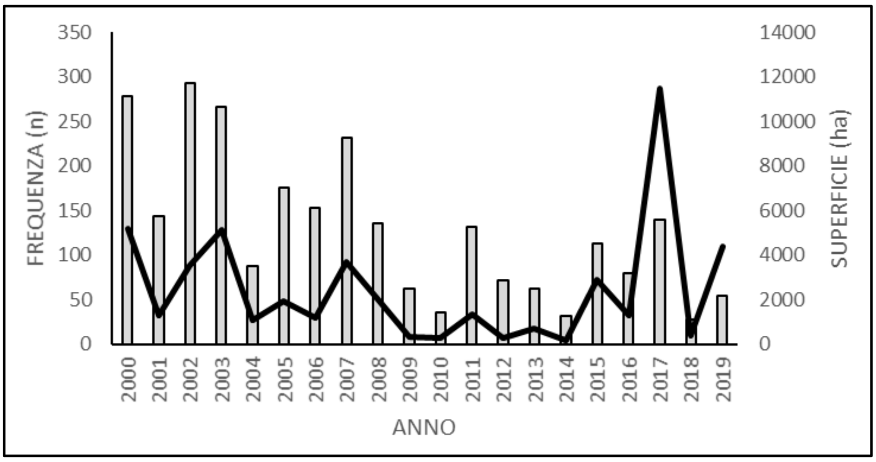


Fig.6-24.Distribution of frequency (in grey) and annual area covered (in black) of fires with an area equal to or greater than 0.5 ha in the period 2000-2019_ Source:(Piano AIB Regione Piemonte 2021-2025)

From a comparison between the total areas covered per year in wooded and non-wooded areas (Figure 6-25) it is possible to note how the proportion between these 2 land cover classes changes between the first period in which a certain equi-distribution between the 2 types is noted and the second period in which there is an evident predominance of the wooded areas travelled over the non-wooded ones by fire.

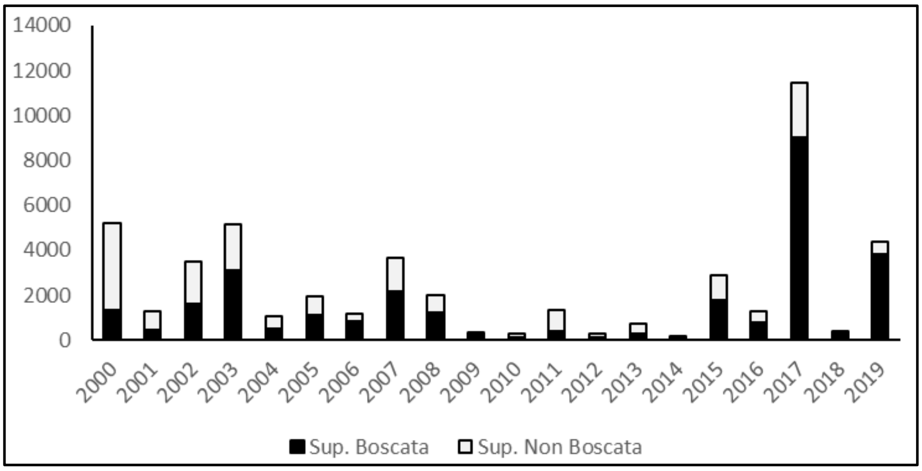


Fig.6-25.Wooded (in black) and non-wooded (in white) annual fire-covered area in the period 2000-2019, considering events with a surface area equal to or greater than 0.5 ha._Source:(Piano AIB Regione Piemonte 2021-2025)

Observing the breakdown of the average annual surfaces covered by fire (Figure 6-26) and the annual frequencies (Figure 6-27) of small events (= small fires, i.e. fires with an area covered less than 10 ha) and large events (= large fires, or fires with a covered area equal to or greater than 10 ha) a clear trend does not emerge; however, it is noted that the **percentage incidence of large-scale events is always very low** compared to small-scale events, which always have the highest frequency. In the years in which the frequency of large fires increases, there is consequently an increase in the total area covered. The year 2017 once again presents noteworthy values: although the frequency of large fires is not particularly high, **the surface area covered** by these fire events is decidedly large, testifying to the exceptional dimensions assumed by a few large fires.

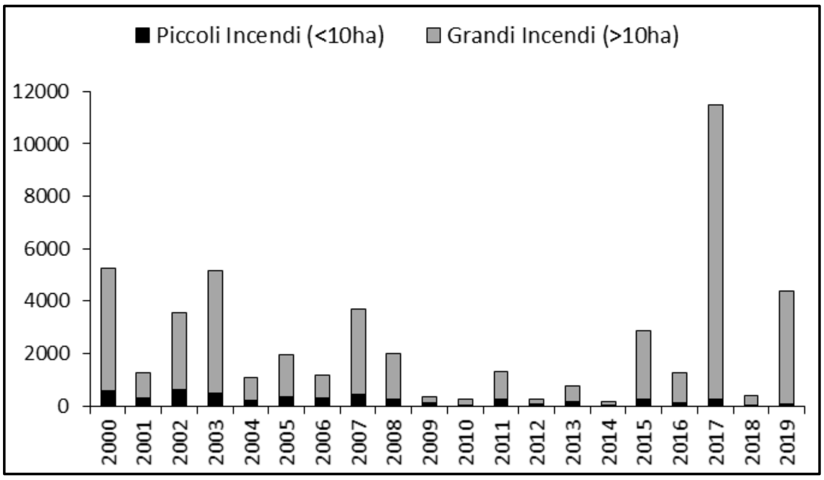


Fig.6-26.Annual area covered in the period 2000-2019 by small-scale events (= small fires, i.e. fires with a covered area of less than 10 ha, in black) and large-scale events (= large fires, i.e. fires with a covered area equal to or greater than 10 ha, in grey), considering events with a surface area equal to or greater than 0.5 ha._ Source:(Piano AIB Regione Piemonte 2021-2025)

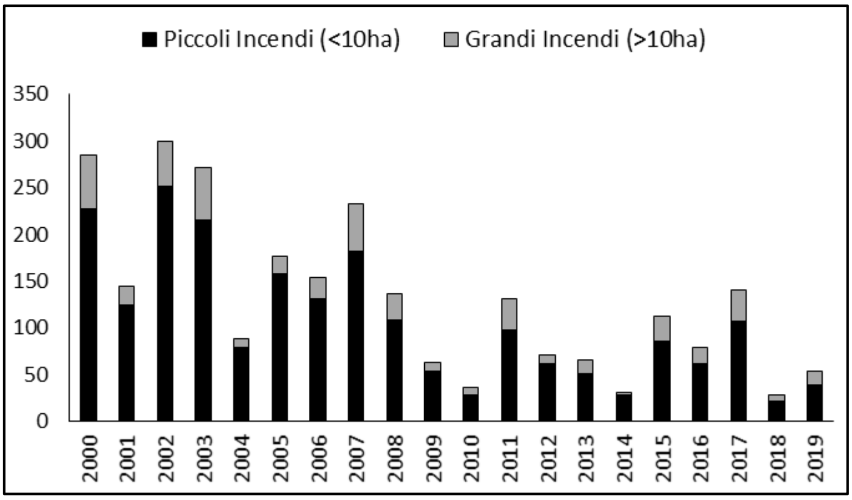


Fig.6-27.Annual fire frequency in the period 2000-2019 of small-scale events (= small fires, i.e. fires with a covered area of less than 10 ha, in black) and large-scale events (= large fires, i.e. fires with a covered area equal to or greater than 10 ha, in grey), considering events with a surface area equal to or greater than 0.5 ha._ Source:(Piano AIB Regione Piemonte 2021-2025)

High values of the surface covered are connected to meteorological trends favourable to the spread of fires, associated with control difficulties. In fact, it is clear that **few large fires define the total area covered** annually: the differences between years with a high overall area covered by fire events and those with a smaller area covered are in fact largely attributable to the contribution of large fires.

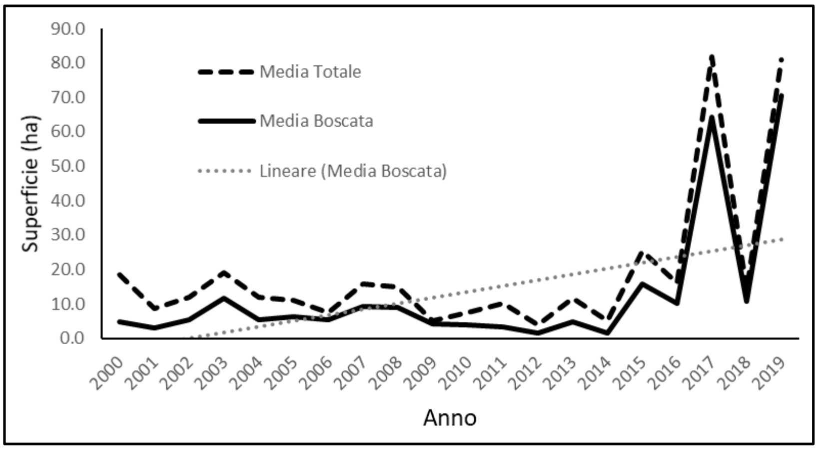


Fig.6-28.Average annual area covered by a single event, wooded (continuous line) and total (dashed line) in the period 2000-2019, considering events with a surface area equal to or greater than 0.5 ha. The linear regression line indicates the weak trend (R2 = 0.27) of surface increase in the period under investigation_ Source:(Piano AIB Regione Piemonte 2021-2025)

6.2.3.2.Large Fires Statistics

Following the results obtained from the analysis of the cumulative distribution, fires having a surface equal to or greater than 10 ha are illustrated in the following figure. Although these events constitute only **10%** of the fires that occurred overall in the historical series considered (2000-2019), they are responsible for **90% of the total area** covered by the fire in the same period. In the historical series analysed, a significant reduction in the annual frequency of major events can be observed, while the area covered, and in particular the wooded area, while showing a high annual variability, shows a tendency to increase (Figure 6-29).

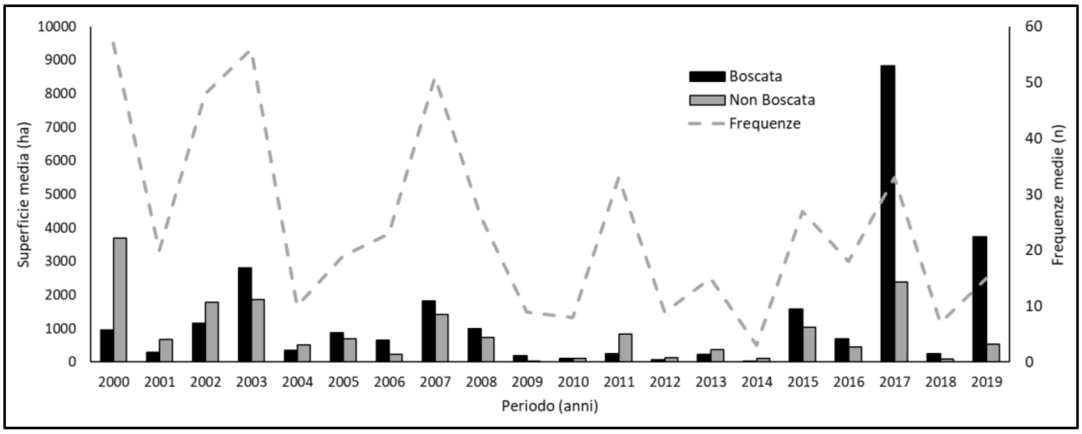


Fig.6-29.Covered area (wooded = black; non-wooded = grey) and total frequency for major fires (total area greater than or equal to 10 ha) referring to the period 2000-2019_ Source:(Piano AIB Regione Piemonte 2021-2025)

This trend relating to the surface covered by fire events is even more evident if we consider the **distribution of the average value** in the period analysed (Figure 6-30).

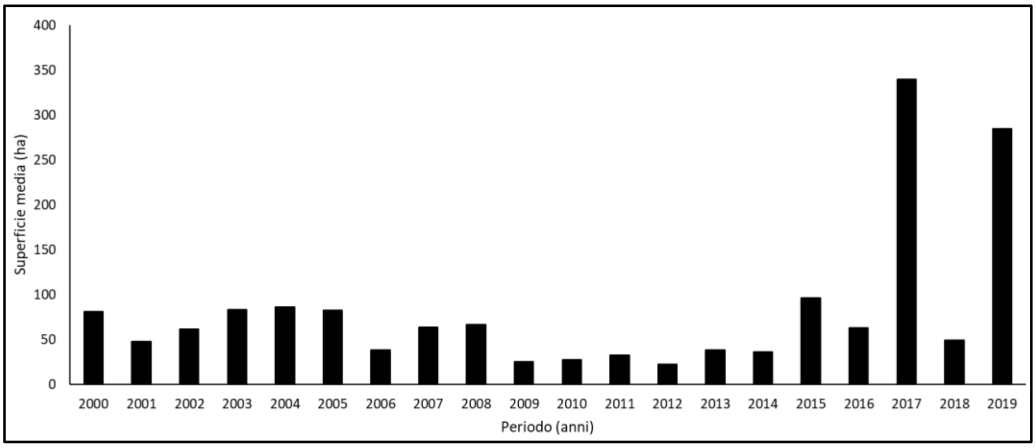


Fig.6-30.Average area covered by major fire (total area greater than or equal to 10 ha) per year for the period 2000-2019_ Source:(Piano AIB Regione Piemonte 2021-2025)

However, if we consider the seasonality of major fires, according to the statistics provided by Antifire plan for Piedmont region, March and October have been the months in which these events produced the greatest surface covered; however, it should be emphasised again that the October data is largely determined by the fires of 2017. In the case of monthly frequency trend, the main frequency peak corresponded only to the month of March, while October did not emerge as particularly problematic. The data relating to the average monthly distributions of fire frequency therefore confirmed the **period between January and April, with a peak in March**, as the **season of maximum danger**. However, it is interesting to note that in August, therefore outside the typical fire season that characterises the Alpine arc, there has been a certain frequency of events with a surface area equal to or greater than 10 ha (Piano AIB Regione Piemonte 2021-2025).

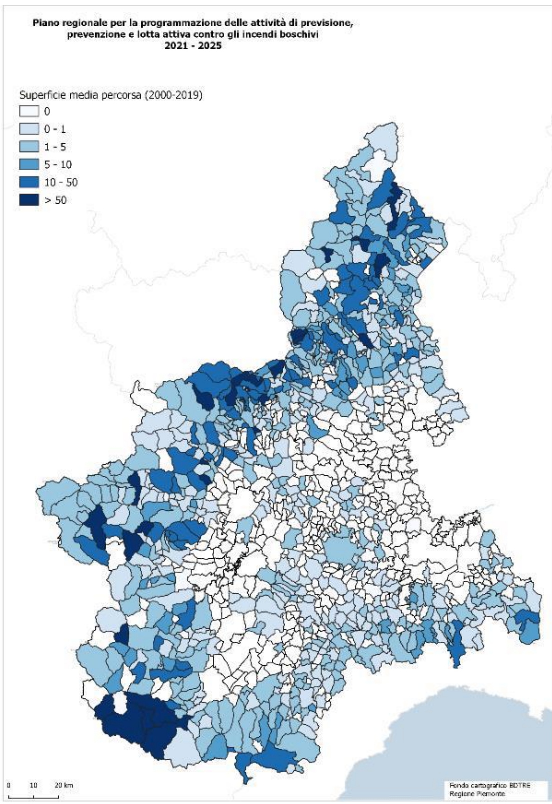
6.2.3.3.Descriptive Statistics At Municipal Scale (Historical Series 2000 – 2019)

The anti-fire plan, for the Piedmont region, has prepared the characterization of the risk profile of the individual municipalities and has been maintained on the basis of some statistics on a purely descriptive level, relating to frequencies and surfaces covered by fires within the municipal area. In addition to the total number of fires that occurred within the municipal boundaries, the areas covered (total, wooded and non-wooded), as well as the percentage of wooded area covered with respect to the total area affected by fire, some other indicators were calculated such as the average area covered by fire during a single event (ha), Median area covered by fire (ha), Maximum area covered by fire during a single event (ha), Number of forest fires that occur on average per year per 10 km2 of land, Number of large forest fires (greater than or equal to 10 ha) which occurred on average per year per 10 km2 of territory, Number of years in which at least one fire occurred (percentage of years with fire),Annual number of fires and Annual number of large fires (greater than or equal to 10 ha). Table(6-7) reports the descriptive statistics on a municipal scale for the period 2000-2019 for the municipalities that in the 20 years included in this historical series have had a number of fires greater than or equal to 20. 47 municipalities in total entered the aforementioned criteria, however here only the 7 municipalities that are located in Susa Valley are reported. Among all the 47 municipalities, Caselette was the municipality with the highest number of fires.

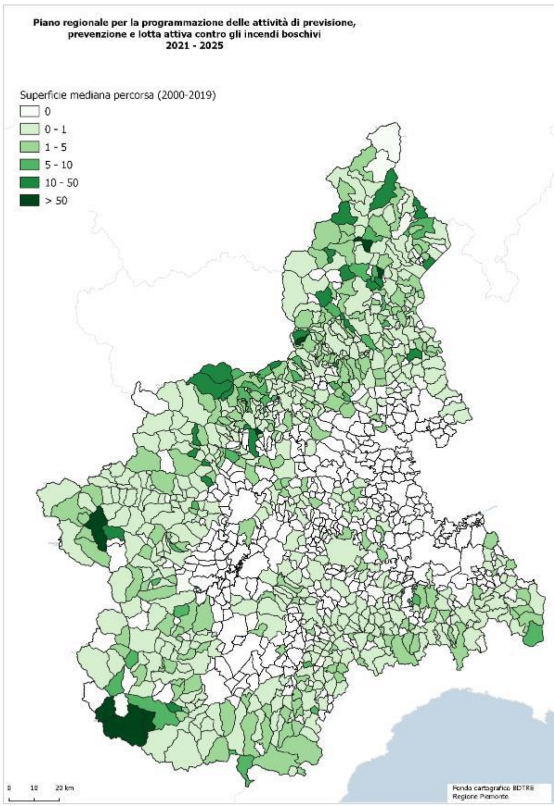
Comune	Total number of FF	fire-covered surface areas(ha)	fire-covered forest surface area(ha)	fire-covered non-forest surface area(ha)	% wooded area fire-covered on the total	Media fire-covered surface area(ha)	median surface F-covered (ha)	maximum surface F-covered (ha)	n FF eachi 10 km2/year	n large FF for each 10 km2/anno	% years with at least 1 FF	Total FF/Year	Total Large FF/year
San Giorio di Susa	25	11,3	5,5	5,9	48,1	0,5	0,3	2,5	0,6	0	45,0	1,3	0,0
Chianocco	36	32,4	21,2	11,2	65,5	0,9	0,2	8,5	1,0	0	80,0	1,8	0,0
Condove	37	710,9	184,7	526,3	26,0	19,2	3,3	302,7	0,3	0,1	100,0	1,9	0,4
Susa	38	38,6	35,0	3,6	90,7	1,0	0,4	13,4	1,7	0	85,0	1,9	0,1
Bussoleno	45	4573,4	3618,2	955,1	79,1	101,6	0,2	4018,6	0,6	0	70,0	2,3	0,2
Mattie	51	97,7	85,7	12,0	87,7	1,9	0,2	44,7	0,9	0	70,0	2,6	0,1
Caselette	106	146,3	142,5	3,8	97,4	1,4	0,0	98,3	3,7	0,1	55,0	5,3	0,1

Table 6-7.Descriptive statistics at municipal scale for the period 2000-2019 for municipalities in Susa Valley Area, with a number of fires in the last 20 years greater than or equal to 20: total frequency; covered areas: total, wooded and non-wooded (ha); % wooded area covered on the total; average covered area (ha); median surface covered (ha); maximum surface covered (ha); average annual number of fires every 10 km2 of municipal territory; average annual number of large fires (surface area equal to or greater than 10 ha) per 10 km2 of municipal area; number of years in which at least one fire occurred (percentage of years with fire); average annual number of fires; average annual number of large fires (greater than or equal to 10 ha)_ Source:(Piano AIB Regione Piemonte 2021-2025)

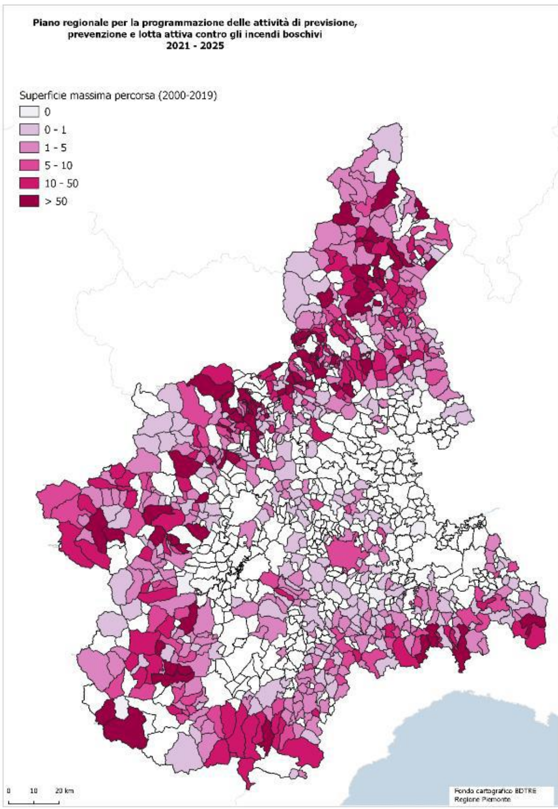
Similar indicators have been calculated visualised in the following maps including average surface covered by fire event, median surface covered by fire event, maximum surface covered by fire event, percentage of the years having a fire event, average number of wildfire each 10 km^2 per year, average number of large wildfires each 10 km^2 per year, number of wildfire per year, number of large wildfires per year. Regarding the surfaces covered by fire, as it can be seen by the maps, the area of Susa Valley on average, has been experiencing a medium to high number of forest fires (deduced from average surface and the median surface covered by the fire). Of course, the average surface is less useful for describing the extension of the typical fire, as the arithmetic mean is highly influenced by the extreme values of the distribution and is a statistic to be considered not very robust, especially when the distributions are highly asymmetrical as in the case of the surfaces covered by fire. As regards to the median surface covered by fire indicator, in the case of highly asymmetrical distributions such as those under examination (that is, distributions characterised by the presence of extreme observations which determine a lengthening of the positive "tail") expresses, better than the arithmetic mean, the magnitude of the typical phenomenon. The variable therefore indicates the area of the "typical" fire in each municipality. Therefore, summarising all the cartographies, it can be said even though the whole area of Susa Valley has been experiencing the phenomenon of wildfire, the areas at the eastern side of “Exilles” comune _with exception of “Cesana Torinese” on the west side, have experienced the higher number of fire events, occurring more frequently overtime (Percentage of years having a fire event and highest number of fire events per year). However, the municipalities experiencing the highest surface covered by the fire event, are mostly situated in the western side of the valley, including Bardonecchia, Oulx, Salbertrand, Cesana Torinese, Sestiere and Sauze di Cesana.



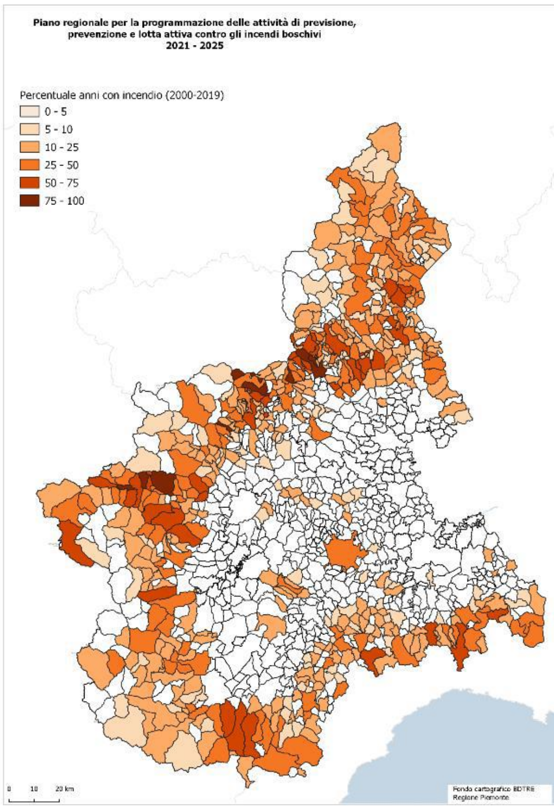
Piano regionale per la programmazione delle attività di previsione, prevenzione e lotta attiva contro gli incendi boschivi
2021 - 2025
Superficie media percorsa (2000-2019)
0
0 - 1
1 - 5
5 - 10
10 - 50
> 50
0 10 20 km
Fondo cartografico BDTRE
Regione Piemonte



Piano regionale per la programmazione delle attività di previsione, prevenzione e lotta attiva contro gli incendi boschivi
2021 - 2025
Superficie mediana percorsa (2000-2019)
0
0 - 1
1 - 5
5 - 10
10 - 50
> 50
0 10 20 km
Fondo cartografico BDTRE
Regione Piemonte



Piano regionale per la programmazione delle attività di previsione, prevenzione e lotta attiva contro gli incendi boschivi
2021 - 2025
Superficie massima percorsa (2000-2019)
0
0 - 1
1 - 5
5 - 10
10 - 50
> 50
0 10 20 km
Fondo cartografico BDTRE
Regione Piemonte



Piano regionale per la programmazione delle attività di previsione, prevenzione e lotta attiva contro gli incendi boschivi
2021 - 2025
Percentuale anni con incendio (2000-2019)
0 - 5
5 - 10
10 - 25
25 - 50
50 - 75
75 - 100
0 10 20 km
Fondo cartografico BDTRE
Regione Piemonte

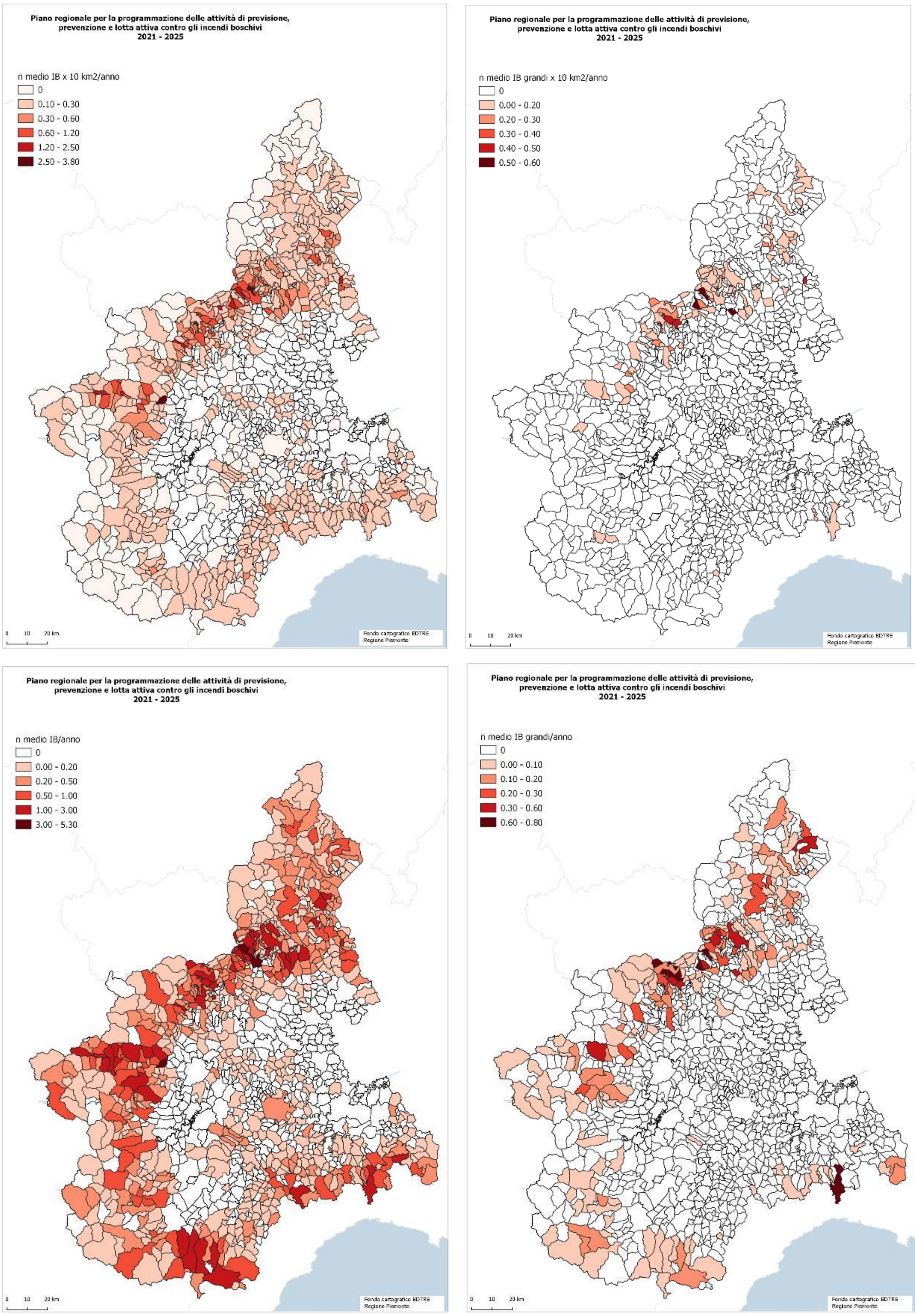


Fig.6-31.Indicators for defining the historic risk profile of municipalities for the 2000-2019 time series: average annual number of fires every 10 km2 of municipal territory; average annual number of large fires (surface area equal to or greater than 10 ha) per 10 km2 of municipal area; average annual number of fires; average annual number of large fires (greater than or equal to 10 ha)_Source: (Piano AIB Regione Piemonte-2021-2025)

6.2.3.4.Descriptive Statistics By Base Area (Historical Series 2000 – 2019)

Below (Table 6-8) are some descriptive statistics for each Base Area, relating to the surfaces covered by the fire events: total, wooded and non-wooded (ha), the number of fires that have occurred, the average surface covered by the fire event (ha) and the maximum surface covered by the fire event (ha) for the time series 2000-2019 for the Base Areas corresponding to Susa Valley area.

Base Area	Total Surface Area(ha)	Forest Surface Area(ha)	Non-Forest Surface Area (ha)	N° of Wildfires	maximum F-covered area(ha)	Media F-covered area(ha)
29	273,7	130,7	143,0	94	46,0	2,9
30	2.476,4	1.777,2	699,2	37	957,2	66,9

Table 6-8.Descriptive statistics by base area for the period 2000-2019: covered areas (total, wooded and non-wooded); total frequency; maximum covered area; average surface traveled_Source(Piano AIB Regione Piemonte 2021,2025)

6.2.3.5.Descriptive Statistics By Forest Area (Historical Series 2000 – 2019)

Below (Table 6-9) are some descriptive statistics for each forest area, relating to the total number of fires, total covered area (ha), percentage of total covered area per season for the 2000-2019 historical series. Among the various Forest Areas presented by the AIB Plan for Piedmont, number 29 is the one with the highest number of fires (541) and the largest total area (6,146 ha) covered. On the other hand, number 30 had one of the highest percentage of fire-covered areas during winter.

Forest Area	Total N° of WF	Total Surface Area F-Covered	% Surface Area DGF (Winter)	% Surface Area MAM (Spring)	% Surface Area GLA (Summer)	% Surface Area SON (Autumn)
29	541	6.145,6	2,6	13,1	9,7	74,6
30	86	268,7	38,6	30,3	3,4	27,8

Table 6-9.Descriptive statistics by forest area for the period 2000-2019: total frequency; total covered area (ha); percentage of total area covered per season_Source:(Piano AIB Regione Piemonte 2021-2025)

6.2.4.Wildfires risk maps

The analysis of the probability of fire spread distance was carried out in the Antifire Plan of the Piedmont region by simulating 15,000 fires lasting 24 hours. The fire density was defined according to the location of the ignition points of the historical series considered (1999-2009). According to the report, considering the diversity of synoptic wind scenarios predisposing large fires, and considering the objective of the probability analysis which aims above all to test the potential for the fire to spread as a result of the territorial characteristics (alignment between vegetation flammability, topography and wind), the simulations predicted a topographic fire scenario with wind alignment along the maximum slope of each cell of the landscape.The fire probability is calculated proportionally to the number of times a cell has been run from the 15,000 simulations, and as previously mentioned, to define Piedmont's vulnerability to fires, reference was made to the resistance and resilience capacity of the ecosystem following the passage of fire (ecological vulnerability) and to the functional value attributed to the forest resource and the relative degree of conflict with the passage of fire (functional vulnerability).

Fig(6-32) illustrates the potential intensity of fire danger. As it can be observed, in the Susa Valley area, surfaces along the river Dora Riparia have very high to high risk of fire intensity, while the other areas have medium and lower fire intensity danger rate. In the same manner, Figure(6-33) demonstrates that all the areas along the Dora Riparia, and from the south of Bardonecchia to the south of the Susa Valley area, have a high probability of fire event happening(Fig.633 and 6-34), however, from comune of “Gaglione” to the east side of the Valley, the probability is very high(Fig.6-33).

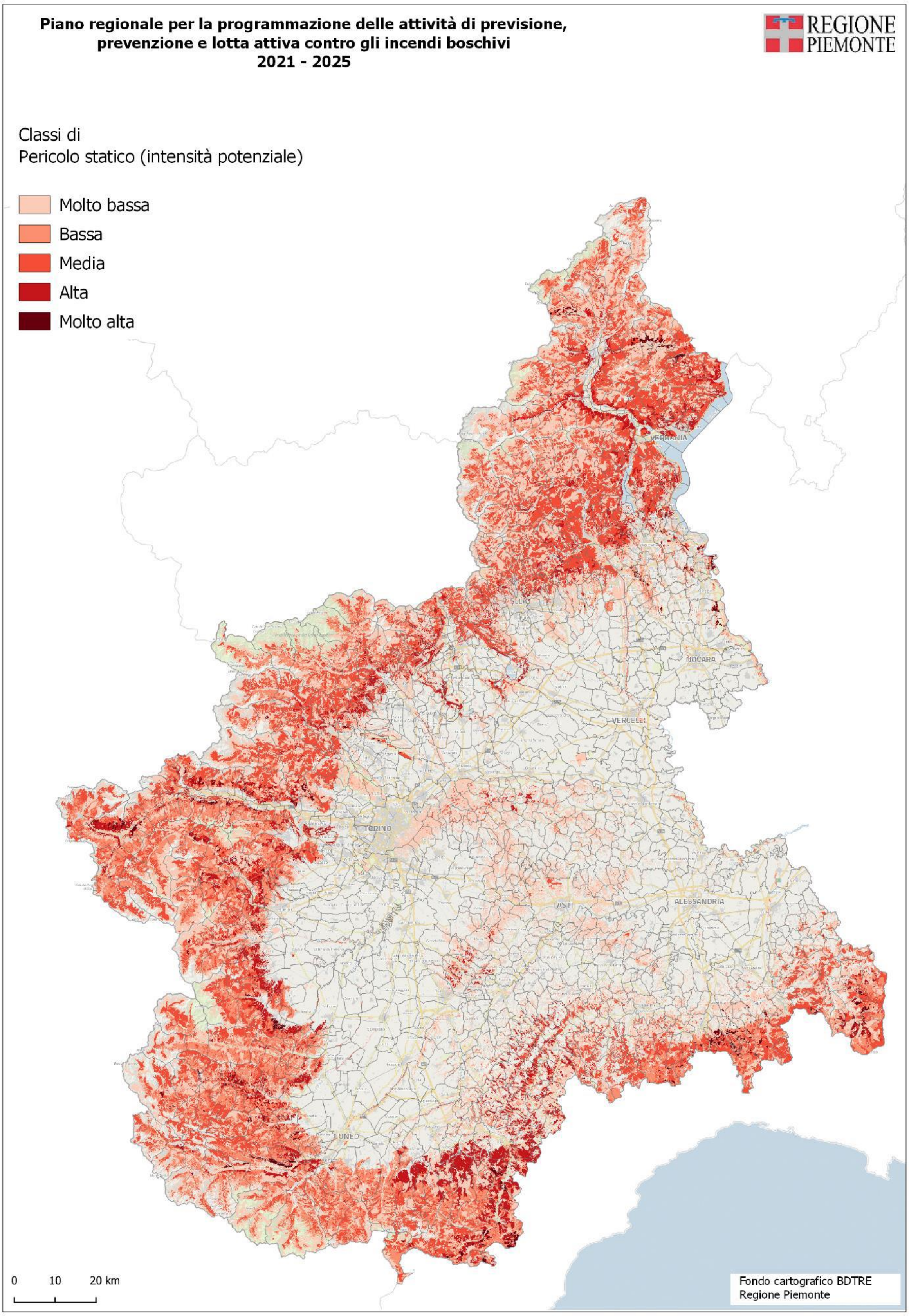


Fig.6-32.Static hazard classes (Potential intensity KW/m)_Source:(Piano AIB Regione Piemonte 2021-2025)

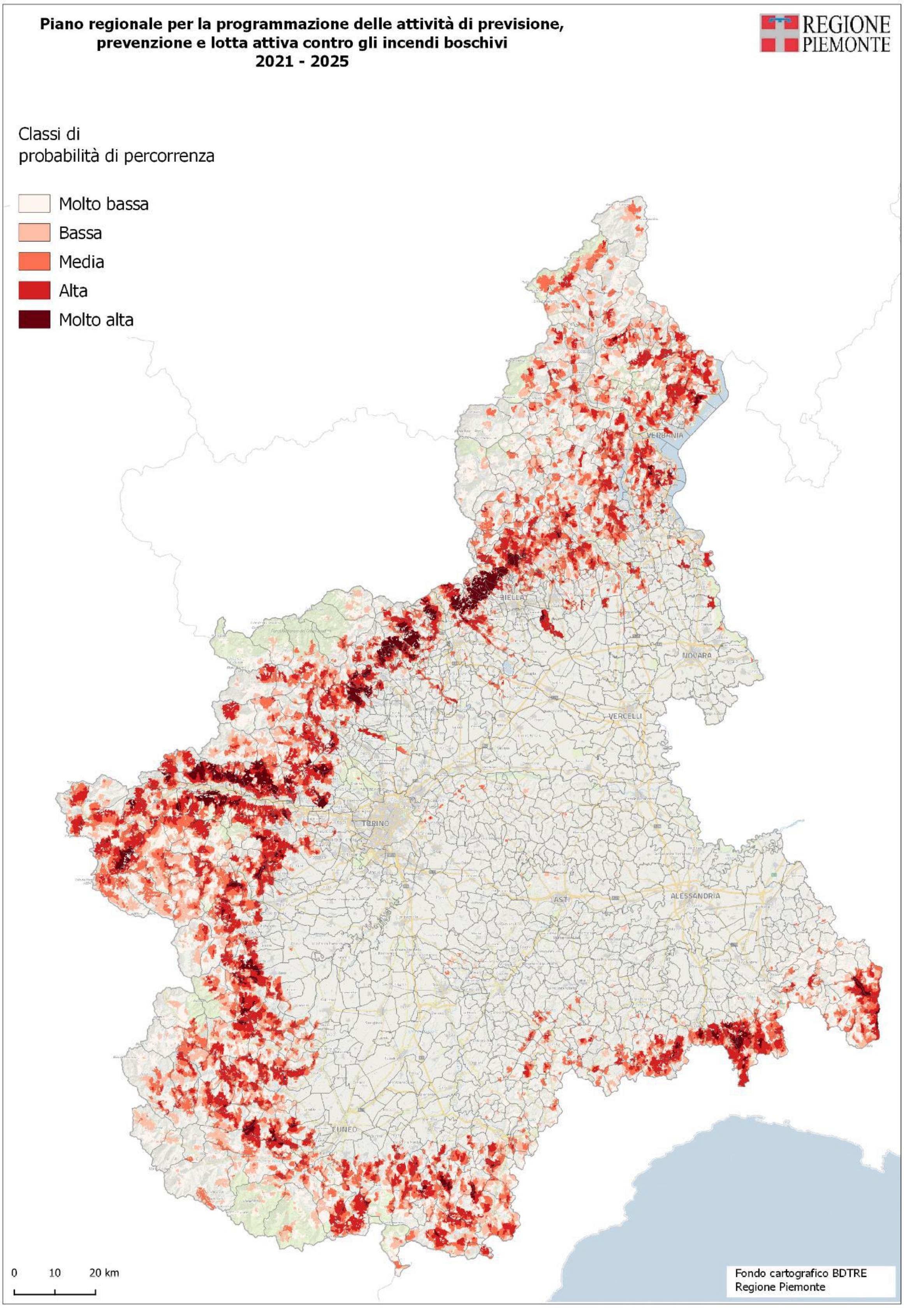


Fig.6-33.Categorised Probability of percorrenza di incendio_Source:(Piano AIB Regione Piemonte 2021-2025)

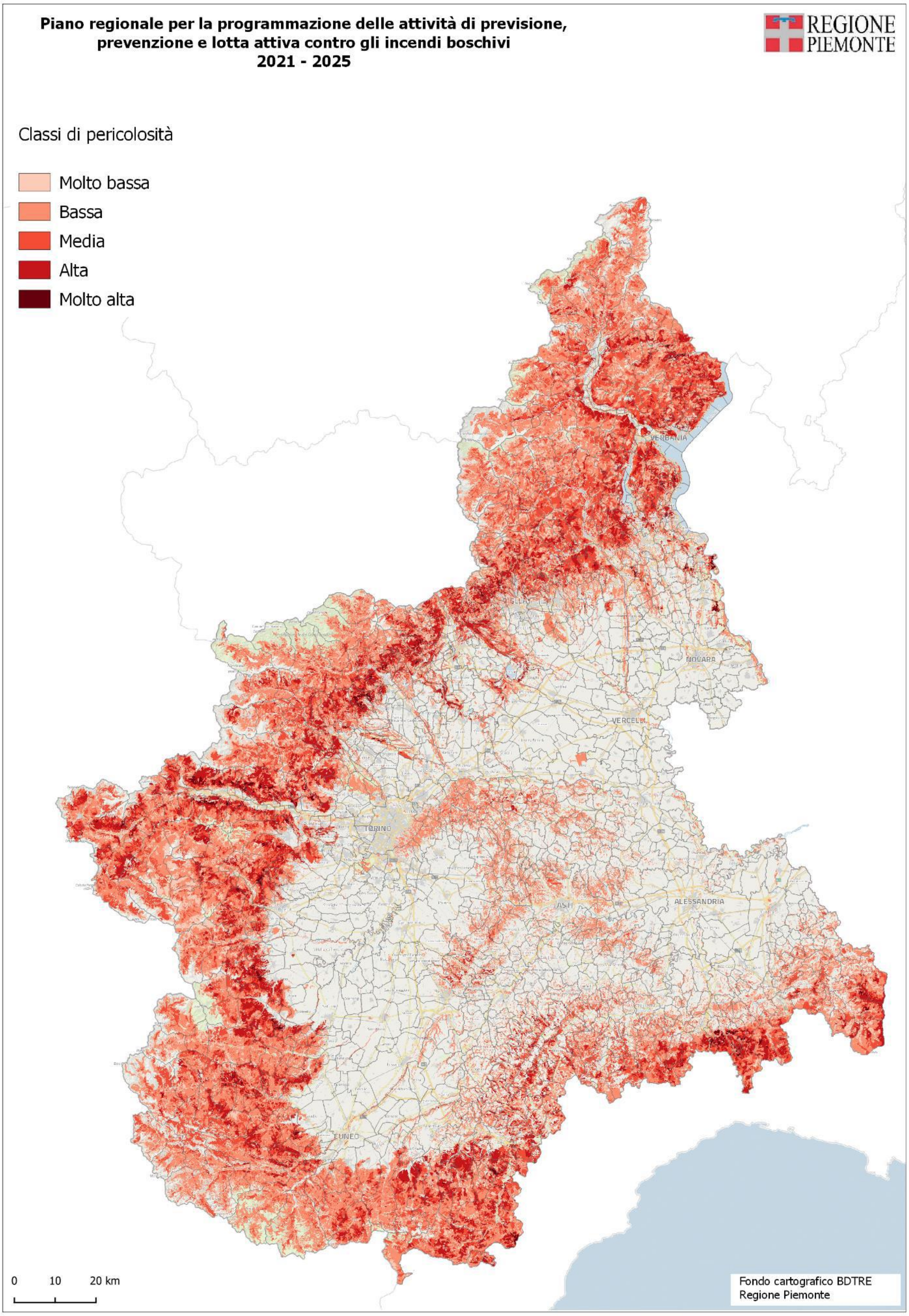


Fig.6-34.Fire Danger Map_Source:(Piano AIB Regione Piemonte 2021-2025)

6.2.3.1.Ecological Vulnerability

The AIB plan made by the Piedmont region had elaborated a list of characteristics that contributed to ecological vulnerabilities, attributing the stability classes to the various forest and land use categories which make up the areas potentially subject to fire in Piedmont. According to the Antifire Plan for the Piedmont region,the two main factors influencing **ecological vulnerability** are **stability** and **degrading**. This plan, in order to calculate the ecological vulnerability have defined hierarchical factors that have been taken into consideration for the definition of the stability classes such as **characteristics of the main wood species**: passive resistance (e.g. oak, larch, larch); of regrowth (e.g. chestnut woods) or **post-disturbance dissemination** (e.g. pine woods, beech woods); **characteristics of other significant hosted species**; **site characteristics** and **limitations** (wet, dry).

Stability has been defined as a set of characteristics of **resistance** and **resilience**. Resistance is linked to the physical/mechanical characteristics of individual species in protecting themselves from fire and maintaining vitality. As regards **degradation**, i.e. the effects of fire on ecosystems, a synthetic index that represents its severity is **the risk of soil erosion.** In particular, as regards the quantification of soil erosion in relation to the passage of fire, the erosion that does not take into account the current cover, but considers the entire territory as if it had just been covered by fire, was considered. The soil erosion values obtained following the passage of fire, expressed as tons/hectare/year of soil loss, were appropriately divided into the following 3 classes. To define ecological vulnerability, a combination matrix between stability and soil erosion was therefore elaborated, defined according to a qualitative scale. As it can be viewed on the map(Fig.6-35), the

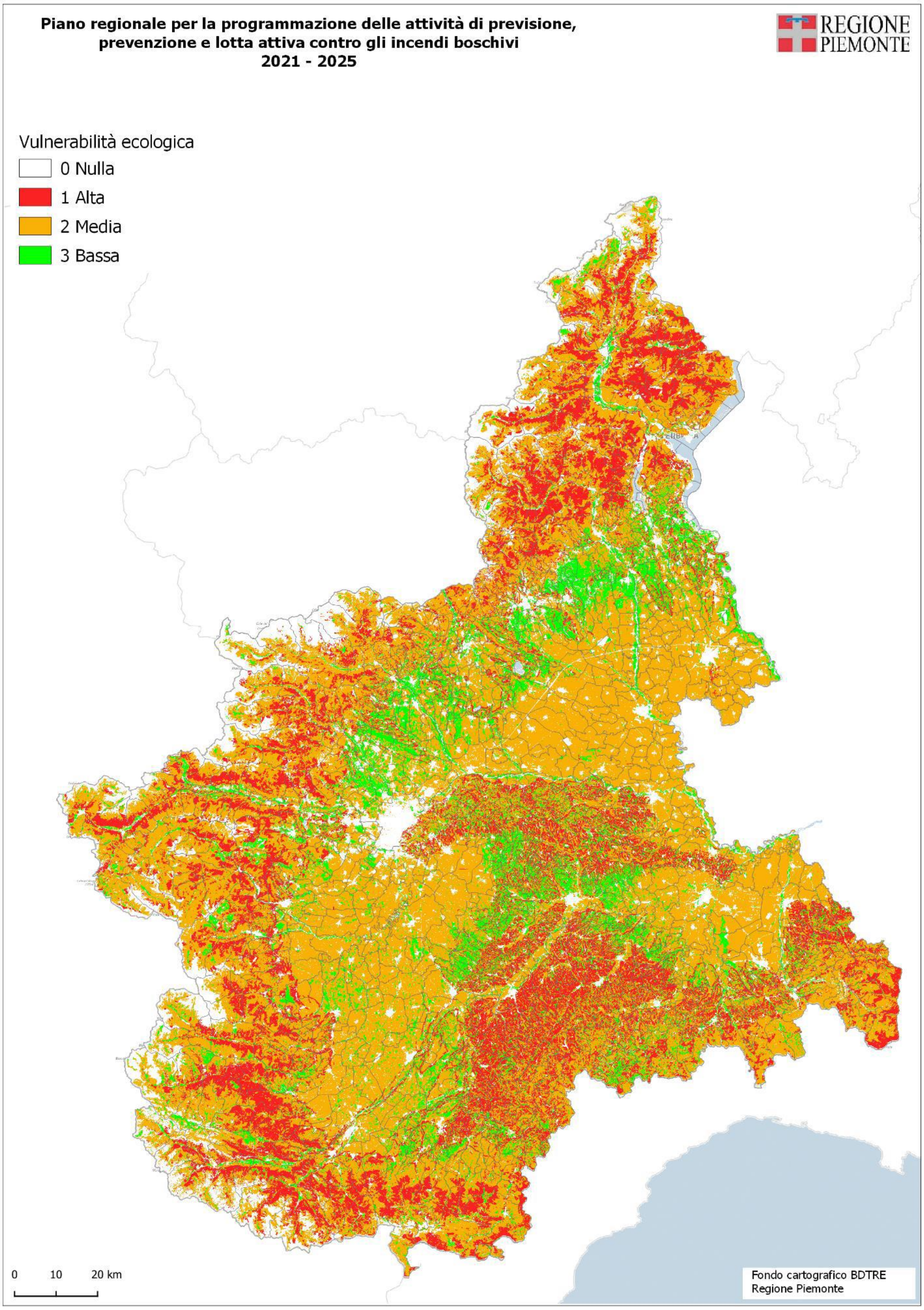


Fig.6-35.Classes of ecological vulnerability_Source: (Piano AIB Regione Piemonte 2021-2025)

6.2.3.2.Functional vulnerability

Functional vulnerability, calculated by the Antifire Plan for the Piedmont Region complements the calculated ecological vulnerability as it focuses on the value assigned to threatened natural resources in terms of their functional role. The function of the resource is that contemplated by forest planning (from the map of the main functional destinations deriving from the studies for the PFTs, destinations of the PFAs), the degree of conflict is assigned on the basis of the studies in the bibliography and experience, through the elaboration of specific comparison matrices. As the produced map (figure 6-36) shows, the functional vulnerability of the Susa Valley area is medium to high throughout the area. However, from Giaglione municipality to the east of the valley, there are surfaces with very high functional vulnerability.

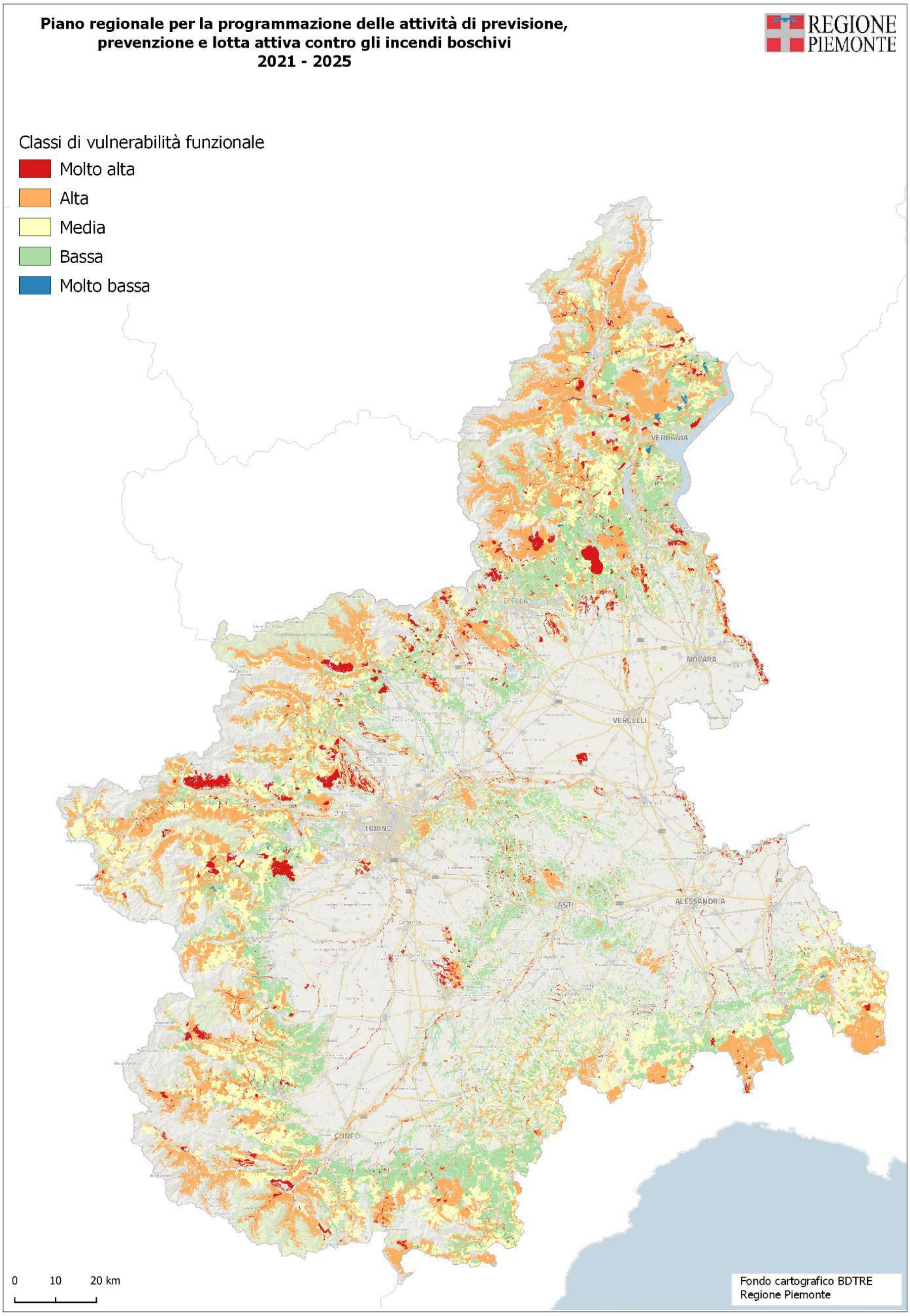


Fig.6-36.Functional vulnerability to fires. The very low class for non-forest areas is not represented_Source:(Piano AIB Regione Piemonte 2021-2025)

6.3.The forest fire event of 2017

October 2017 saw the drought situation in the Italian North-West worsen further, while in the rest of the country the rains in September (and the further showers in October in the Adriatic and in the South) had alleviated the water crisis that had been dragging on since spring. In addition to the problems of drinking water supply in many municipalities, especially in southern Piedmont, the extreme aridity of the soil and undergrowth have penalised the sowing of wheat in the plains and favoured the spread of numerous and serious forest fires in the Alps, especially at the end of the month (Cat Berro and Mercalli, 2017).
As a matter of fact, according to the ArpaPiemonte Website, 2017 in Piedmont was the **3rd hottest year** in the last 60 years, with a **thermal anomaly** of about +1.5 °C compared to the climatology of the period 1971-2000. Furthermore, in 2017 about 700 mm of precipitation fell in Piedmont, with a **rainfall deficit** of 351 mm (equal to 33%) compared to the 1971-2000 norm, thus making it the **4th driest year** in the last 60 years (ArpaPiemonte Website). In fact, the Mediterranean region experienced **extreme wildfires** unusually late in 2017 (there were different events of Forest Fire in Portugal, Forest Fire in Corsica and Italy). In the third ten days of October a serious sequence of extensive and persistent forest fires hit the **western Alps** and in particular the **Cuneo** and **Turin hills**, with the most important episodes concentrated between the 22nd and 29th in the Stura di Demonte, Varaita, Chisone valleys, Susa, Orco, Chiusella, and in the territories of Cumiana and Cantalupa (Pinerolese), to which other events in the Lombardy Alps and Pre-Alps were added at the end of the month. Residual outbreaks were still active between 31 October and 1 November around Ribordone, Cumiana and Giaveno (Turin) (Cat Berro and Mercalli, 2017).

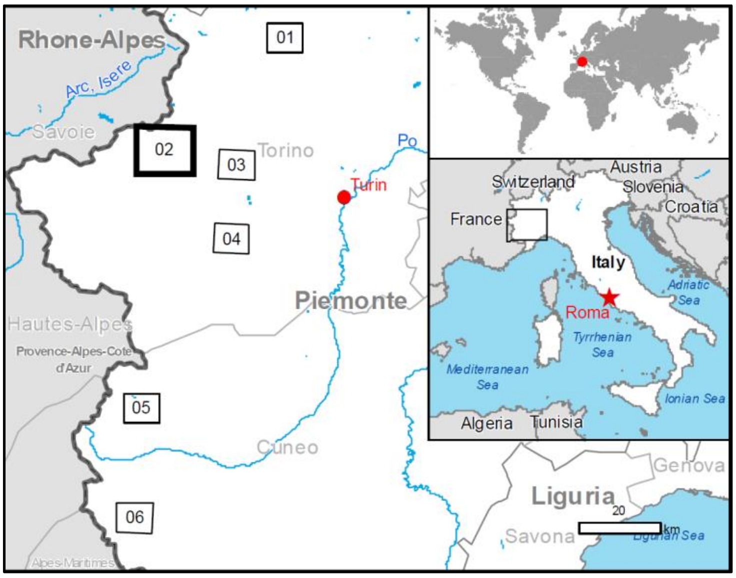


Fig.6-37.The location of the wildfire event for Susa Valley in 2017_Source: (Susa Delineation Map by Copernicus Monitoring Service, 2017)

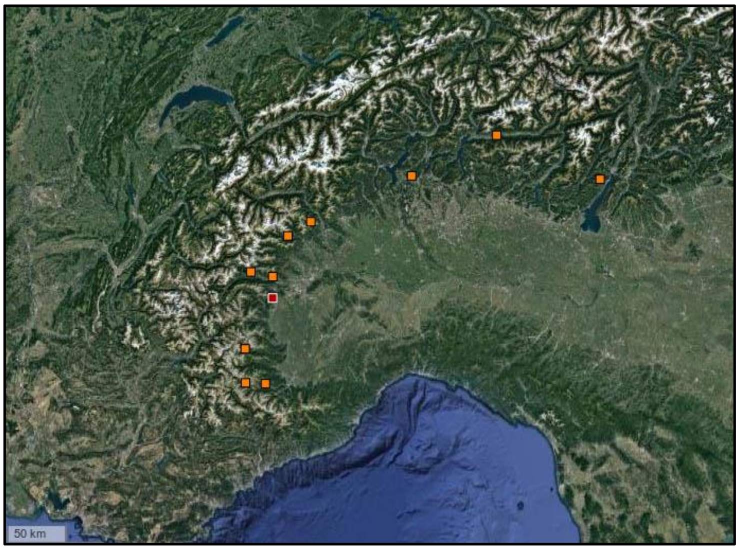


Fig.6-38.Localization of the forest fires that affected Northern Italy from 22 October 2017: most of the events were concentrated in Piedmont (in Sambuco and Pietraporzio in Valle Stura di Demonte, in Casteldelfino in Val Varaita, in Roure in Val Chisone, in Cumiana and surroundings, in Caprie, Rubiana and Chianocco-Bussoleno -Mompantero in Val Susa, in Ribordone, Sparone and Locana in Valle Orco, in Rueglio and Traversella in Valchiusella), but in the last days of the month, because of the persistent föhn from the north, important fires also hit Campo dei Fiori (Varese) , the area of Morbegno in Valtellina, and Tremosine-Tignale (Alto Garda)(Nimbus Website Report). Image source: (European Forest Fire Information System (EFFIS), EU Copernicus program).

The most extensive and persistent fire developed in Val di Susa, around 10 am on Sunday 22 October 2017 on the **slopes immediately upstream of Bussoleno**, as the **föhn wind** just strengthened. Propelled by the gusts, the fire travelled over a thousand metres in altitude in less than three hours, lapping the villages of Argiassera and Richettera (evacuated in the evening) and in the following days it moved westwards involving the SCI (Site of Community Interest) of the **Orrido di Foresto** and then the southern slopes of Rocciamelone. Here, with the new onset of the **dry westerly wind** at dawn on Friday 27 October, the fire spread to vast Scots pine forests, turning into an impressive **"crown" fire** that was difficult to control despite the intervention of helicopters and canadairs, which up to the night between Sunday 29 and Monday 30 it devastated the slopes **above Mompantero** at altitudes between approximately 700 and 2200 m, but extending over pasture up to 2800 m near the Cà d'Asti refuge (Cat Berro and Mercalli, 2017).
For the last two weeks of October firefighters have been trying to control the fires in the Piedmont region in Northwestern Italy. The fires were fanned by the recent strong winds and spread quickly through dry autumn leaves and trees. According to the media, more than **270 fire department staff** and volunteers were working to extinguish a series of fires in the **Val di Susa** region alone, just 30 kilometres west of the Piedmont capital Turin. Helicopters and the Italian fire department's Canadair airborne fleet had to be deployed to fight the spreading forest fire, as the mountainous terrain makes it difficult to access some areas(Copernicus Emergency Service Website). The most serious fire burned for **eight consecutive days** (22-29 October 2017) mixed deciduous forests, xeric grasslands and Scots pine forests on the orographic **left side of the Val Susa** between Chianocco, Bussoleno, Mompantero and Venaus. Here an impressive view of flames about fifty metres high (the pylon in the foreground is 18 m high...) on 29 October in the pinewoods of Mompantero, at the base of Rocciamelone, under foehn gusts at 90 km/h (Cat Berro and Mercalli, 2017).
Italy's Department of Civil Protection activated **Copernicus EMS** on 28th October for the production of **delineation maps** (showing the extent of fire_Fig. 6-39) over 6 areas of interest. The maps have been produced using Pleiades very high resolution optical satellite imagery. In order to investigate the causes and characteristics of the event, the Copernicus Emergency Management Service elaborated 7 delineation maps that will be discussed in this section. The forest fires mostly involved the provinces of Torino and Cuneo. Since October 10, when the state of maximum danger for forest fires was declared, there were more than 200 interventions in the areas of **Cumiana, Caprie, Cantalupa, Rubiana, Bussoleno, Traversella, Ribordone, San Germano Chisone, Fontanile, Perrero , Mompantero, Traversella in Torinese, Barge, Pietraporzio, Casteldelfino and Cortemilia in the province of Cuneo, and Borgomanero**. At the date

of 27th of October 160 regional volunteers were working and 120 firefighters with 60 vehicles were involved in on field activities. Both the regional and national resources were involved in the activities to manage the ongoing situation, from 18th to 26th October, state aviation fleet crews, in support of operations carried out by land teams and regional air carriers, carried out more than 60 flights in the area for a total of about 330 extinguishing liquids burnings (Copernicus Emergency Service Website).

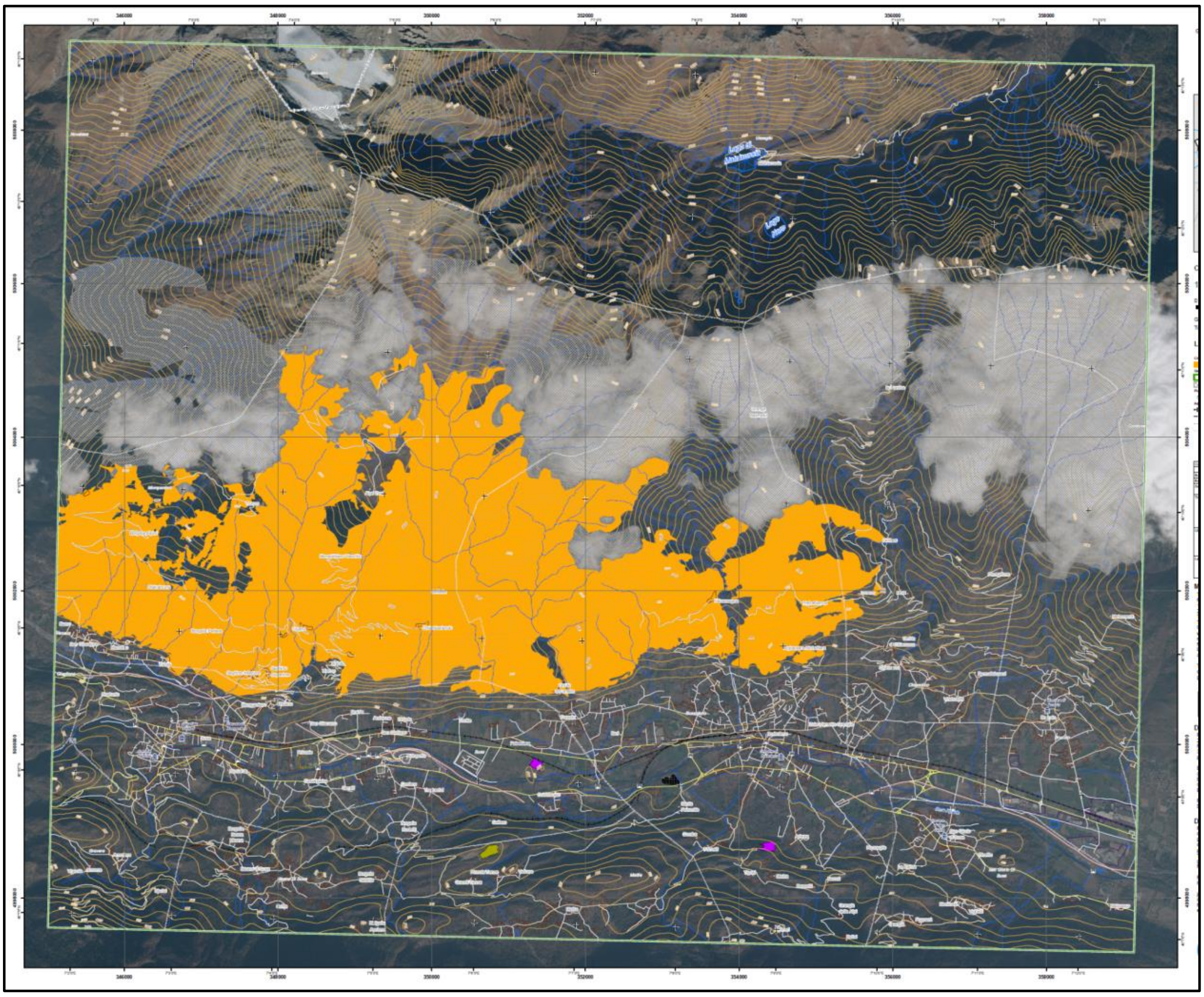


Fig.6-39.Copernicus Emergency Service Delineation Map for Susa Valley area burned areas in Orange_Source:(Copernicus Emergency Service Website, 30/10/2017 10:40 UTC)

Fig.6-40.The impressive plume of smoke that developed in the initial stages of the fire of Bussoleno on 22 October 2017, seen from Susa. Note, above, the formation of a real cloud of the "Pyrocumulus" genus, due to the condensation of the vapour above the column of hot air rising above the pyre, in a convective process similar to that which generates cumulonimbus clouds summer thunderstorms- Source: (Nimbus Website photo by Carlo Ravetto).

Fig.6-41.October 27, 2017: the huge plume of smoke from the fire in the pine forest on the southern slope of Rocciamelone, in the territory of Mompantero, Val Susa-Source: (Nimbus Website photo by Daniele Cat Berro).

Fig.6-42.On 27 October 2017, 9 am: at dawn on the sixth day of fire, the entrance to the foehn rekindles the flames that extend into the pine forest at the foot of Rocciamelone, upstream from Mompantero, near Susa. Flames more than 30 m high emit from the pine forest near the Trucco hamlet, at an altitude of 1700 m along the road that leads to La Riposa, the starting point for the ascent to Rocciamelone (peak on the left, 3538 m)-Source:(Nimbus Website)

6.3.1.The Cause of Wildfire Event of 2017

The reports attribute the cause of the wildfire event in 2017 to the climatic reasons. The fires, very probably at least largely of **arson origin**, were able to spread explosively and sometimes uncontrollably due to an exceptional and unfavourable combination of climatic and environmental factors such as **drought** among the most marked for a century; **desiccation of the soil** and **undergrowth** and **vegetation stress** also aggravated by the **extreme summer heat** and the consequent **intense evapo-transpiration**; strong gusts of **föhn** on 22, 23, 27 and 29 October; **absence of snow** even at higher altitudes, sometimes with flames extending above 2000 m; **abundant dry biomass** (shrubs, recently fallen leaves...) also available following the re-naturalization processes of low mountain slopes cultivated until a few decades ago (Cat Berro and Mercalli, 2017).

In fact, according to the statistics, much of Piedmont did not receive a drop of water in October, a very rare situation for a month which is usually among the rainiest of the year in Northern Italy. In Turin, in the entire rainfall series begun in 1802, it had only happened in the very dry 1921. The cause must be sought in the anomalous persistence of high pressures over western Europe (situation of atmospheric "blockage"). In these situations, the few Atlantic perturbations generally flow from west to north, heading more towards the Balkans, "skipping" the Po side of the Alps which remains downwind of the mountains in prevailing föhn conditions. Only a few flakes of snow arrived on the western border of the Alps brought by the fronts from the North-West on 8 and 22 October, but as of today - 1 November - the glaciers remain in the conditions they were in at the end of summer, completely bare or almost of snow both residual from the winter of 2016-17 and recent (Cat Berro and Mercalli, 2017).

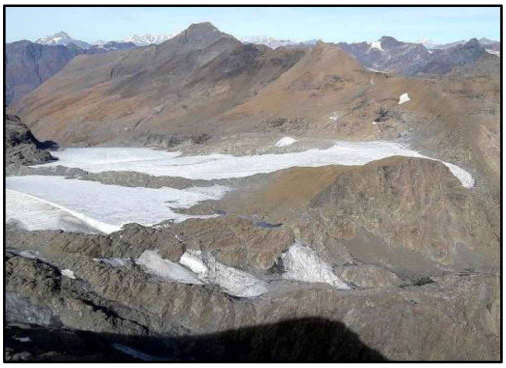


Fig.6-43.The Rocciamelone glacier from the peak of the same name on the morning of 1 November 2017, completely bare of residual snow and recent as at the end of summer_Source: (Nimbus Website).

Therefore sunny, dry and also hot weather prevailed in Piedmont, in particular during the phases marked by powerful **subtropical anticyclones**, with the 0 °C isotherm rising to an altitude of 4350 m above Lombardy on 16 October (radio survey of Milan-Linate) and at 4200 m above the Cuneo area on 26 October (radio sounding of Levaldigi). At low altitudes, apart from **ephemeral favonic** episodes that reached the plains (more frequent in the valleys), the calm atmosphere and the consequent **thermal inversions** trapped increasing quantities of dust and polluting compounds in the air, to which were added at the end of October smoke from mountain fires (Cat Berro and Mercalli, 2017).

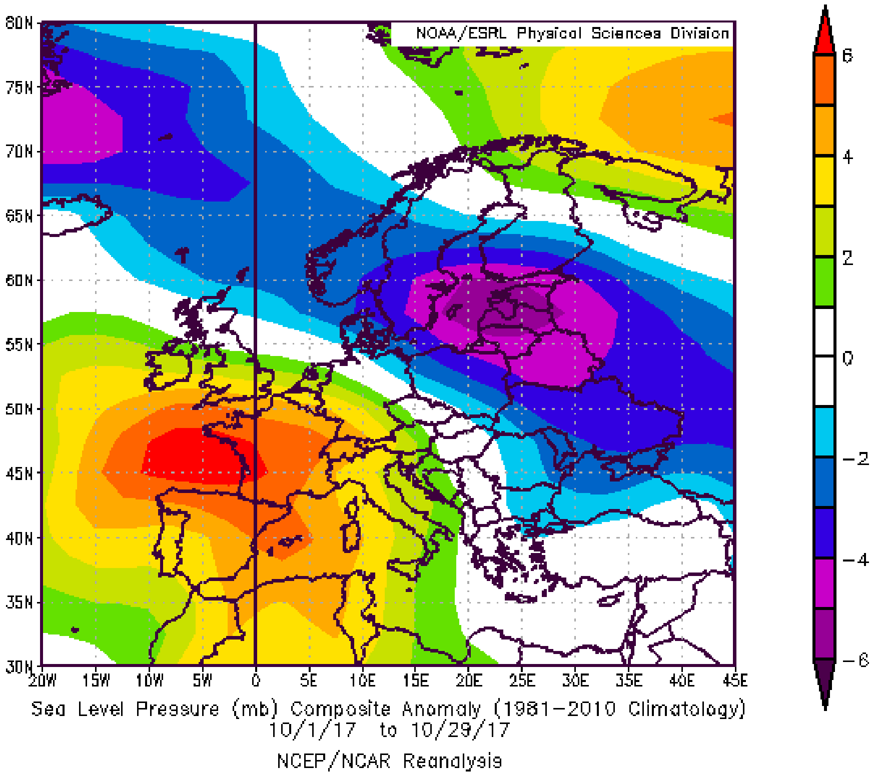


Fig.6-44.Ground air pressure anomalies in October 2017 in Europe. As highlighted by the orange-red colours, the anticyclones have insisted much more than usual on the south-western sector of the continent, forcing the Atlantic frontal systems to flow mostly from the North Sea towards the Balkans. The few perturbations that directly reached Italy occurred with flows on average between West and North on the ground, unfavourable for producing precipitation in the north-western regions (Source:Nimbus Website Report, 2017).

The **anomalous heat** was rather constant, especially in the **plains** (at high altitudes in the Alps there were brief coolings on the occasion of the north-western fronts, dampened by the föhn effect downstream). With an average monthly temperature of 16.2 °C, 2.1 °C above the 1981-2010 average, Turin experienced its 4th warmest October since 1753, after the - moreover very recent - cases of 2001 (record), 2006 and 2014. On the rest of Northern Italy, less subject to föhn conditions, the thermal anomaly was a little less marked (9th October warmest since 1878 in Parma, with a difference of +1.6 °C), and along the peninsula the month was even a little cooler than normal (Cat Berro and Mercalli, 2017).

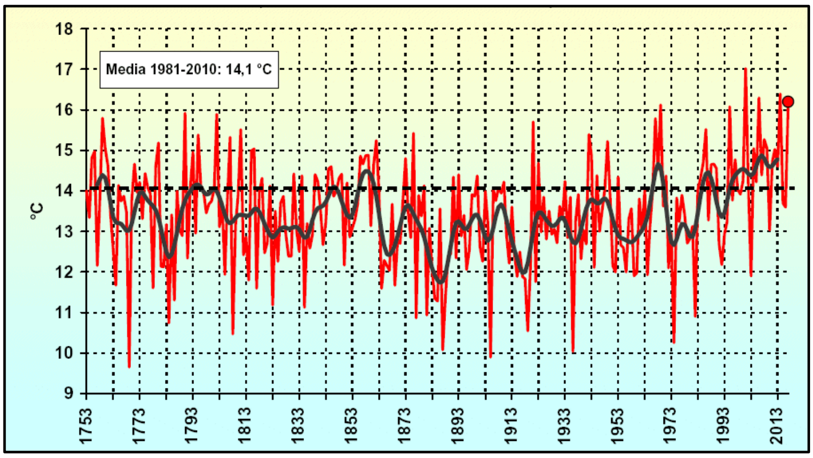


Fig.6-45.Series of average temperatures in October in Turin since 1753: that of 2017 occupies the fourth position among the warmest_Source: (SMI-www.nimbus.it, 2017)

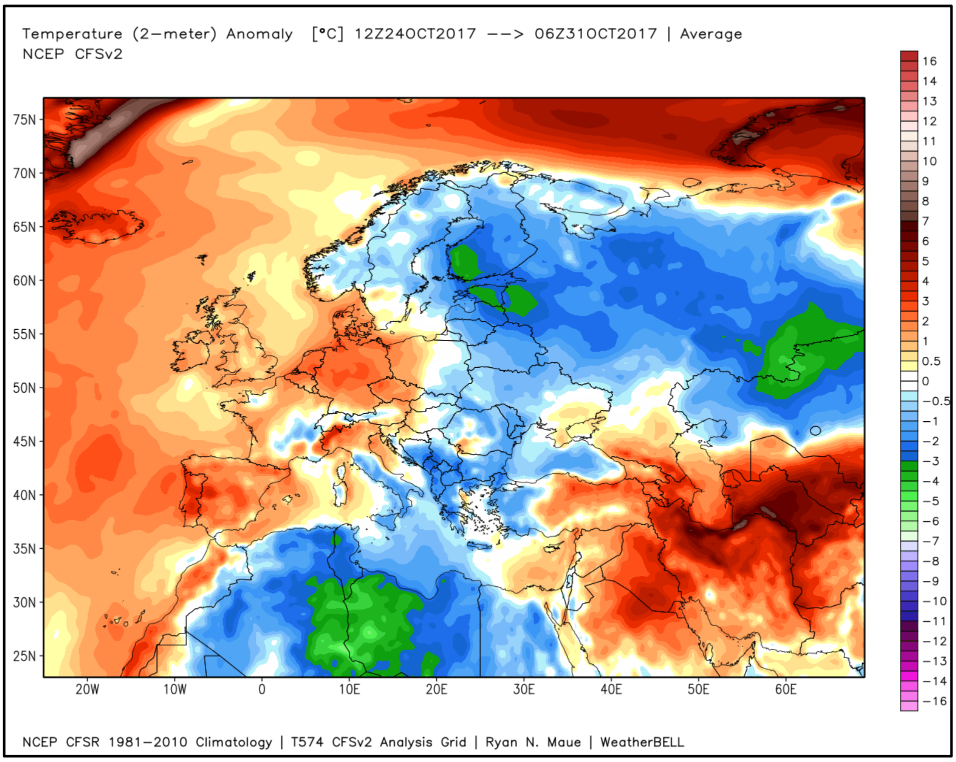


Fig.6-46.The thermal difference between the western Alps overheated by the föhn (anomalies between +2 and +3 °C) and the cooler Central-Southern Italy (anomaly about -1 °C) for the northern air flows was particularly appreciable in the last week of October 2017- source: (SMI-www.nimbus.it taken from weatherbell).

While in the North-East, in Emilia and on the Tyrrhenian side the drought was concentrated between winter, spring and summer 2017, abating almost everywhere in September, in the North-West the rainfall deficit worsened between September and October (Cat Berro and Mercalli, 2017).

In fact, in Turin from 1 July to 31 October 2017, only 101 mm of water was measured, an amount equal to just 35% of the 1981-2010 average. In the same period, only in 1832 and 1871, it rained even less, but at the time the average temperatures were 2-2.5 °C cooler than this year, evaporation from the soil was therefore more moderate and the effects of drought on the territory probably less marked (Cat Berro and Mercalli, 2017).

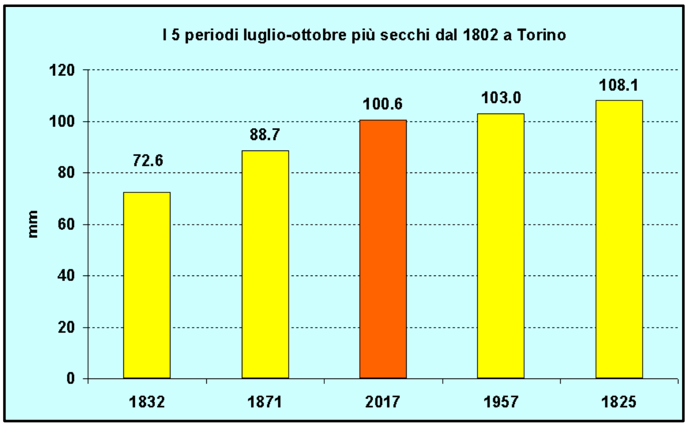


Fig.6-47.The five driest July-October periods since 1802 in Turin_the case of 2017, with 100.6 mm, ranks third among the most critical, but also considering the aggravating effect of higher temperatures and increased evaporation, it could be the case of autumn drought with the most significant effects on the territory_Source:(SMI-www.nimbus.it, 2017)

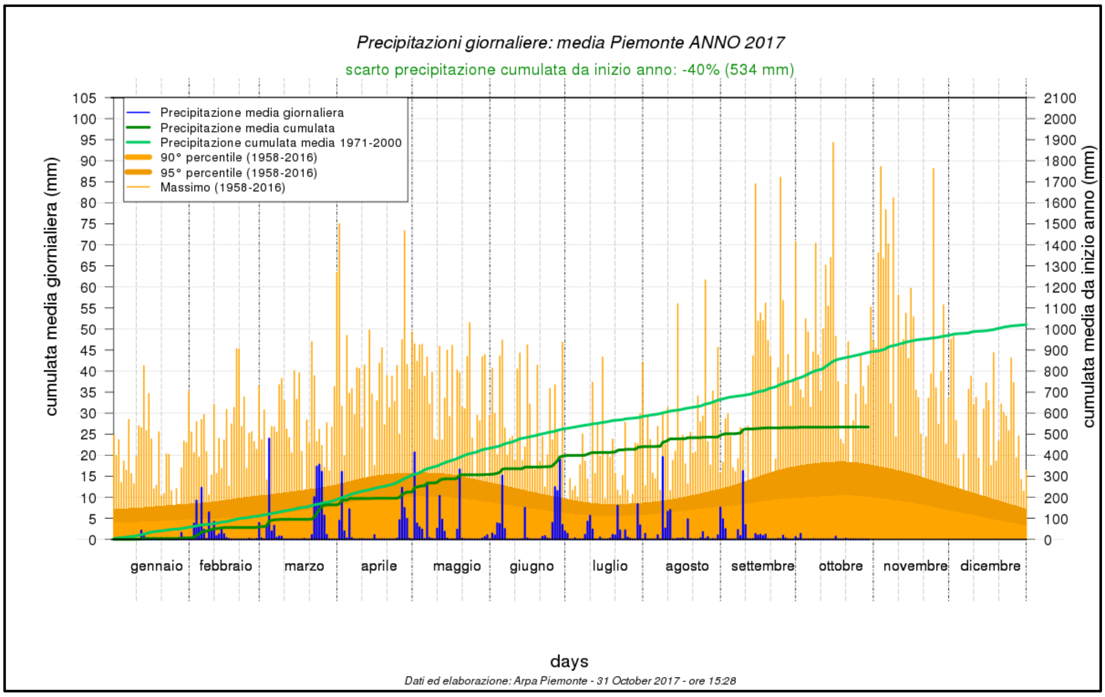


Fig.6-48.Rainfall Deficit Anomaly in Piedmont. In Piedmont as a whole, an average of just 534 mm of rain and melted snow fell between January and October 2017 according to the widespread ARPA measurement network, with an overall deficit of 40% (in this case compared to the 1958-2016 average). The localities of southern Piedmont, subject to extreme drought already during the summer, contributed to this anomaly-Source:(SMI-www.nimbus.it, 2017)

The average cumulative rainfall of 2017 in Piedmont was approximately 700 mm and was lower than the 1971-2000 norm, with a deficit of approximately 351 mm, which corresponds to 33%; 2017 is the 4th driest year in the historical distribution of the years 1958-2017.

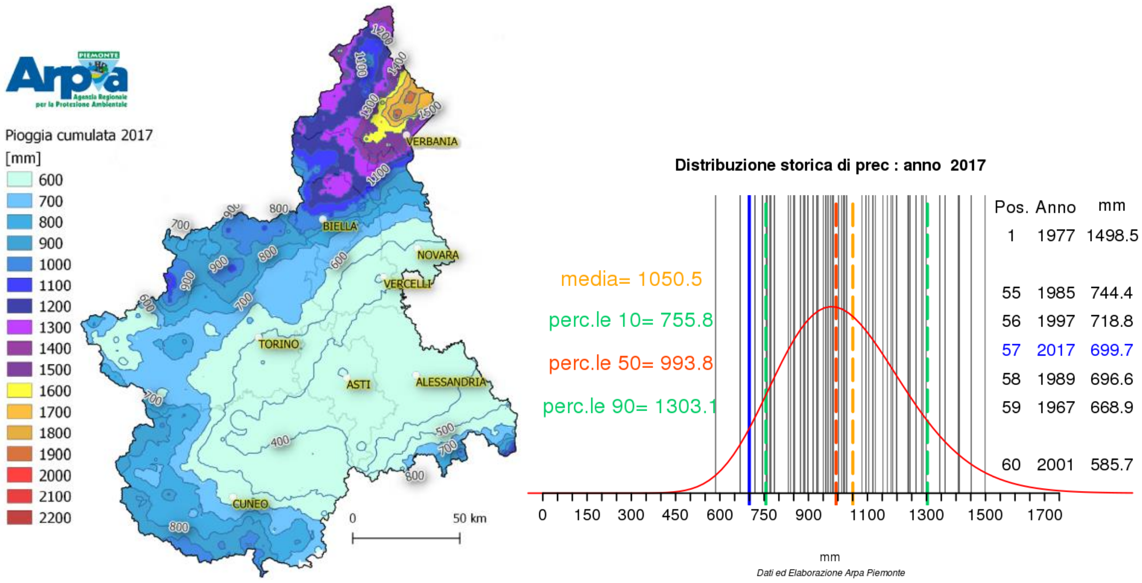


Fig.6-49.Cumulative annual value of the regional average precipitation in Piedmont in 2017 (Left) and its relative position in the historical distribution of the last 60 years (right)_Source: (Arpa Piemonte, Sistemi Previsionali, 2018)

	Anomalia (%)	Posizione	Media (mm)	% record	Luogo	Data ed ora	mm
Gennaio	-86	7° più secco	8.2	0			
Febbraio	-1	37° più secco	55.9	1			
Marzo	+30	16° più umido	105.1	15	Cicogna (VB)	23-mar-2017 12.:00 UTC	208.2
Aprile	-47	15° più secco	62.4	0			
Maggio	-34	25° più secco	86.5	1			
Giugno	-5	33° più secco	91.1	3	Monte Carza (VB)	28-giu-2017 21:40 UTC	177.6
Luglio	-27	15° più secco	44.2	1			
Agosto	-31	16° più secco	56.9	2			
Settembre	-38	16° più secco	39.5	1	Cicogna (VB)	10-set-2017 04:10 UTC	203.6
Ottobre	**-98**	**1° più secco**	**3.0**	**0**			
Novembre	-11	24° più secco	69.8	0			
Dicembre	+42	15° più umido	77.1	9	Piani di Carrega (AL)	11-dic-2017 23:00 UTC	271.6
Anno	-33	4° più secco	699.7	0			

Table 6-10.Monthly average cumulative rainfall in Piedmont. The anomaly is reported for each month percentage from the 1971-2000 norm, the position relative to the corresponding dryest or driest month rainfall of the entire time series, the percentage of weather stations that recorded theirs cumulative daily precipitation record, and finally where and when the most intense value was observed. In orange (dry) or blue (wet) the months in the top 10 historical positions, in bold those in the top three. Only stations active for at least 5 years are taken into consideration_Source: (Arpa Piemonte, Sistemi Previsionali, 2018)

The long dry autumn period is particularly significant, precisely in that part of the year with the wettest climate in Piedmont. Starting from 11 September and up to 4 November, a day with an average precipitation exceeding 5 mm was never observed in Piedmont. This meteorological drought lasting 55 consecutive days also affected all activities related to the availability of water resources (Arpa Piemonte, Sistemi Previsionali, 2018).

The peak of the rainfall deficit occurred at the end of October when all the water basins south of the Po were in conditions of extreme meteorological drought as can be seen from the 3-month SPI maps (Figure 8) (Arpa Piemonte, Sistemi Previsionali, 2018).

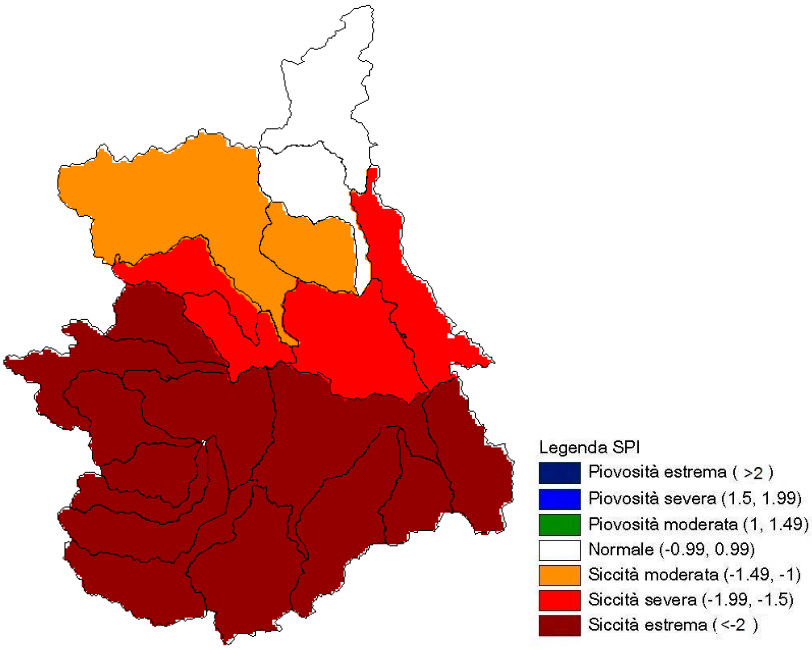


Fig.6-50.Severity of the SPI meteorological drought index calculated in October 2017 over a three-month period_Source: (Arpa Piemonte, Sistemi Previsionali, 2018)

In 2017 there were a total of 84 foehn days in the region.

gen	feb	mar	apr	mag	giu	lug	ago	set	ott	nov	dic
7	5	9	9	3	4	8	4	7	8	6	14

Table 6-11.Number of foehn days per month_Source: (Arpa Piemonte, Sistemi Previsionali, 2018)

6.3.2.Effects of Wildfire Event of 2017

Reports state that the wildfire of 2017 was probably the worst wave of fires that Piedmont has known at least in the last 50 years, comparable only to the crises of the föhn periods of 14-15 February 1990 (Prarostino fire, near Pinerolo, with dozens of houses destroyed) and 5 -7 February 1999 (large fire on Monte San Giorgio in Piossasco, victim of a young 22-year-old AIB volunteer, Davide Bertrand). Moreover, the unusual season in which the fires developed with such extension and violence was surprising: in the Alps, in fact, most of the episodes are generally concentrated between February and March, following the annual minimum of rainfall, with the undergrowth rich of dry biomass after autumn leaf fall and before the onset of (usually regular) spring rains (Cat Berro and Mercalli, 2017). In this section some other damages caused by the wildfire event of 2017 are reported. The main effects of wildfire can be categorised as **Forest Resources damage and loss of wooded areas**, **Human casualty**, **pollution** and **Debris flow**.

The **loss of wooded areas** by the fire seems to be very serious. the preliminary estimate was over 6200 hectares (> 62 km2) between Cuneo and Turin according to the EU-Copernicus satellite database, which however did not include the significant fires of Roure and Traversella, so the total could be more than 7000 hectares (> 70 km2), of which 2400 attributable to the largest fire in the area between Mompantero and Bussoleno (Val Susa) (Cat Berro and Mercalli, 2017).

As far as the human casualty concerns, In addition, a 28-year-old young man - Alberto Arbrile - died of a heart attack while he was cutting trees around his house in Cantalupa (near Pinerolo) to counter the advance of the flames, the destruction of rural mountain buildings, repeaters and lines electric (e.g. on the heights of Mompantero, Val Susa). The flames also touched the alpine shelters "Piazza" (Traversella) and "Melano-Casa Canada" (Frossasco), saved by the action of volunteers (Cat Berro and Mercalli, 2017).
The **wildfire delineation** product provides an assessment of the event's impact, its spatial distribution, and extent. The thematic layer has been derived from post-event satellite images by means of visual interpretation. The estimated accuracy is 5 m CE90 or better, from native positional accuracy of the background. 3 main data sources were used for the map including the pre-event image being the aerial orthoimage by e-Geos acquired on august 2012 with 0% cloud coverage, the Post-event image distributed by Airbus DS acquired on 30 October 2017 with 17.5% of cloud-coverage at 9.5 off-nadir angle provided under COPERNICUS by the European Union and ESA, abd Base Vector Layers from Geoportale Nazionale and inset maps and finally population data from 2010 along with the DTM layer. According to the map, the burnt area after the event covered from the east of the Susa Valley, the areas in the north of Bussoleno until the western sides, including the areas in the north of San Giuseppe, spreading in the northern forest areas (Copernicus Emergency Service, 2017).
Based on the results published by the Copernicus Emergency Service(2017), 2451.2 hectares of the affected area were burnt, affecting 3.6% of the population living in those areas_ a total of 678 inhabitants. The majority of the damage by the forest fire was to the local resources, in fact it caused damage to 4.8 hectares of residential areas, and 32 kilometres of the local roads. No highway, primary road, railway or bridges were damaged. However, it burnt 114 hectares of agricultural areas, 1283 hectares of forests and 990 hectares of vegetated area.

Consequences within the AOI	Elevation Contour (m)			
		Unit of measurement	Affected	Total in AOI
Burnt area		ha	2451.2	
Estimated population		No. of Inhabitants	678	19043
Settlements	Industrial	ha	0.0	46.9
	Residential	ha	4.8	743.7
Transportation	Highways	km	0.0	9.8
	Primary roads	km	0.0	36.8
	Secondary roads	km	0.2	99.2
	Local roads	km	32.0	361.0
	Railways	km	0.0	27.1
	Bridges	No.	0	20
Utilities	Sport and recreation constructions	ha	0.0	5.0
	Other civil engineering works not elsewhere classified	ha	0.0	6.1
	Constructions for mining or extraction	ha	0.0	1.8
	Dump site	ha	0.0	2.9
	Dam	No.	0.0	1.0
Land use	Heterogeneous agricultural areas	ha	114.2	2404.7
	Forests	ha	1283.4	5306.9
	Shrub and/or herbaceous vegetation assoc	ha	990.4	6208.3
	Open spaces with little or no vegetation	ha	63.2	1891.9

Table 6-12.The affected areas in the LandCover after the Event in wildfire 2017.Source: (Copernicus Emergency Service, 2017)

The wildfire caused significant **Air Pollution**. In a context of already high air pollution in western Valpadana due to the scarce mixing of the lower atmospheric layers in the long anticyclonic periods, in the days between 24 and 27 October 2017 the **dense particulate matter** due to the fumes of the fires in the Alps was added. The stagnant blanket of fumes almost obscured the sun and made the air unbreathable especially in the Pinerolo area, in the lower Valle Orco, in the lower Val Chiusella, but even in Turin, where on the morning of Friday 27, the plume of smoke from the fire on Rocciamelone, unusual ash falls to the ground were observed (about 45 km from the point of origin) (Cat Berro and Mercalli, 2017).

The ARPA Piedmont control units detected **exceptional concentrations of PM10 in the air** in the Turin area, with an average daily peak, also on 27 October, of 354 micrograms/m3 in Beinasco, the highest value in the regional series of air quality measurements beginning in 2000, 7 times higher than the threshold of 50 micrograms/m3 already considered unhealthy (details here). Even in the absence of a real entry of the föhn into the plain, the frontal passage from the North-West in the afternoon of the 27th allowed a partial mixing of the air and a general reduction in the quantities of particulate matter at low altitude, although still high. However, with the entry of weak currents from the east and the continuation of fires around Locana and Ribordone, the exceptional daily average of 179 micrograms/m3 at 1600 m in Ceresole Reale (Gran Paradiso) on 30 October could be noted (Cat Berro and Mercalli, 2017).

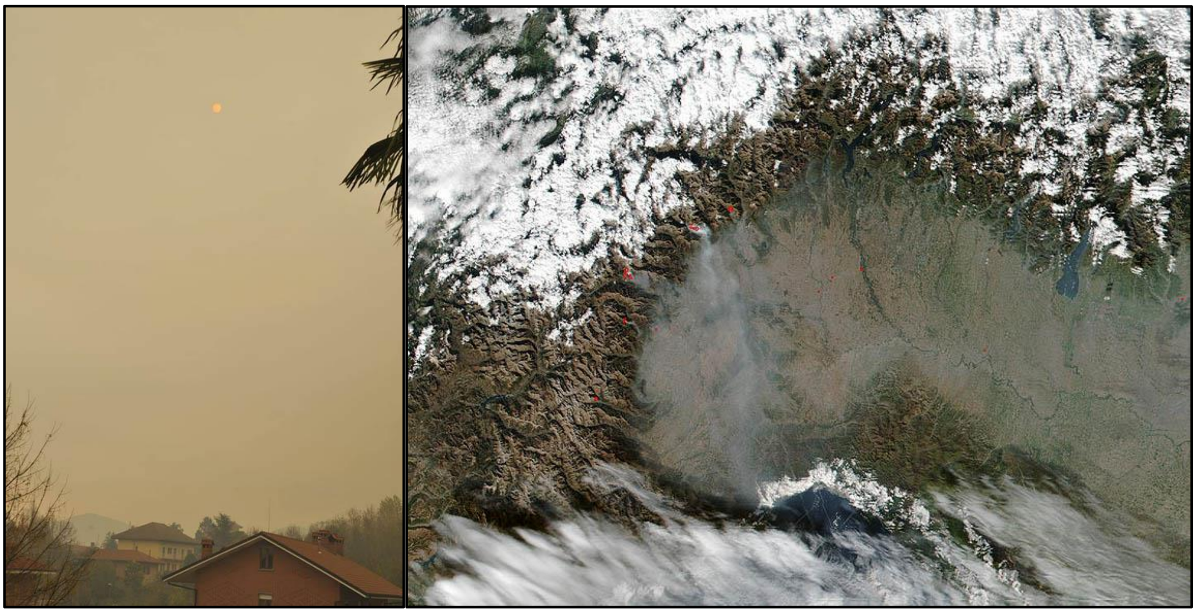


Fig.6-51.On 25 October 2017, the smoke from the fires around Cumiana almost completely obscures the sun in Giaveno- Source: (www.nimbus.com photo. Maurizio Tron).The fumes of the fires over western Piedmont in the satellite images respectively of 25 October (10:15 UTC, NASA-Terra, MODIS sensor) and 27 October 2017 (h 12:30 UTC, SNPP-VIIRS).Source: (www.nimbus.com taken from NASA-Earth Data).

Last but not least, the consequences of the wildfire continued in the subsequent years and they also caused a **Debris Flow**. In one case, on 07 June 2018 a debris flow, which originated in the "Comba delle Foglie" catchment basin, hit the town of the San Lorenzo hamlet in the municipality of Bussoleno (TO). There were no casualties. Several buildings were damaged or destroyed. A volume of sludge deposited in the fan is estimated to be between 15,000 m3 and 2,000 m3. The entire fan area was devoid of any structured form of water network for collecting rainwater. The main predisposing cause is the fire that occurred in autumn 2017 which affected a large area of the Val di Susa and which modified the geomorphology of the mountain slopes, making large quantities of mobilizable debris available. The main trigger was the series of rain events that affected the area in spring 2018, with rainfall rates of up to 100 mm/h (Pittarello, 2019).

Fig.6-52.Mompantero, 31 October 2017: the soil of the undergrowth covered by the fire, completely stripped of the litter and of the outcropping organic layer, and reduced to a fragile and arid surface dangerously susceptible to erosion in the event of heavy rains in the coming months_Source:(f. Daniele Cat Berro, www.nimbus.com, 2017).

7.Proposed methodology and workflow for the automatic extraction of data in a Wildfire Digital Twin Framework

The research goal for the current thesis is to provide an automatic extraction procedure using Google Earth Engine and using available open-access EU datasets. This chapter, after a brief part dedicated to the potential applications of a wildfire DT (Section 7.1), covers the technical steps towards achievement of the above mentioned target including the calculation of AOI, image retrieval, index calculation, statistical calculations such as pixel distribution, time series scatter plot for trend studies and surface area covered.
Technical activities conducted during the research include the creation of algorithms utilising the datasets and functionalities available by Google Earth Engine (GEE) environment for automatic/semi-automatic extraction of burned areas, burn severity, and vegetation recovery.
Based on these algorithms, a further statistical analysis has been developed to understand the results better and have a more accurate interpretation of the obtained images.
Finally 3D models of all the index images have been created using QGIS version 3.28.3 to provide a more comprehensive understanding of the situation.

7.1.Potential Applications for Wildfire Digital Twin

As it has been mentioned previously in **chapter 02(Section 2.7.7)**, to correctly predict the behaviour of the fire and its effects on the environment and communities nearby, a wildfire digital twin should include a broad variety of data and modelling techniques. Some of the main themes for wildfire digital twin include **Terrain and Vegetation** (to predict the path of the fire and the at-risk areas), **Weather Condition** (real-time weather data to model how the fire would spreading different conditions i.e. Wind direction and speed, temperature and humidity etc.), **Fire Behaviour** (to model the behaviour of fire in different condition by taking into account the fire intensity, flame length, rate of spread and fireline intensity), **Fire Suppression** (to monitor the effectiveness of different types of fire suppression techniques), **Emergency Response** (to model the probable response of the emergency services namely the fire departments, police, medical personnel to manage the wildfire response), **Evacuation Planning** (can be used to simulate scenarios including likely paths of the fire and the best evacuation routes for people and vehicles), and **Damage Assessment** (to model the extent of the damage and help with recovery and reconstruction efforts).

7.1.1.1.The Wildfire Damage Assessment Digital Twin: Possible Use-Cases

The Wildfire digital twin for which the framework would be defined for the current research is the Wildfire Damage Assessment Digital Twin. This thematic digital twin can be possibly used in a variety of assessment processes from evaluating the physical or financial damage to human casualty, or identifying risky areas, identification of causes of the damage (vegetation cover, climatic reasons, human activities etc.) in order to help the decision makers and other stakeholders have a more accurate and efficient judgement, leading to better coordinations between organisations and forces involved.

1.Evaluating the Extent and Costs of Damage: A digital twin for a wildfire damage assessment can be a useful tool for determining the extent of the fire's damage and disturbance including the number of structures/buildings/facilities destroyed, the amount of land burned and would help with assessing the cost of these damages and disruptions.

2.High-risk Zone Identification: A digital twin can assist in identifying the regions most at risk for wildfires by analysing data on wildfire damage. This information can be used to prioritise wildfire prevention efforts and guide decisions about land use planning.

3.Mitigation Strategies Assessment: The effects of various fuel reduction techniques or prescribed burns, among other wildfire mitigation methods, can be replicated using a digital twin. This can assist land managers in identifying the best methods for lowering the danger of wildfires.

4.Post-Fire Recovery Support: Communities can use a digital twin to plan their post-wildfire recovery and development efforts. A digital twin can support targeted and effective recovery efforts by accurately estimating the degree of harm and destruction.

5.Burn Severity Mapping and Burned Area Mapping: A digital twin can be used to map the degree/severity of burn in various wildfire-affected regions. Prioritising **post-fire recovery initiatives** like **reforestation**, **soil erosion control**, and **habitat restoration** can be made easier with the aid of this knowledge.

6.Assessment of Structural Damage: The structural harm brought by the fire to buildings and other infrastructure can be evaluated using a digital twin. This can help identify the buildings that require maintenance or reconstruction and can offer crucial information for insurance and relief efforts.

7.Vegetation Recovery: The regrowth of vegetation in the burned-out regions can also be modelled using a digital twin. Decisions regarding post-fire management can be based on this knowledge, which can also assist in predicting the long-term effects of the fire on the ecosystem.

8.Risk Assessment: Based on elements like vegetation type, topography, and weather conditions, a digital twin can be used to evaluate the risk of subsequent fires in the affected regions. Making decisions about land management and setting priorities can both benefit from this knowledge.

9.Used as an Archive: The wildfire digital twin can be a place where all the documents and analysis related to wildfires in a certain area are archived, making it easy for further studies and mitigation and preventive plans.

The present research provides the preliminary resources for Burn Severity Mapping and Burned Area Extraction Mapping and Vegetation Recovery.

7.1.3.Possible Sensors for the Damage Assessment Wildfire Digital Twin

In order to create a digital twin for a wildfire, a variety of information is required to gather all different possible types of information. Unmanned Aerial Vehicles (i.e Drones), equipped with cameras or sensors, **IOT Devices** including **Weather sensors**, **Smoke detectors**, **Soil moisture sensors**, **Hydrological Monitoring Sensors**, and **the satellite imagery** are the main sensors used.
Current research focuses on developing methodology for extracting burned areas and burn severity and vegetation recovery, using Satellite Imagery with Sentinel 2 Sensor.

Sensor	Sub-Category	Use Case
UAV_Drones	Equipped with high resolution cameras	In order to generate 3D models and maps of the burn region, the sensors collect aerial images of the wildfire-affected area. The 3D models can be used to determine the size of the wildfire's damage, the locations of burned-out buildings, and the topography of the affected region.
	Equipped with sensors that can detect the presence of hotspots (Potential threat for reignition)	Everyone involved can receive more precise and timely information by updating the digital twin with the real-time data collected from the drones.
IoT Devices	Weather sensors	To track temperature, humidity, wind speed, and other weather conditions in regions that are prone to wildfires, IoT weather sensors can be installed. This information can be used to forecast when a wildfire will commence and to estimate the potential damage it might cause.
	Smoke detectors	To detect the presence of smoke and notify firefighters and other first responders of the location of a wildfire, smoke detectors can be linked to the digital twin.
	Camera networks	To check for smoke and flames, IoT-enabled cameras can be installed in wildfire-prone regions. This information can be used to assess the damage caused by wildfires as well as to rapidly discover and respond to them.
	Soil moisture sensors	The moisture content of soil and vegetation can be monitored using IoT-enabled soil moisture monitors. The potential spread of a wildfire can be predicted using this data, and its potential harm can be calculated.
	Hydrological Monitoring Sensors	Hydrological Surveillance IoT sensors can offer useful data for evaluating the harm produced by wildfires. The use-cases include Water Quality Monitoring (due to increase in the sediments and pollutants in water after WF), Flood Warning(due to lack of vegetation and increase of runoff water), Post-Fire Recovery(by monitoring water level, soil moisture etc),
Satellite Imagery and LiDAR data	Landsat, Sentinel2, VIIRS, MODIS	Burn Severity, Extent of fire, Post-fire Recovery, Burned Area mapping, soil moisture, tree mortality, soil erosion, vegetation recovery.

Table 7-1.The sensors that can be used to build a Wildfire Damage Assessment Digital Twin at the Tree level_Source:(Author)

7.2.Workflow

Since wildfires often occur nearby human settlements, involving at least the urban fringe, making settlements resilient to natural disasters is becoming a top concern for many local governments. Natural disasters have been in the spotlight, becoming a key issue for towns as they become resilient, in addition to the ongoing stressors that governments must manage, such as social, economic, and financial ones.

By creating a digital twin, cities can find solutions to their complex problems. A digital twin is a depiction of the area with the different types of information from various sources, helping to observe, analyse, manage, predict and prevent the upcoming events.

Current section tries to illustrate a possible framework for a wildfire digital twin that would be the big picture for the present research. The suggested digital twin consists of 3 main data types, namely “Fire Risk Assessment Data”, “Remote Sensing Data” and “Administrative Data” such as reports. Some of these steps in the workflow have been covered in the previous chapters and this chapter continues to work exclusively on Remote Sensing Data types.

For implementation of the wildfire digital twin, the following workflow can be adopted:

1. Identification of the main stakeholders and users of the intended digital twin and their needs and *desiderata*
2. Identification of the specific data types and data sources/ organisations and stakeholders involved (Chapter 07 and 08)
3. Historical studies of the area based on the available documents and open data (chapter 06)
4. Identification of the technology to calculate the post-fire burnt area (Chapter 07).
5. Automation/semi-automation of remote sensing analysis task using Google Earth Engine (GEE) platform incorporating remote sensing and machine learning methodologies for index analysis and QGIS for 3D modelling (chapter 07)
6. Identification of the challenges (Chapter 08).

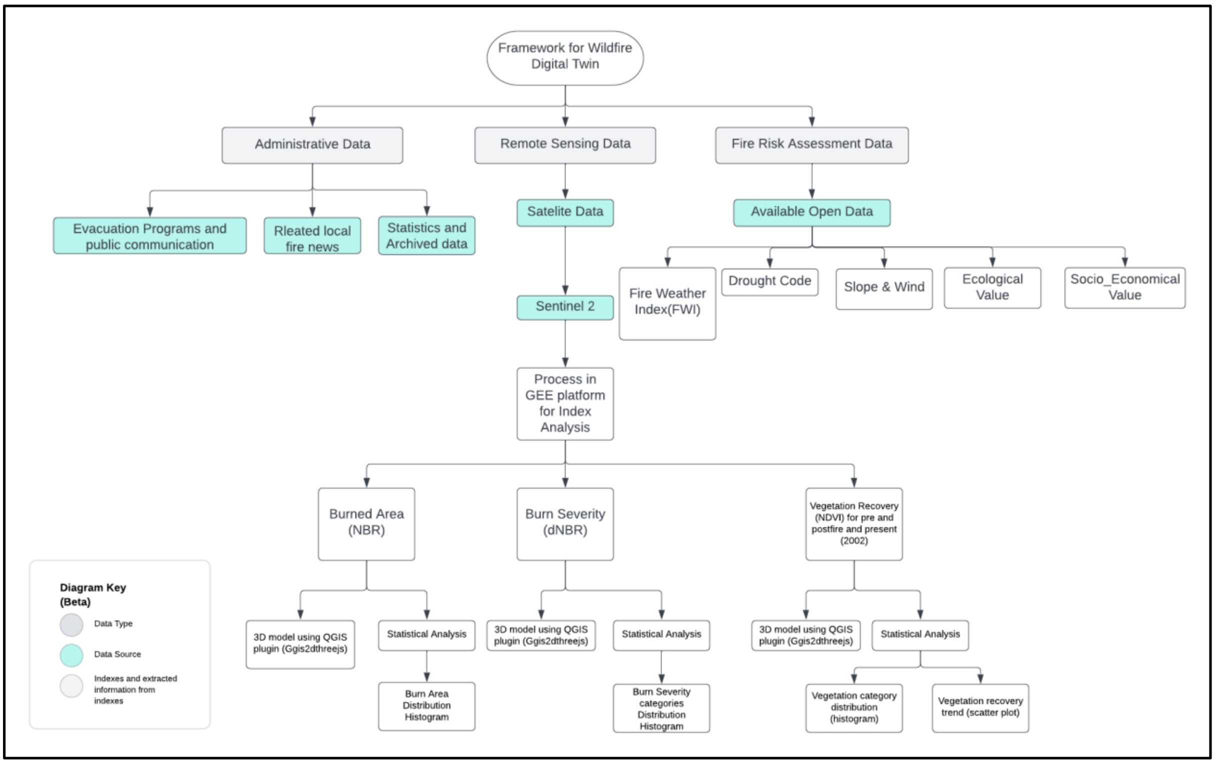


Fig.7-1.Proposed workflow for the implementation of a wildfires DT_Source: (Author)

7.3.Data gathering (automatic extraction of satellite images)

7.3.1.Defining the Area and the Period of Analysis

The area of analysis is considered as a rectangle drawn on the location in which Susa Valley is located, the area is adapted from the **CEMS boundary (AOI)** and **delineation map** from **CEMS shapefile**. Focusing on the area, it can be roughly depicted as San Didere from the eastern side, Margone on the northern side, Mattie on the south and Giaglione on the western side. In precise terms, it can be specified using the following coordinate points in the provided snippet. The values inside the bracket indicate the Latitude and Longitude of the points corresponding to each angle of the region of interest.
In order to import the area of analysis, the following script can be utilised:

```
var CEMS-AOI=
       ee.Geometry.Polygon(
        [[[7.003083958928165, 45.21869339705463],
          [7.003083958928165, 45.110246992050875],
```

```
          [7.219377293889102, 45.110246992050875],
          [7.219377293889102, 45.21869339705463]]], null, false),
affectedAreaCEMS =
ee.FeatureCollection("users/ZamariMaryam/EMSR253_02SUSA_DEL_v2_observed_even
t_a");
```

Alternatively, it is possible to draw using the drawing tools provided by google earth engine. However, to replicate the same Region of Interest, it is preferable to use the script.
The “false” parameter in the above code snippet refers to the “geodesic” attribute in GEE. For geometries like points, lines, polygons, and circles, the geodesic parameter decides whether to use geodesic measurements (i.e., measurements on a curved Earth surface) or planar measurements (i.e., measurements on a flat map projection).
Planar measurements are used when geodesic is set to false, which is suitable for small areas on a generally flat surface. Geodesic measurements are used when the parameter is set to true, which is suitable for large areas or regions with considerable curvature. In our situation, setting it to false makes the most sense in terms of the reasoning. Fig.7-2 demonstrates the area of analysis along with the CEMS fire delineation geometry.

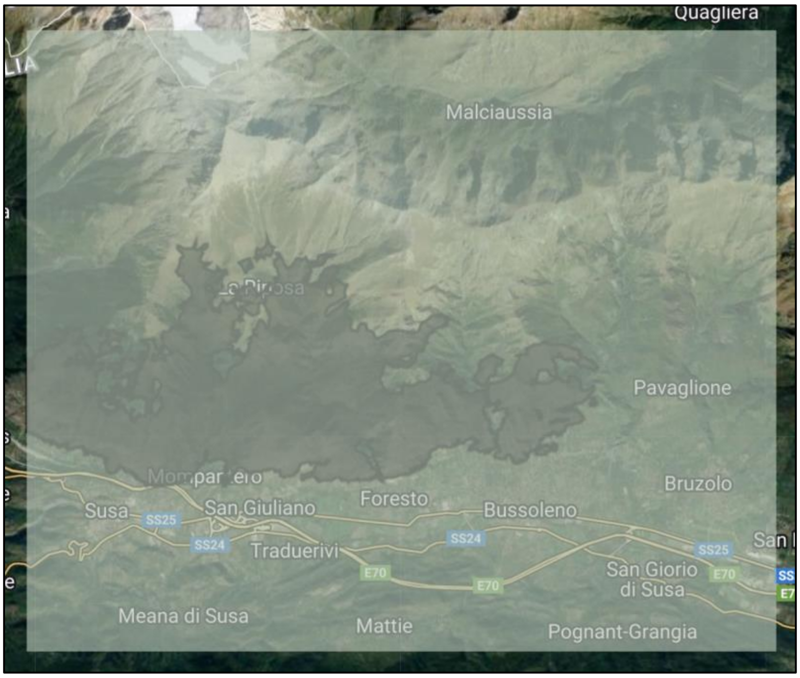


Fig.7.2.Area of Analysis and CEMS Delineation Boundary_Source:(Author)

7.3.2.The Datasets used for the Image Analysis

The datasets for the current research have been selected from the Sentinel-2 mission. Sentinel-2 (S2) is a global 5-day revisit frequency, high-resolution, multispectral imaging project. The S2 Multispectral Instrument (MSI) collects data in 13 spectral bands at three geographic resolutions: visible and NIR at 10 metres, red edge and SWIR at 20 metres, and atmospheric bands at 60 metres. It offers statistics that can be used to evaluate the condition and evolution of the vegetation, soil, and water cover.
The product used from this mission is Surface Reflectance, with availability of the images from **2017/03/28** till Present.

7.3.3.The Periods of Analysis

The period of analysis for the index calculation is one of the main parameters to be considered, since it would determine the condition in a given moment, or the seasonal changes in the region of interest.
For calculation of the Burned Areas (**NBR** index), two dates for pre-fire and post-fire are needed, which have been chosen very close to the date of calculation of Copernicus EMS Delineation map for the fire event of 2017. The pre-fire and post-fire dates for the EMS delineation map were respectively **20/08/2012** and **03/11/2017**.
For index calculation of this research, the collection has been filtered with **('2017-04-01' , '2017-06-20')** as start and end dates, and an image with the sensing date of **2017/06/19** has been selected for calculation of the NBR pre-fire event, and **('2017-10-30' , '2017-11-20') date filter** resulting in an image with **2017/11/16** date for Post-fire NBR is selected. The same images were utilised for **Burn Severity** analysis.
All the images except the pre-fire image used for NDVI (2017/07/04), have been extracted from the **Sentinel 2 Level-2A orthorectified atmospherically corrected surface reflectance** dataset. However, for the case of that specific image, because of the unavailability of an image with lower cloud percentage in the Level-2A dataset, the **Level-1C orthorectified top-of-atmosphere reflectance** dataset is used.

Regarding the vegetation recovery calculation, for which **NDVI** index is calculated, 3 different time-frames have been considered, corresponding to three years representative for the pre, post and current -event situation, but always considering the same season (i.e. June), that should guarantee to have the same vegetation condition during the most active moment of the phenological cycle. Considering the Alpine region season for vegetation, the period of May/June had been considered, the collection was filtered by **('2017-06-20', '2017-07-10')**, **('2018-05-01 ', '2018-06-20')** and **('2022-05-01' , '2022-06-20')** start and end periods and 3 images were finally selected, with the following dates: **2017/07/04** for the **pre-fire**, **2018/06/19** for **post-fire** and **2022/06/18** for **current condition.** These images were processed in order to obtain NDVI values of the AOI for, respectively, the pre-fire, post-fire and Present situation, and thus provide an overview of the vegetation recovery.

7.4.Performed Analysis: Index Calculation Process

This section explains the process of analysing satellite images for the purpose of index calculations. The indexes calculated for the research include Normalised Burn Ratio (NBR), dNBR(for Burn Severity) and Normalised Differential Vegetation Index (NDVI) that would help us with the vegetation recovery tracking.

7.4.1.Satellite Image Preprocessing and Data Selection

We need to apply a set of procedures to the raw satellite data in order to prepare it for further analysis and interpretation because the raw satellite data frequently contains different types of distortions, noise, and other artefacts that can affect the accuracy and reliability of later analysis. The accuracy and dependability of subsequent analysis can be significantly impacted by preprocessing, making it a crucial stage in the analysis of satellite imagery. Preprocessing correctly can help to lessen noise and artefacts, boost image quality, and increase the information content of the data.
Preprocessing steps can include various corrections such as radiometric and geometric corrections, atmospheric correction, image registration and mosaicking, and noise reduction. For the purpose of the analysis in our case, a filter for Cloud Pixel Percentage is applied and set to 20%, to filter the available data further for less cloudy images in the resulting collection. The collection is further filtered by the dates (see section 7.2.3 for Date filters).

```
var sentinel2= dataset
                  .filterDate('2022-05-01','2022-06-20')
```

```
                   .filterBounds(roi)
                   // Pre-filter to get less cloudy granules.
                   .filter(ee.Filter.lt('CLOUDY_PIXEL_PERCENTAGE',20))
                   .select(['B4','B3','B2','B8','B12']);

print(sentinel2);
```

The print() method shows the resulting image collection (all the images in the database corresponding to the filters declared) under the “Features” parameter in the Console of GEE.

7.4.2.Image Search and Preprocessing

The image list resulting from the collection is further investigated to select the image that covers all the areas of analysis (not all the images resulted after filtering cover the AOI). In GEE each image is selectable using its ID. The structure of the EE asset ids for Sentinel-2 L2 assets is **COPERNICUS/S2_SR/20151128T002653_20151128T102149_T56MNN**. Here, the first numeric component denotes the date and time of sensing, the second numeric component denotes the date and time of product production, and the last 6-character string is a special granule identifier denoting its UTM grid reference.

Each single image is loaded in the platform to visualise and be selected (See code snippet below). After the image selection, it is possible to proceed to index calculation.

```
var image =
           ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
'20220618T102559_20220618T103528_T32TLR')
             .select(['B12','B8','B4']);

Map.centerObject(geometry);
Map.addLayer(image);
```

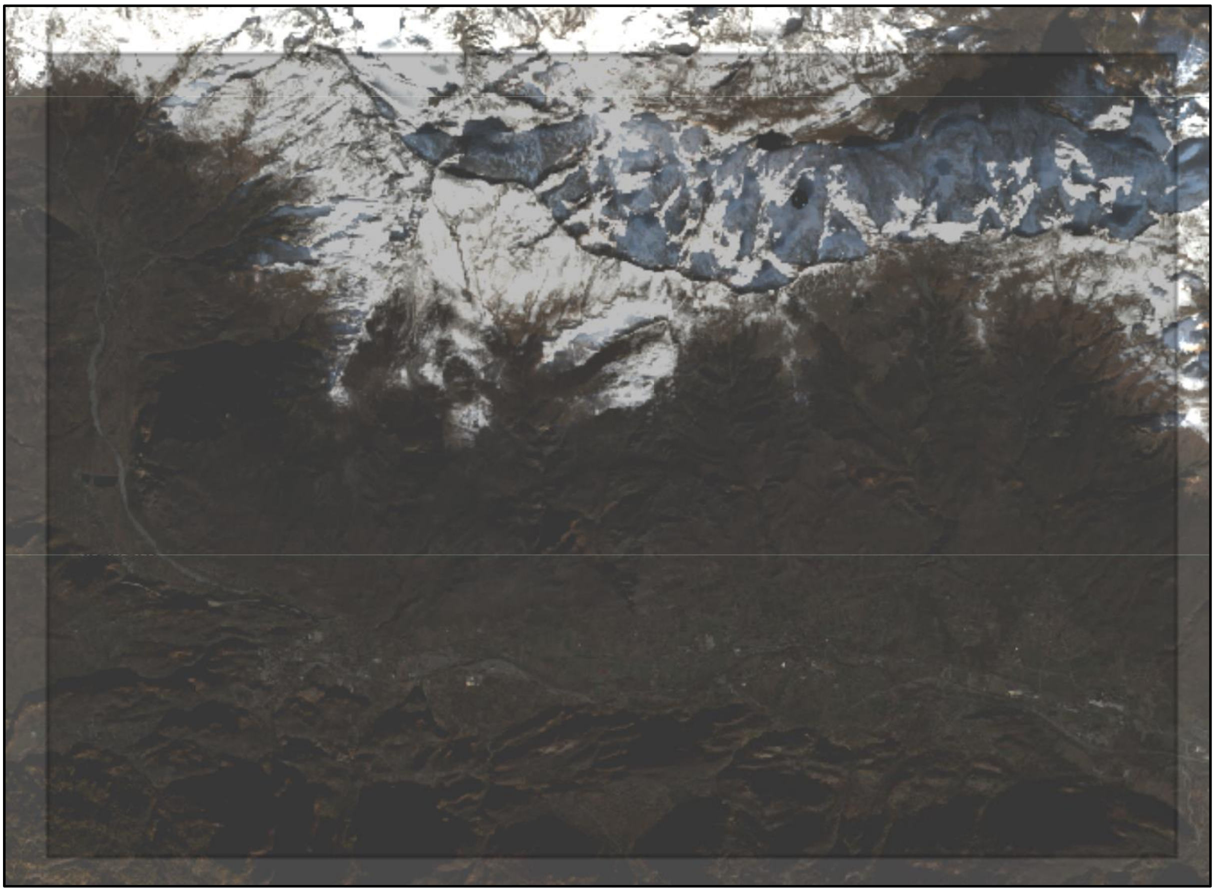


Fig.7-3.True colour representation of the resulting image for the area of analysis, before filtering for the necessary bands for the index. R:B4, G:B3 , B:B2 are the band combinations for Sentinel 2 data sets_Source:(Author)

In the case that no single image covering the whole area of analysis was found, it is necessary to do the analysis on a collection of images that were sensed in a suitable time period for the analysis. One of the benefits of this method is that the manual work that would go into searching the image would be eliminated and the process can be considered fully automatic, however for the events that are time-sensitive, the results would be a bit affected by the fact that the values of pixels might change, since the resulting image would be a **median** of all the images that have been sensed over that period of time. In order to minimise the faults, it is better to define a short period of time for the start and end date of image collection.
In case of the pre-fire NDVI, because of unavailability of images with lower cloud cover in GEE platform for the Bottom of Atmosphere/surface reflectance image, the image was downloaded as the C1 level (Top of atmosphere). In this case, there was a need to do the preprocessing for atmospheric correction to reduce the faulty values. The below code demonstrates this process:

```
//recalling the image
  var imageTOA = ee.Image('COPERNICUS/S2_HARMONIZED/' +
'20170704T103019_20170704T103637_T32TLR');

 //Importing the SIAC atmospheric correction module
var siac = require('users/marcyinfeng/utils:SIAC');
var imageBOA = siac.get_sur(imageTOA);

print('image BOA: ' , imageBOA);
```

Figure (7-4) and figure (7-5) depict the **Level C1 (top of atmosphere)** image and the **Level 2A** image generated after the **atmospheric corrections.**

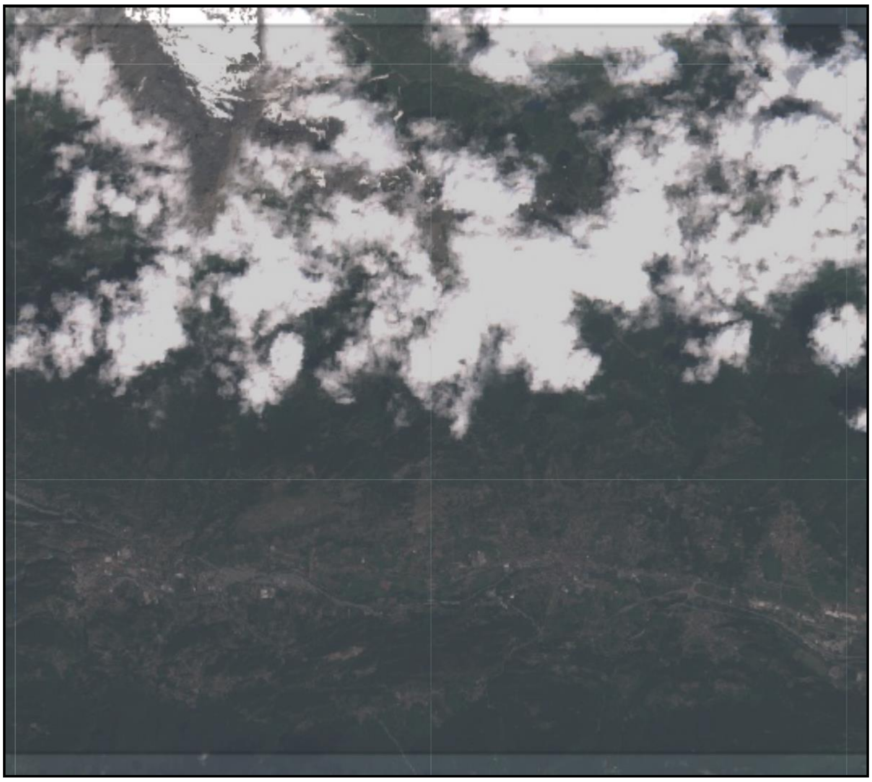


Fig.7-4.True colour representation of the Level C1 (TOA) image, for pre-fire situation sensed in 2017/07/04_Source:(Author)

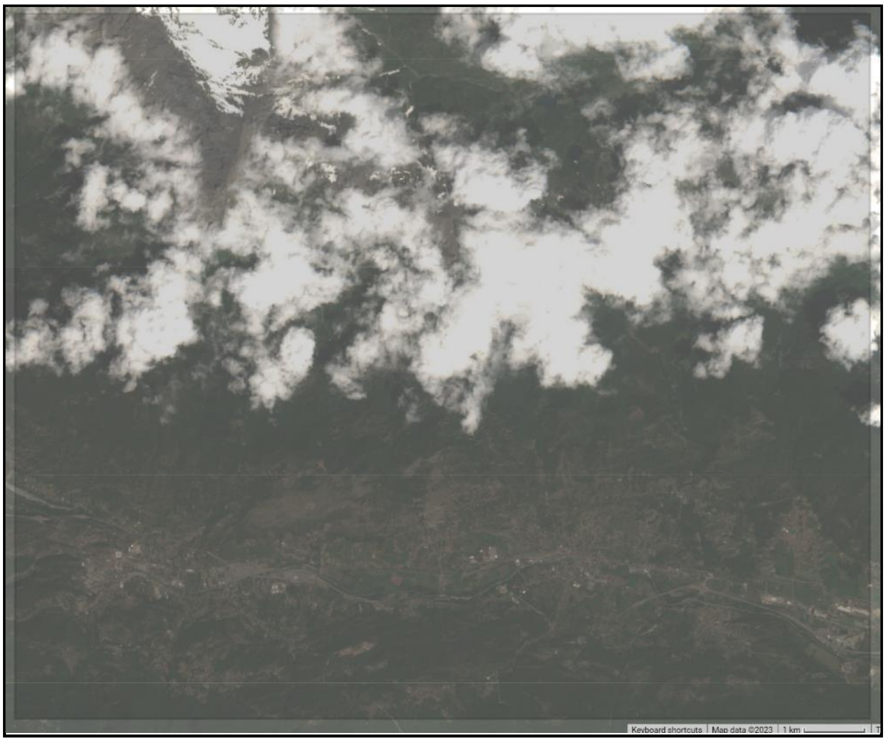


Fig.7-5.True colour representation of the atmospherically corrected image, for pre-fire image sensed in 2017/07/04 _Source:(Author)

7.4.3.Index Calculation: Pre-fire (2017)

7.4.3.1.Vegetation health (NDVI)

Normalised Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between **near-infrared** (which vegetation strongly reflects) and **red light** (which vegetation absorbs)(GIS Geography, 2022). NDVI always **ranges from -1 to +1**. But there isn't a distinct boundary for each type of land cover. It is calculated using the following formula.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

NDVI can be used to monitor vegetation health and detect changes over time, but it is less useful for assessing fire damage, which typically results in the complete loss of vegetation and for damage assessment NBR is a more direct way to check for damages done. It is calculated using the red band (B4 in Sentinel 2) and the Near Infrared (B8 in Sentinel 2).

In the case of pre-fire NDVI calculation, a variety of periods of time have been searched (all in May-June-July time-period) to finally achieve a result with less cloudy conditions **(less than 20%).** The image selected for pre-fire NDVI calculation was sensed in the date of ***2017/07/04*** which is a suitable date for vegetation assessment in the Alpine region, with the image-id of **"20170704T103019_20170704T103637_T32TLR"**. In the first step, the image was recalled from the database and was filtered by the necessary bands.The defined expression then was applied to the image and the resulting image was called NDVI, memorised inside the "bandIndexImage".

```
var image = ee.Image('COPERNICUS/S2_HARMONIZED/' +
'20170704T103019_20170704T103637_T32TLR')
                   .select(['B4','B3','B2','B8','B12']);

//----- Expression using image band indices to calculate NDVI ----------
var bandIndexExp = '(b("B8") - b("B4")) / (b("B8") + b("B4"))';
var bandIndexImg = image.expression(bandIndexExp).rename('NDVI');

//---------------------Visualisation phase -----------------------------------
//Initial Visualisation parameters for NDVI.
var ndviVis = {min: -1, max: 1 , palette:['#000000','#a50026','#d73027',
'#f46d43', '#fdae61', '#fee08b', '#ffffbf', '#d9ef8b', '#a6d96a', '
      #66bd63', '#1a9850', '#006837']};

Map.centerObject(geometry);
Map.addLayer(bandIndexImg , ndviVis, 'NDVI1');
```

Fig(7-6) demonstrates a preliminary and unclassified visualisation of the resulting NDVI image.

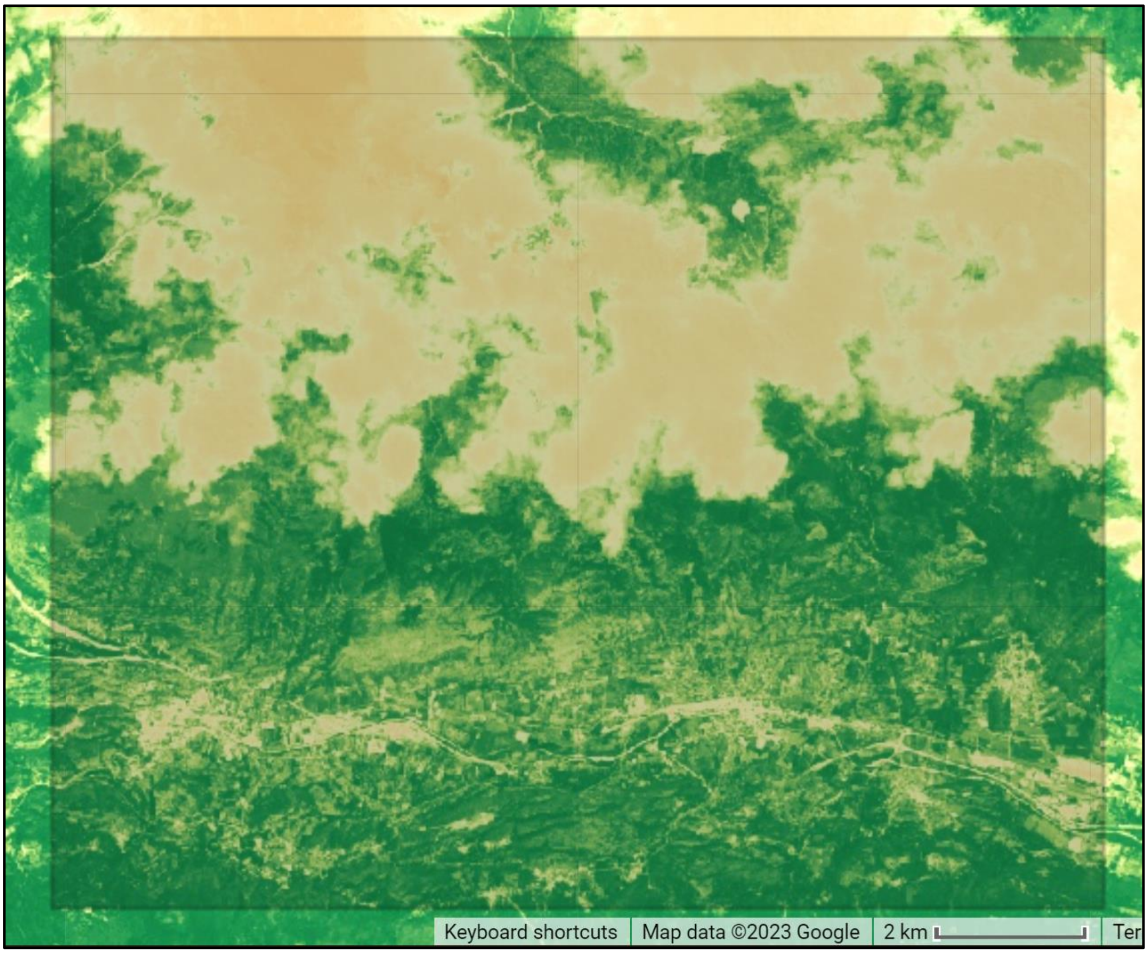


Fig.7-6.unclassified NDVI pre-fire image_Source: (Author)

The final stage was to define the visualisation parameters for the NDVI, considering the range of values (-1 to 1), and In order to have a more accurate interpretation, a colour palette was associated with each part of the spectrum. For this purpose, 12 appropriate thresholds have been defined for generating the algorithm that would process and categorise the image for the visualisation, each of them representing a distinct category of vegetation status. The thresholds and their associated symbologies have been adapted from the Sentinel Hub website and incorporated into the research starting from -0.2 and ending with 1.0, and for the interpretation of each threshold the field knowledge of the experts has been taken into consideration. The following table summarises the symbology , and thresholds and the interpretation of each of them.

Colour		NDVI Range	Interpretation/Classification
	#000000	NDVI < -0.2	Areas with little to no vegetation cover, such as bare soil, water bodies, or urban areas.
	#a50026	-0.2 < NDVI ≤ 0	areas with little to no vegetation cover, but may include some sparse vegetation, such as grasslands or shrublands.
	#d73027	0 < NDVI ≤ 0.1	with low vegetation cover, such as sparsely vegetated areas, degraded lands, or recently disturbed areas.
	#f46d43	0.1 < NDVI ≤ 0.2	areas with moderate vegetation cover, such as croplands, grasslands, or forests with low leaf density.
	#fdae61	0.2 < NDVI ≤ 0.3	areas with moderate to high vegetation cover, such as grasslands, forests, or croplands with moderate leaf density.
	#fee08b	0.3 < NDVI ≤ 0.4	areas with high vegetation cover, such as dense forests, croplands with high leaf density, or wetlands.
	#ffffbf	0.4 < NDVI ≤ 0.5	areas with very high vegetation cover, such as mature forests, dense wetlands, or highly productive croplands.

Colour		NDVI Range	Interpretation/Classification
	#d9ef8b	0.5 < NDVI ≤ 0.6	areas with extremely high vegetation cover, such as dense tropical rainforests or other ecosystems with high biomass
	#a6d96a	0.6 < NDVI ≤ 0.7	areas with very dense vegetation cover, such as old-growth forests or other ecosystems with high biomass.
	#66bd63	0.7 < NDVI ≤ 0.8	areas with extremely dense vegetation cover, such as old-growth forests or other high biomass ecosystems.
	#1a9850	0.8 < NDVI ≤ 0.9	areas with near-optimal vegetation density and productivity, such as highly productive croplands or other ecosystems with high biomass.
	#006837	0.9 < NDVI ≤ 1.0	areas with optimal vegetation density and productivity, such as highly productive croplands or other ecosystems with high biomass.

Table 7-2.Thresholds and interpretations for NDVI images_Source:(Author)

In order to automate the process of classification, an algorithm was developed that would analyse the resulting NDVI image based on the threshold values and classify them based on the ranges. This algorithm created a classified image, assigning a number to each class based on which threshold each pixel would be associated with. This number was finally used to visualise the image (each number was associated with a colour). The algorithm is lastly applied to the previously calculated NDVI image. The following code snippets demonstrate the process:

```
// algorithm that creates a classified image based on NDVI ranges, implemented on the
NDVI image previously calculated by the formula
var ndvi_classified = bandIndexImg.expression(
  "(b('NDVI') < threshold_noVegetation) ? 0" +
    ": (b('NDVI') <= threshold_sparseGrassland) ? 1" +
    ": (b('NDVI') <= threshold_degradedLandsRecentDisturbed) ? 2" +
    ": (b('NDVI') <= threshold_moderateVegCover) ? 3" +
    ": (b('NDVI') <= threshold_moderateHighVegCover) ? 4" +
    ": (b('NDVI') <= threshold_highVegCover) ? 5" +
    ": (b('NDVI') <= threshold_veryHighVegCover) ? 6" +
    ": (b('NDVI') <= threshold_extremHighVegCover) ? 7" +
    ": (b('NDVI') <= threshold_veryDenseVegCover) ? 8" +
    ": (b('NDVI') <= threshold_extremDenseVegCover) ? 9" +
    ": (b('NDVI') <= threshold_nearOptimalVegCover) ? 10" +
    ": (b('NDVI') <= threshold_optimalVegCover) ? 11" +
      ":12" //unclassified
  , {

     threshold_noVegetation : threshold_noVegetation ,
     threshold_sparseGrassland : threshold_sparseGrassland ,
     threshold_degradedLandsRecentDisturbed : threshold_degradedLandsRecentDisturbed ,
     threshold_moderateVegCover : threshold_moderateVegCover ,
     threshold_moderateHighVegCover : threshold_moderateHighVegCover,
     threshold_highVegCover:threshold_highVegCover,
     threshold_veryHighVegCover:threshold_veryHighVegCover,
     threshold_extremHighVegCover:threshold_extremHighVegCover,
     threshold_veryDenseVegCover:threshold_veryDenseVegCover,
     threshold_extremDenseVegCover:threshold_extremDenseVegCover,
     threshold_nearOptimalVegCover: threshold_nearOptimalVegCover,
     threshold_optimalVegCover: threshold_optimalVegCover,
    }).rename(['NDVI']);
//---------------------Visualisation phase ---------------------------------
// Colour association to each index (class/range)
var ndviVis = {min: 0, max: 11 , palette:['#000000','#a50026','#d73027', '#f46d43',
```

```
'#fdae61', '#fee08b', '#ffffbf', '#d9ef8b', '#a6d96a', '  #66bd63', '#1a9850',
'#006837']};

Map.centerObject(geometry);
Map.addLayer(ndvi_classified , ndviVis, 'NDVI2');
Map.addLayer(geometry);
```

The resulting images are similar to the following image, highlighting the different categories of vegetation cover (Results are visible in chapter 08).

7.4.3.2. Burned Area Extraction (NBR index)

To benefit from the magnitude of spectral difference, NBR uses the ratio between NIR and SWIR bands, according to the formula shown below. A high NBR value indicates healthy vegetation while a low value indicates bare ground and recently burnt areas. Non-burnt areas are normally attributed to values close to zero.

$$NBR = \frac{NIR-SWIR}{NIR+SWIR}$$

The image selected for pre-fire Normalised Burn Ratio (NBR) calculation necessary for Burned Area Extraction, was sensed in the date of ***2017/07/04*** with the image-id of "**'20170704T103019_20170704T103637_T32TLR'**" (the same image which was used also for pre-fire NDVI calculation). In the first step, the image was recalled from the database and was filtered by the "B12" and "B8" bands. Secondly, an expression was created in order to calculate the NDVI index, and was memorised inside a variable called bandIndexExp. The defined expression then was applied to the image and the resulting image was called NBR, memorised inside the "bandIndexImage". The final stage was to define the visualisation parameters for the NBR index, considering the range of values (-1 to 1), and associating a colour palette to each part of the spectrum. And lastly, the map is added as a layer to the platform.

```
var image = ee.Image('COPERNICUS/S2_HARMONIZED/' +
'20170704T103019_20170704T103637_T32TLR') //Pre_Fire image
                        select(['B12','B8']);

// Expression using image band indices to calculate NBR
var bandIndexExp = '(b("B8") - b("B12")) / (b("B8") + b("B12"))';
var bandIndexImg = image.expression(bandIndexExp).rename('NBR');

//--------------------Visualisation phase---------------------------------
// Visualization parameters for NDVI.
var nbrVis = {min: -1, max: 1 , palette:['red','orange','green']};


Map.centerObject(geometry);
Map.addLayer(bandIndexImg , nbrVis, 'NBR1');
```

7.4.4.Index Calculation:Post-wildfire (2017)

7.4.4.1.Normalised Difference Vegetation Index(NDVI)

Before and after a wildfire, the NDVI may alter. The quantity and quality of vegetation in a region has an impact on the NDVI value. The NDVI values will represent the vegetation's health and intactness before a fire. Because there is less vegetation to reflect the near-infrared light that the NDVI index depends on after a fire, the NDVI readings will be much lower. The NDVI values can also be impacted further by the existence of ash, charred debris, and other post-fire features. In order to determine the size and severity of a fire, it can be useful to compare the NDVI readings before and after a fire.
The image with the image-id of **"20180619T103019_20180619T103559_T32TLR"** was acquired on ***2018/06/19***, which is an appropriate date for vegetation assessment in the Alpine region, and was used to compute the post-fire NDVI. The post-fire image was taken into consideration during the same time frame as the pre-fire image for the purpose of better assessment. The method for calculating post-fire NDVI is shown in the code snippet below.

```
//For NDVI we would need the same time of the year:
var image = ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
'20180619T103019_20180619T103559_T32TLR') //post-fire image
                        .select(['B4','B8']);

// Expression using image band indices to calculate NDVI
var bandIndexExp = '(b("B8") - b("B4")) / (b("B8") + b("B4"))';
var bandIndexImg = image.expression(bandIndexExp).rename('NDVI');

//--------------------Visualisation phase -----------------------------------
// Visualization parameters for NDVI.
//The same process of the pre-fire NDVI is repeated for creating thresholds and
visualisation
```

7.4.4.2.Burnt Area extraction (NBR index)

For the post-fire NBR calculation, an image with date of ***"2017/11/16"*** and with the image-id of "20171116T103311_20171116T103542_T32TLR" was selected. Here's an example code for calculating the Burned Area Extraction using the NBR index in Google Earth Engine for the Susa Valley region in Piedmont, Italy, for the specified time period:

```
 var image =
        ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
'20171116T103311_20171116T103542_T32TLR')
           .select(['B12','B8']);

// Expression using image band indices to calculate NBR
var bandIndexExp = '(b("B8") - b("B12")) / (b("B8") + b("B12"))';
var bandIndexImg = image.expression(bandIndexExp).rename('NBR');

//--------------------Visualisation phase ------------------------------
// Visualization parameters for NDVI.
var nbrVis = {min: -1, max: 1 , palette:['red','orange','green']};

print(image);
```

```
Map.centerObject(geometry);
Map.addLayer(bandIndexImg , nbrVis, 'NBR1');
```

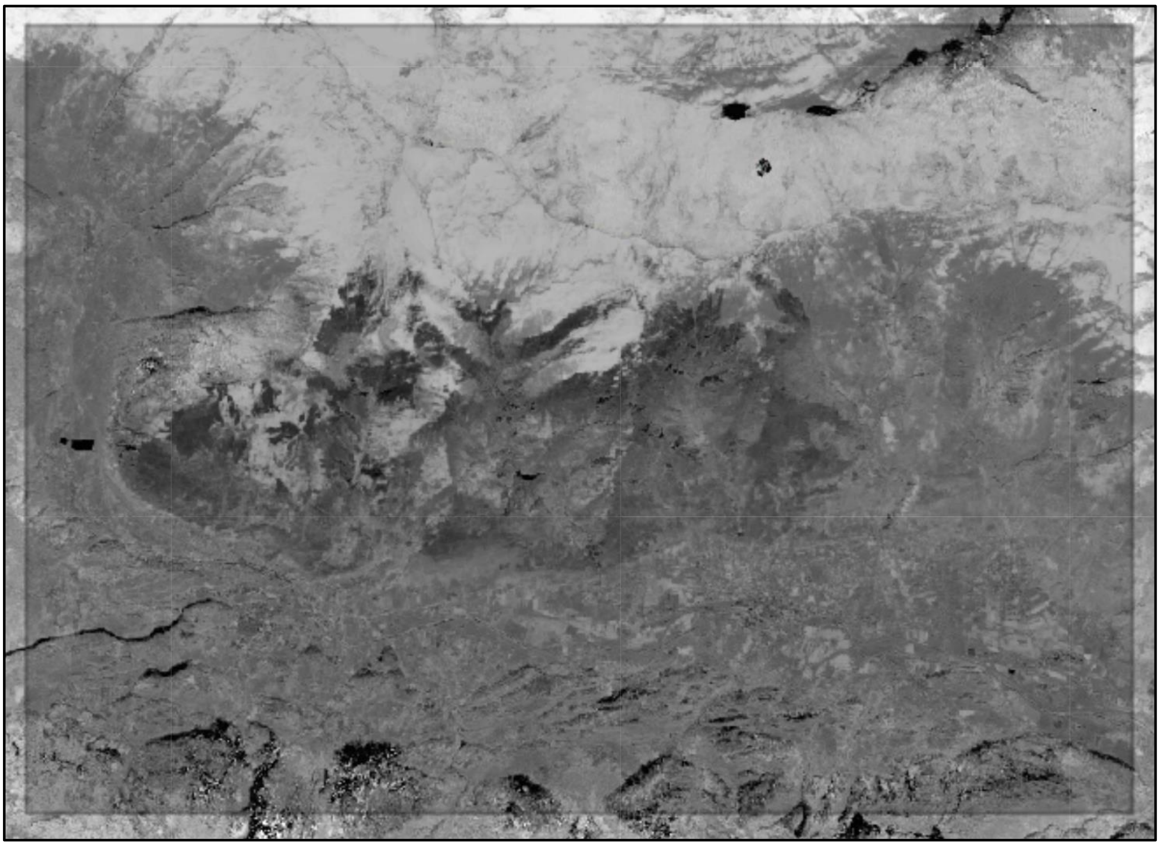


Fig.7-7.post-fire NBR Calculation image with -1 to 1 value range, without using multicolor visualisation parameters_Source:(Author)

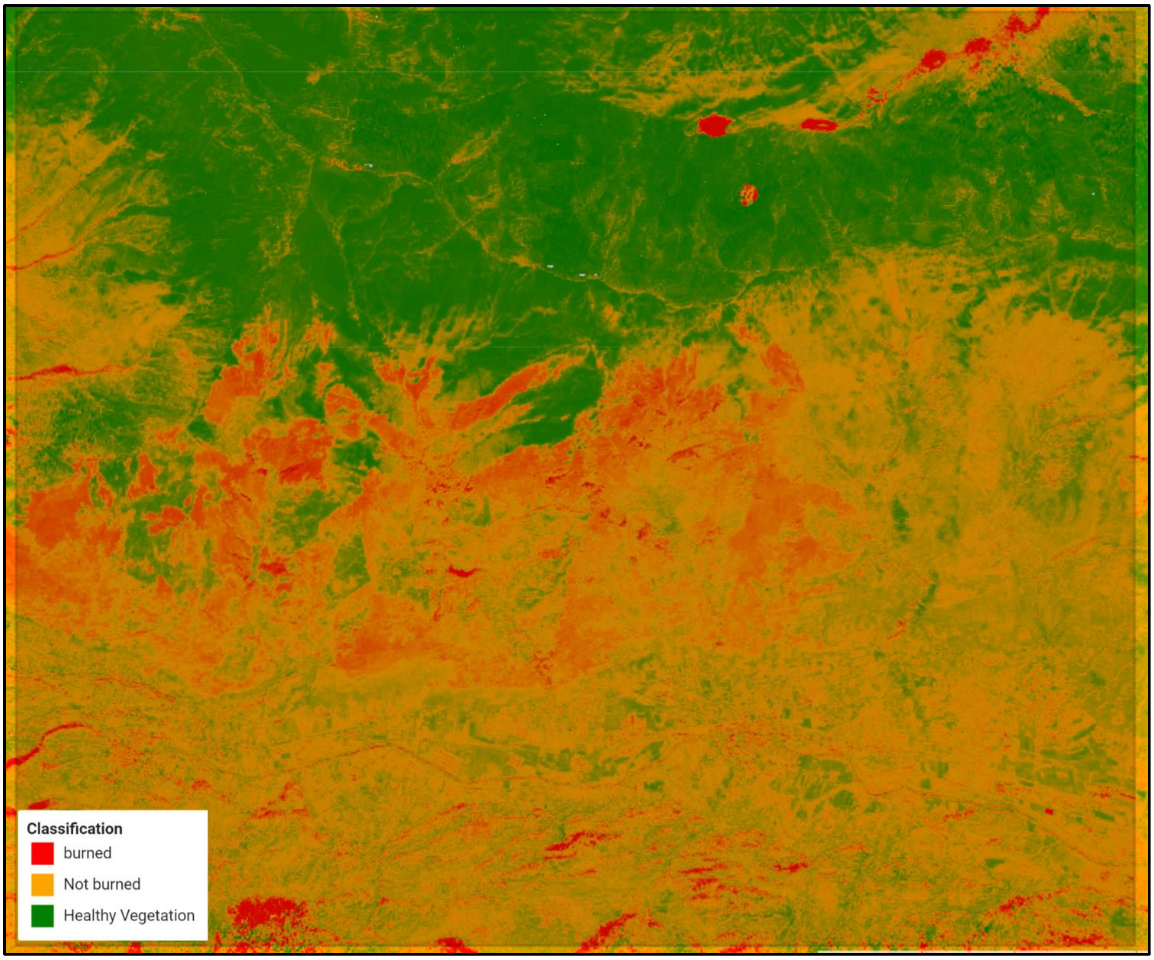


Fig.7-8.post-fire NBR Calculation image with -1 to 1 value range, after using multicolor visualisation parameters_Source:(Author)

7.4.4.3.Burn Severity Analysis

dNBR or ΔNBR = PrefireNBR - PostfireNBR

For the process of Burn Severity, the first step is to recall pre-fire and post-fire images, filtering them by the necessary bands for calculating NBR (B8 and B12 for Sentinel 2).

```
// importing pre-fire and post-fire NBR images (the same dates for which NBR was calculated)
var pre-fire_image = ee.Image('COPERNICUS/S2_HARMONIZED/' +
'20170704T103021_20170704T103806_T32TLR')
                        .select('B8', 'B12');
var post-fire_image = ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
'20171116T103311_20171116T103542_T32TLR')
                        .select('B8', 'B12');
```

The next step is to calculate the NBR index for both periods and apply it to the images.

```
//---------------------NBR Calculations for Post and pre-fire-----------------
-
// Expression using image band indices to calculate NBR
var bandIndexExp = '(b("B8") - b("B12")) / (b("B8") + b("B12"))';
var pre-fire_nbr = pre-fire_image.expression(bandIndexExp).rename('NBR_pre-
fire');
var post-fire_nbr = post-fire_image.expression(bandIndexExp).rename('NBR_post-
fire');
```

The last part of the process is the algorithm of the Burn Severity index, which is the delta or the difference between post-fire-nbr and pre-fire-nbr.

```
// delta_nbr calculation(Burn Severity formula)------------------------------
// delta_nbr calculation(Burn Severity formula)--------------------------------
var delta_nbr = pre-fire_nbr.subtract(post-fire_nbr).rename('dNBR');

// Clip the dNBR image to your geometry
var clipped_dNBR = delta_nbr.clip(geometry);
print("delta_nbr", delta_nbr);
```

The final step is configuring the visualisation parameters, and applying them. The first step is to define thresholds for visualisations. -0.1 is the threshold for the low burn severity, 0-1 is the threshold for moderate burn severity and 0.27 is the threshold for high burn severity.
Then, an algorithm deciding about the burn severity of each pixel is defined (burnSeverity variable in the code). This algorithm defines the condition for association of each pixel to burnSeverity categories previously defined, based on the delta_nbr value for that pixel. The expression() function's conditional statement determines whether the value of delta_nbr exceeds each threshold in decreasing sequence of severity. If the threshold_high is exceeded, the pixel receives a burn intensity of 3. (high severity). The pixel is given a burn intensity of 2 if delta_nbr is between threshold_high and threshold_moderate. (moderate severity). The pixel is given a burn intensity of 1 if delta_nbr is between threshold_moderate and threshold_low (low severity). Finally, the pixel is given a burn severity of 0, which denotes no burn, if delta_nbr is less than threshold_low. The resultant layer is then renamed to burnSeverity using the rename() method.
visSeverity variable at the end, defines the visualisation parameters for each threshold and the map is visualised. The thresholds relative to each burn severity category are derived from the table suggested by USGS website and rounded in order to be in-line with the values calculated using NBR.

Severity Level	dNBR Range (scaled by 10^3)	dNBR Range (not scaled)
Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.99
Low Severity	+100 to +269	+0.100 to +0.269
Moderate-low Severity	+270 to +439	+0.270 to +0.439
Miderate-high Severity	+440 to +659	+0.440 to +0.659
High Severity	+660 to +1300	+0.660 to +1.300

Table 7-3.Burn severity levels obtained calculating dNBR, proposed by USGS Source: (UN SPIDER Knowledge portal Website)

```
//thresholds lt
var threshold_enhanced_regrowth_high = -0.3;
var threshold_enhanced_regrowth_low = -0.1 ;
var threshold_unburned= 0.3;//0.99;
var threshold_low_severity= 0.4;
var threshold_moderate_low_severity= 0.5;
var threshold_moderate_high_severity= 0.7;
var threshold_high_severity= 1;


// defining the burn severity image based on the thresholds and values_3,2,1,0 are values
for visualisation
var burnSeverity = clipped_dNBR.expression(
      "(b('dNBR') <= threshold_enhanced_regrowth_high) ? 0" +
    ": (b('dNBR') <= threshold_enhanced_regrowth_low) ? 1" +  // Moderate-high burn
severity
    ": (b('dNBR') <= threshold_unburned) ? 2" +  // Moderate-low burn severity
    ": (b('dNBR') <= threshold_low_severity) ? 3" +
    ": (b('dNBR') <= threshold_moderate_low_severity ) ? 4" +
    ": (b('dNBR') <= threshold_moderate_high_severity) ? 5" +
    ": (b('dNBR') <= threshold_high_severity) ? 6" +
      ":7"
  , {
     threshold_enhanced_regrowth_high : threshold_enhanced_regrowth_high ,
     threshold_enhanced_regrowth_low : threshold_enhanced_regrowth_low ,
     threshold_unburned : threshold_unburned ,
     threshold_low_severity : threshold_low_severity ,
     threshold_moderate_low_severity : threshold_moderate_low_severity ,
     threshold_moderate_high_severity : threshold_moderate_high_severity ,
     threshold_high_severity : threshold_high_severity  ,
  }).rename(['burnSeverity']);

// Display the burn severity map       )
var visBurnSeverity = {min: 0, max: 7, palette: ['#778835', '#a7c050', '#0be344',
'#f8fc11', '#f8b140', '#f8671a', 'a600d4', 'Grey']};
Map.addLayer(burnSeverity, visBurnSeverity, 'Burn Severity');
```

7.4.5.Current Situation (2022)

7.4.5.1. Vegetation health (NDVI)

The image with the image-id of “**20220618T102559_20220618T103528_T32TLR**” was sensed on **2022/06/18**. Just like the post-fire image, the present image was taken into consideration during the same time frame as the pre-fire image for the purpose of better assessment. The method for calculating post-fire NDVI is shown in the code snippet below.

```
//Loading the image
var image = ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
'20220618T102559_20220618T103528_T32TLR')
                        .select(['B4','B8']);

// Expression using image band indices to calculate NDVI
var bandIndexExp = '(b("B8") - b("B4")) / (b("B8") + b("B4"))';
```

```
var bandIndexImg = image.expression(bandIndexExp).rename('NDVI');

//--------------------Visualisation phase -------------------------
// Visualization parameters for NDVI.
//The same process of the pre-fire NDVI is repeated for creating thresholds and
visualisation
```

7.4.6.Statistics Calculation

In order to have quantified results, some statistical analysis has been done on the different images. These statistics demonstrate the percentage of burned areas, the surface covered by the burned area and other categories.

7.4.6.1. Statistics on NBR_Burned Area Extraction

In order to do the burned area surface that had covered the image, a series of steps needed to be done. First of all, burned areas needed to be extracted as a separate image from the compiled NBR image.
To accomplish this task, some threshold has been defined to highlight the burned area and create a masking image out of it. The defined threshold is applied on the NBR image previously calculated, to select the pixels that had values less than -0.1. Then this mask is applied on the image to get a binary image. (Fig.7-8) shows the resulting binary image for the burned areas.

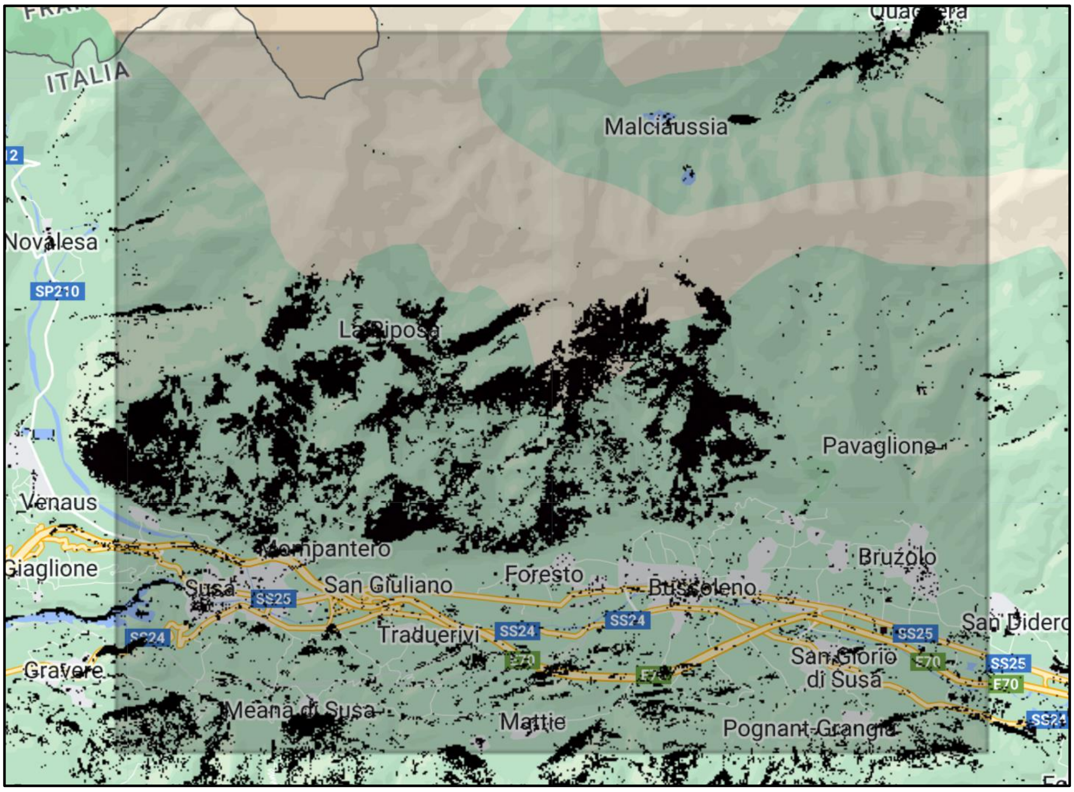


Fig.7-9.The Burned Area Binary Mask resulted from the post-fire NBR image_Source:(Author)

Final step of the preparation of the image for area calculation is to merge the bands of the BurnedArea image and the full image into 1 band, so that it would not lead to errors in the platform.

```
//-------Area Calculation--------------------
var thresh_burned = -0.1; //lt
//------------------------------QUANTIFICATION OF STATISTICS-----------
// Create binary masks for NBR pixel categories
var burnedMask = bandIndexImg.lt(thresh_burned);

// Mask the image based on the binary masks
var burnedNBRImage = image.updateMask(burnedMask);

//-------Merging the masked image (merging the two bands in 1 band)--
var burnedNBRImageMerged = burnedNBRImage
                                .select(['B8', 'B12'])
                                .reduce(ee.Reducer.sum())
                                .toFloat()
                                .rename('burnedNBRImageMerged');

//------Merging the complete image into 1 band
var imageMerged= image
                    .select('B8', 'B12')
                    .reduce(ee.Reducer.sum())
                    .toFloat()
                    .rename('imageMerged');
```

Final step is to develop the algorithm needed for automatic area and burned area calculation and their conversion to hectares.

```
//calculating pixel area for the image
var totalAreaImage = ee.Image.pixelArea()
  .updateMask(imageMerged.mask())
  .rename('totalArea');

var burnedAreaImage = totalAreaImage
  .updateMask(burnedNBRImageMerged)
  .rename('burnedArea');

//calculating the areas of images based on the pixel area
var areas = totalAreaImage
  .addBands(burnedAreaImage)
  .reduceRegion({
    reducer: ee.Reducer.sum(),
    geometry: BurnedRoi,
    scale: 10,
    crs: 'EPSG:32632',
    maxPixels: 1e13
  });
//calculating different area category and percentage of burned area
var burnedArea = areas.getNumber('burnedArea');
var totalArea = areas.getNumber('totalArea');
var percentage = burnedArea.divide(totalArea).multiply(100);
```

```
//Conversion into hectare
print('Burned Area (Hectares)', burnedArea.divide(10000));
print('Total Area (Hectares)', totalArea.divide(10000));
print('Burned Fraction (%)', percentage);
```

7.4.6.2.NBR_Burned Area Values Distribution (Histogram)

The next statistical analysis done for the Burned areas, has been the automation of the process of creating a histogram. This process has been done on pre-fire and post-fire NBR images and also the Burned Area binary Mask to demonstrate the pixel distribution for each segment of NBR value for both of these images. In order to create the histogram for both the pre-fire and post-fire NBR the following algorithm has been adopted:

```
var histogram_NBR = ui.Chart.image.histogram({
  image: bandIndexImg, //NBR image
  region: CEMS-AOI,
  scale: 10,
  maxBuckets: 50,
  minBucketWidth: 0.01,
})
  .setOptions({
    title: 'NBR Histogram_pre-fire',
    hAxis: { title: 'NBR' },
    vAxis: { title: 'Pixel Count' }
});
```

On the other hand, for the Burned Area masked image, a bit of preparation was needed because the NBR was calculated in a method in which the resulting mask contained two bands, while for our algorithm it is important to merge the two bands together. In order to do that, the NBR has been calculated using the NormalisedDifference() function, and then applied on the mask as follows.

```
var nbr_ND = image.normalizedDifference(['B8', 'B12']).rename('NBR_ND'); //NBR using Normalised Difference
var thresh_burned = -0.1; //lt

// Create a binary mask for burned areas
var burnedMask = nbr_ND.lt(thresh_burned );

var burnedNbrImage_ND = nbr_ND.updateMask(burnedMask);
```

7.4.6.3.Vegetation Recovery Distribution and Trend Overtime

In order to see the vegetation recovery trend, two types of analysis have been automated. One is the NDVI Histogram, which shows the distribution of the pixels of each vegetation category for each image, and the other one is the NDVI scatterplot, showing the NDVI trend overtime using the 3 single images we previously had. This statistical analysis, coupled by the index extraction and visualisation done beforehand, is essential for a more precise interpretation of the images.

1. NDVI_Histogram

The first statistical analysis done for understanding the vegetation recovery better overtime, was to generate the histogram of all the 3 periods of study, once for NDVI values, and the second time for each vegetation category (that were defined based on aforementioned thresholds).
The following code snippet demonstrates the algorithms and steps done to obtain the said histogram for the pre-fire image, which was replicated for other two periods of study. This algorithm utilises the **ui.chart** method in GEE to build the histogram element.

```
//For NDVI I would need the same time of the year(Preferably)---> Dates:
var image_pre-fire = ee.Image('COPERNICUS/S2_HARMONIZED/' +
'20170704T103019_20170704T103637_T32TLR') //Pre_Fire image
                         .select(['B4','B8']);

//---------- Expression using image band indices to calculate NBR----------------------
var bandIndexExp  = '(b("B8") - b("B4")) / (b("B8") + b("B4"))';
var NDVI_pre-fire  =  image_pre-fire.expression(bandIndexExp).rename('NDVI');


//---Histogram-------------
var histo_NDVI_pre-fire = ui.Chart.image.histogram({
  image: NDVI_pre-fire,
  region: affectedAreaCEMS,
  scale: 10,
  maxBuckets: 50,
  minBucketWidth: 0.01,
})
  .setOptions({
    title: 'NDVI Histogram_pre-fire',
    hAxis: { title: 'NDVI' },
    vAxis: { title: 'Pixel Count' }
});


//---------------------Test For Categories-----------------------------
print(histo_NDVI_pre-fire);
```

2.NDVI Scatterplot

The second statistical analysis for the vegetation recovery trend was the generation of a scatter plot that calculated the **mean NDVI value** for all the pixels of each image, and demonstrated them on a time series diagram.
In order to produce such scatterplot, first of all each of the Satellite images needed to be recalled, and the metadata property "system:time_start" for each of them needed to be set to a millisecond timestamp format, to be used later on in the process of scatter plot creation.
In the second step, the NDVI index was calculated for each image and the mean value of the pixels was calculated.
The final part includes creation of the scatterplot using the timeseries formed by the collection of timestamps of the images.

```
// Load the three images.
var image_pre-fire = ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
20170704T103019_20170704T103637_T32TLR)  //Pre_Fire image
```

```
                          .select(['B4','B8'])
                          .set('system:time_start', ee.Date('2017-06-19').millis());

var image_post-fire = ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
'20180619T103019_20180619T103559_T32TLR')  //post-fire_Fire image
                          .select(['B4','B8'])
                          .set('system:time_start', ee.Date('2018-06-19').millis());

var image_2022 = ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
'20220618T102559_20220618T103528_T32TLR')  //present image (2022)
                          .select(['B4','B8'])
                          .set('system:time_start', ee.Date('2022-06-18').millis());

// Function to calculate NDVI.
var ndvi_pre-fire = image_pre-fire.normalizedDifference(['B8', 'B4']).rename('NDVI');
var ndvi_post-fire = image_post-fire.normalizedDifference(['B8', 'B4']).rename('NDVI');
var ndvi_2022 = image_2022.normalizedDifference(['B8', 'B4']).rename('NDVI');

// Reduce the NDVI image to a mean value for each image.
var ndvi_pre-fire_mean = ndvi_pre-fire.reduceRegion({
  reducer: ee.Reducer.mean(),
  geometry: affectedAreaCEMS,
  scale: 10,
  maxPixels: 1e9
});

var ndvi_post-fire_mean = ndvi_post-fire.reduceRegion({
  reducer: ee.Reducer.mean(),
  geometry: affectedAreaCEMS,
  scale: 10,
  maxPixels: 1e9
});

var ndvi_2022_mean = ndvi_2022.reduceRegion({
  reducer: ee.Reducer.mean(),
  geometry: affectedAreaCEMS,
  scale: 10,
  maxPixels: 1e9
});

var features = ee.FeatureCollection([
  ee.Feature(null, {'system:time_start': image_pre-fire.get('system:time_start'), 'ndvi':
ndvi_pre-fire_mean.get('NDVI')}),
  ee.Feature(null, {'system:time_start': image_post-fire.get('system:time_start'),
'ndvi': ndvi_post-fire_mean.get('NDVI')}),
  ee.Feature(null, {'system:time_start': image_2022.get('system:time_start'), 'ndvi':
ndvi_2022_mean.get('NDVI')})
]);


// Create a chart and set the x-axis to 'system:time_start' property and y-axis to NDVI.
var chart = ui.Chart.feature.byFeature(features, 'system:time_start')
    .setChartType('ScatterChart')
    .setOptions({
      title: 'NDVI Time Series',
      vAxis: {title: 'NDVI'},
```

```
      hAxis: {title: 'Date', format: 'MMM-yyyy'},
      pointSize: 15,
      series: {
        0: {pointShape: 'circle'},
      }
    });

// Adding the chart using ui library for the visualisation
ui.root.widgets().add(chart);
```

7.5.The 3-Dimensional Model

As far as the development of the 3D model is concerned, GEE still does not have the possibility to generate it automatically, and it can only provide us with the SRTM data for the given area. Such data needs to be converted to 3D using QGIS (or other platforms able to utilise SRTM data to generate 3D models).
The first step of the 3D model generation of the area of analysis on which the analysed satellite data would be demonstrated, is to download the analysed images for each index, and the period of time. This step would help us be assured that the values remain consistent. The snippet to export images in GEE is as follows:

```
//this is the example code for post-fire NBR index.
Export.image.toDrive({
  image: bandIndexImg , /*here the analysed image variable name is inserted*/
  description: 'S2SrHarmonized-20171116T103311_20171116T103542_T32TLR_post-
fireNBR',
  scale: 10,
  region: geometry,
})
```

After running the code, the following window opens which allows us to initialise the exporting process and export image in clouds, or in the drive or to get an earth engine asset. For our purpose, we exported the image in Drive, in GEO_TIFF format.

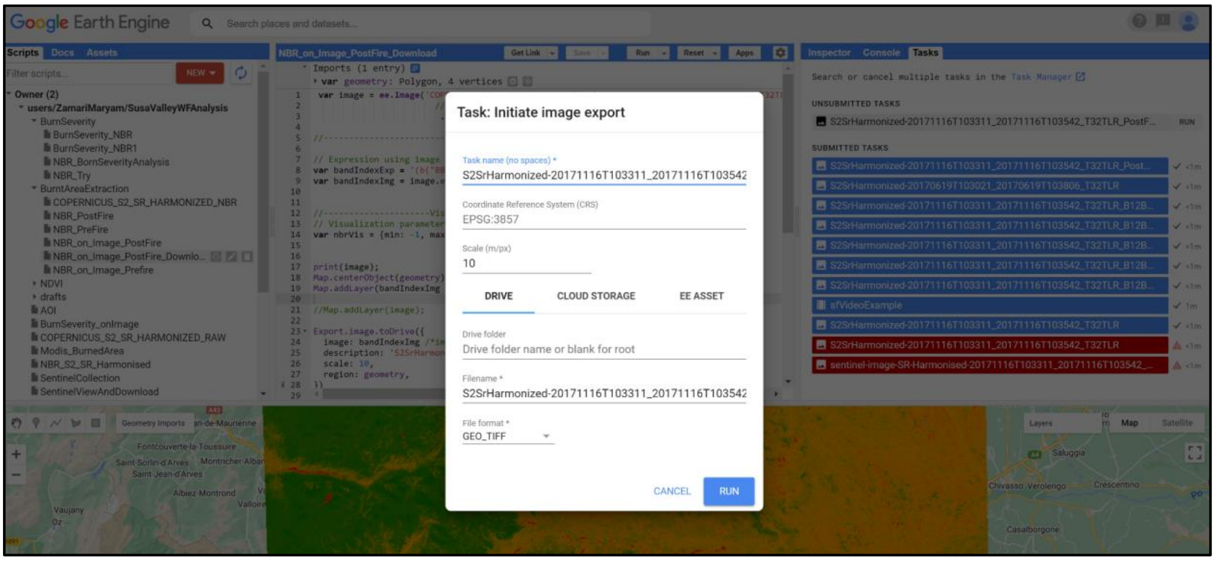


Fig.7-10.Exporting analysed images for 3D model creation_Source:(Author)

The resulting image is imported into QGIS software, and the visualisation is configured again, because the output image contains 1 single band (NBR), with its related values.

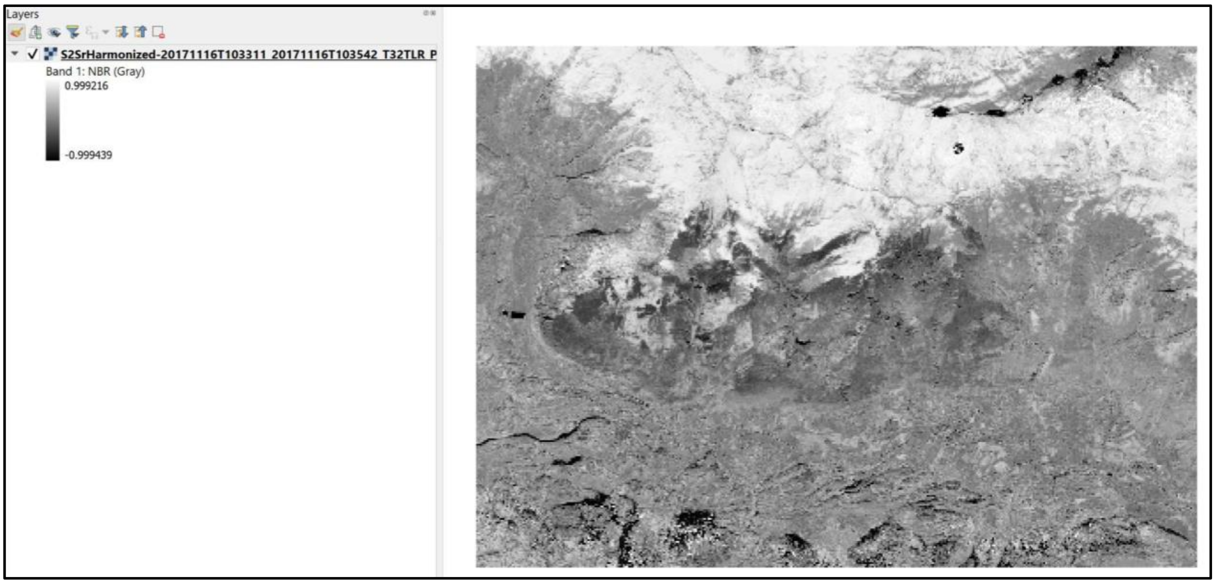


Fig.7-11.Imported Calculated NBR Image in QGIS_Source: (Author)

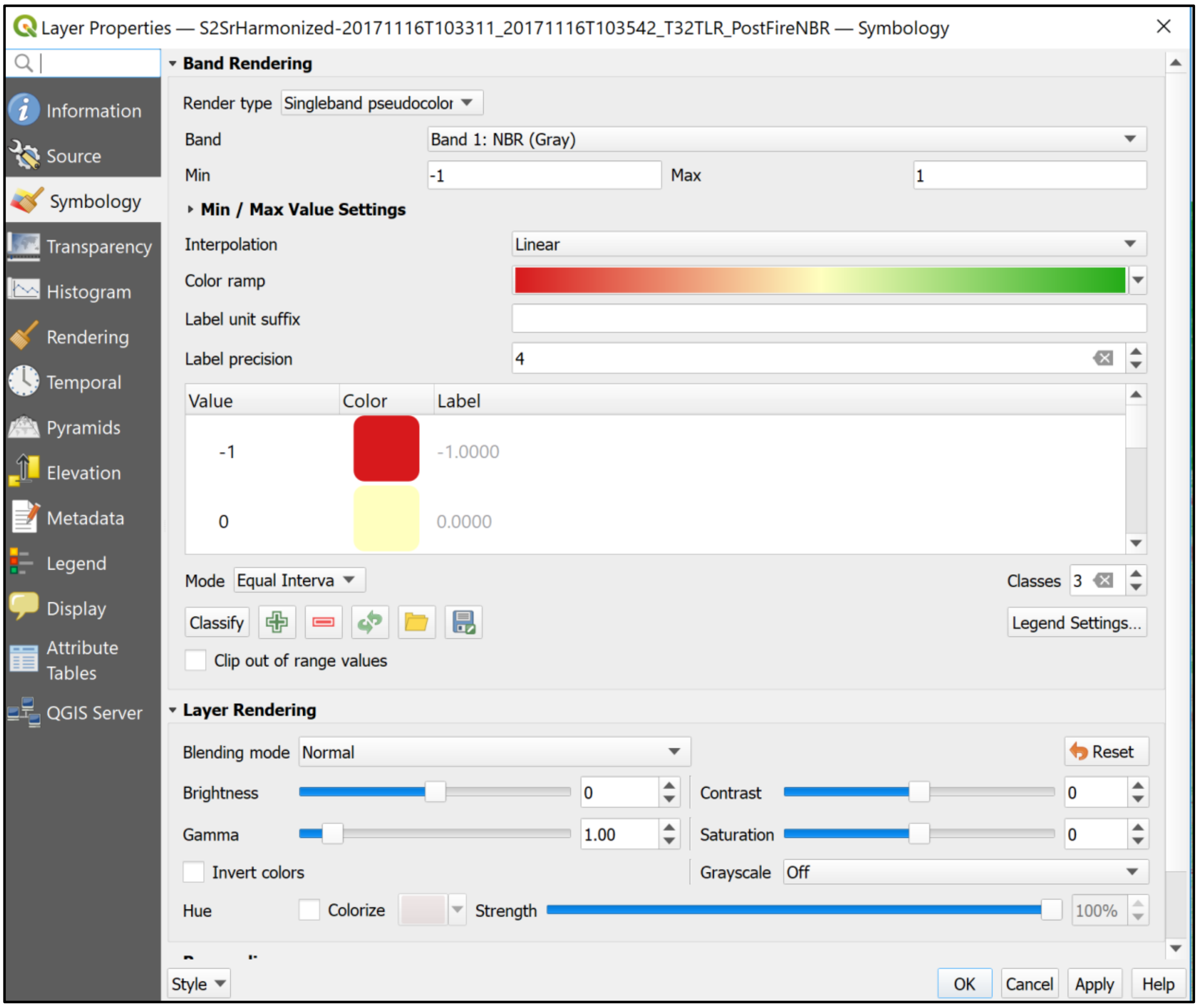


Fig.7-12.post-fire NBR image Visualisation Configuration in QGIS_Source;(Author)

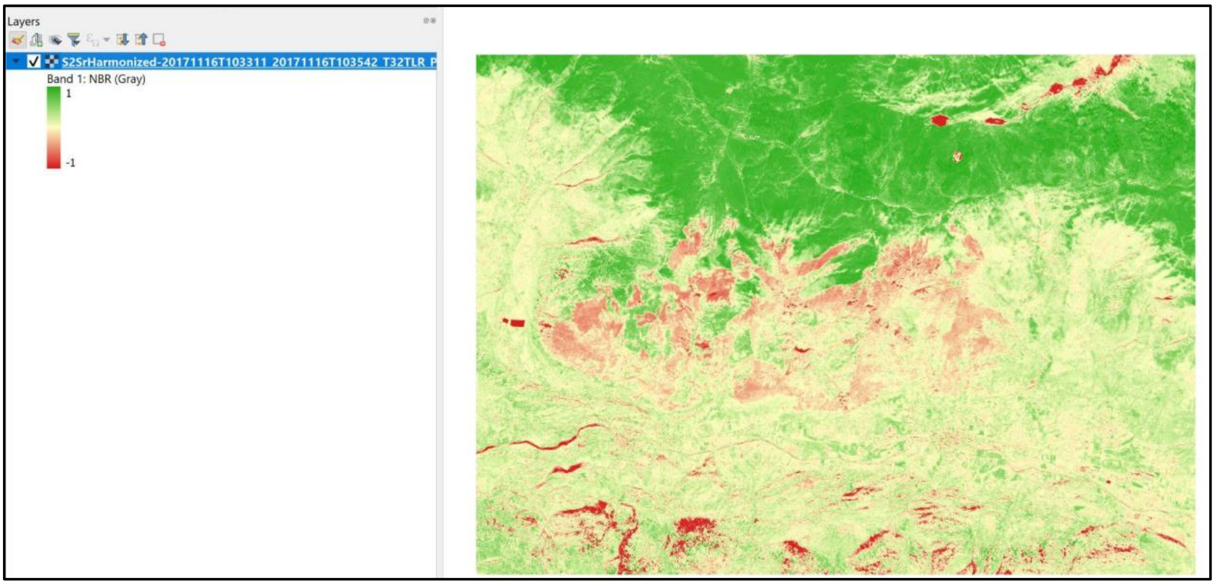


Fig.7-13.post-fire NBR image_Source:(Author)

Second important step in the process for creating the 3D model includes obtaining the elevation data for each pixel of the image (DEM). In order to do that, the Shuttle Radar Topography Mission (SRTM) data is required, which provides consistent, high-quality elevation data with a nearly global reach.

The code snippet to generate the slope and elevation data is as follows:

```
//since I am doing all the analysis for the same geographic area, I can use any
of the images of the area to generate the SRTM data
var image =
           ee.Image('COPERNICUS/S2_SR_HARMONIZED/' +
'20220618T102559_20220618T103528_T32TLR');

//defining the elevation and slope variables
var elevation = dataset.select('elevation').clip(geometry);
var slope = ee.Terrain.slope(elevation).clip(geometry);

//adding the slope and elevation layers, and defining min and max values for
further visualisation
Map.addLayer(slope, {min: 0, max: 60}, 'slope');
Map.addLayer(elevation,{min:0, max:5000}, 'slope');

//downloading the slope and elevation image
Export.image.toDrive(slope, 'slope');

Export.image.toDrive(elevation, 'elevation');
```

However, it is possible to use the plugins inside the used software (in our case, QGIS), to download the related data. This method can be considered more optimal because it reduces the workload and increases the speed of elaboration, since most of the steps will be performed in the same software.

In order to download the SRTM data in QGIS, the SRTM plugin is used. To authenticate and authorise users, the SRTM downloader plugin in QGIS requires an account on the Earthdata website. Access to the SRTM data is only permitted for registered users due to authorization and security considerations. The SRTM data is made available by NASA's Earthdata platform (EarthData Website).

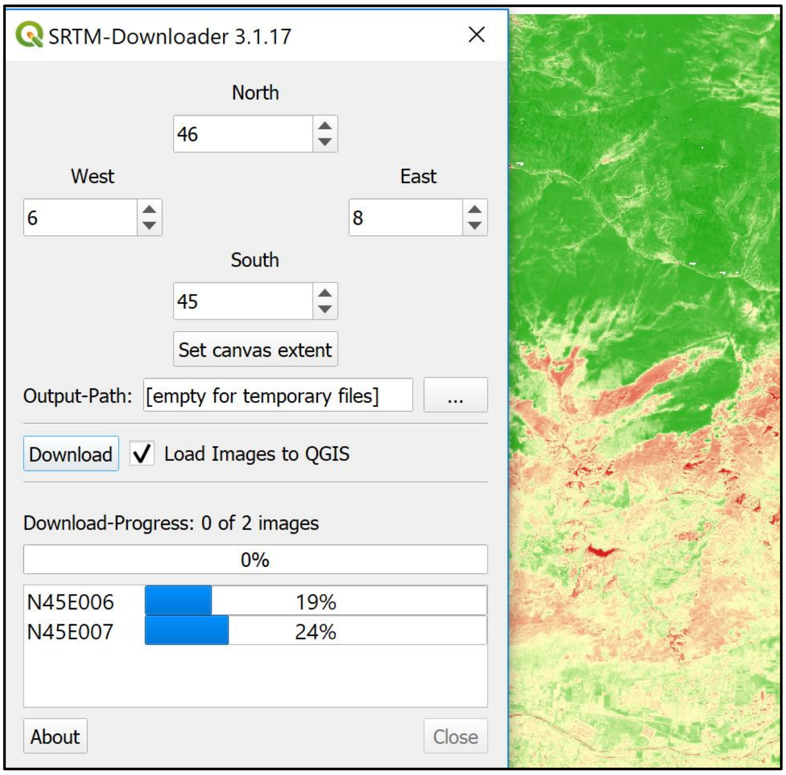


Fig.7-14.Downloading SRTM data for the Area of Analysis_Source:(Author)

This process generates a DEM image, which for each pixel of the image, the respective elevation value is assigned and represented. The layer is then clipped to the extent of the NBR layer to be prepared for the next step.

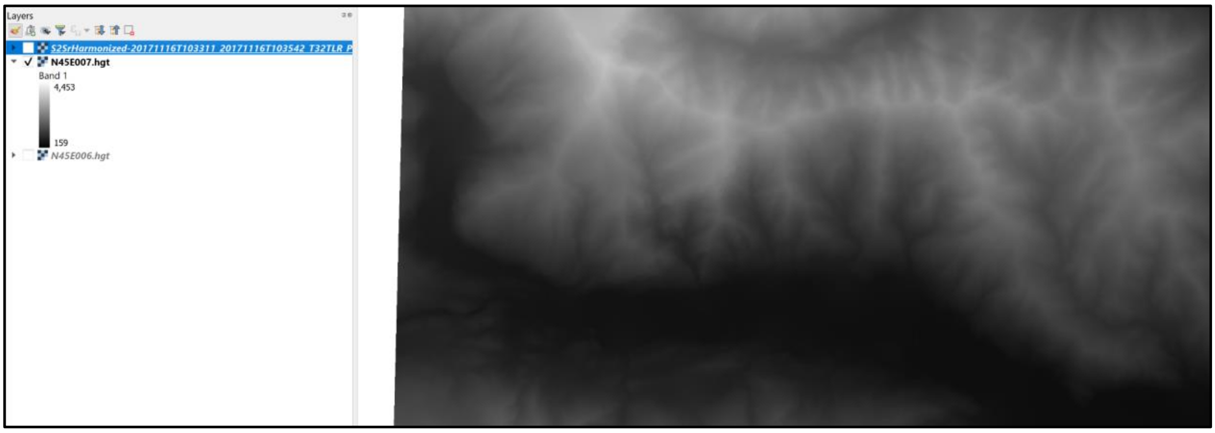


Fig.7-15.Resulting SRTM image for the Area of Analysis_Source: (Author)

The next step is to use the Qgis2threejsExporter plugin. On web platforms, this plugin renders DEM and vector data in three dimensions. Different types of 3D objects can be created, and it is possible to generate files for online publishing. The 3D model can also be saved in the glTF file for 3DCG or 3D printing.

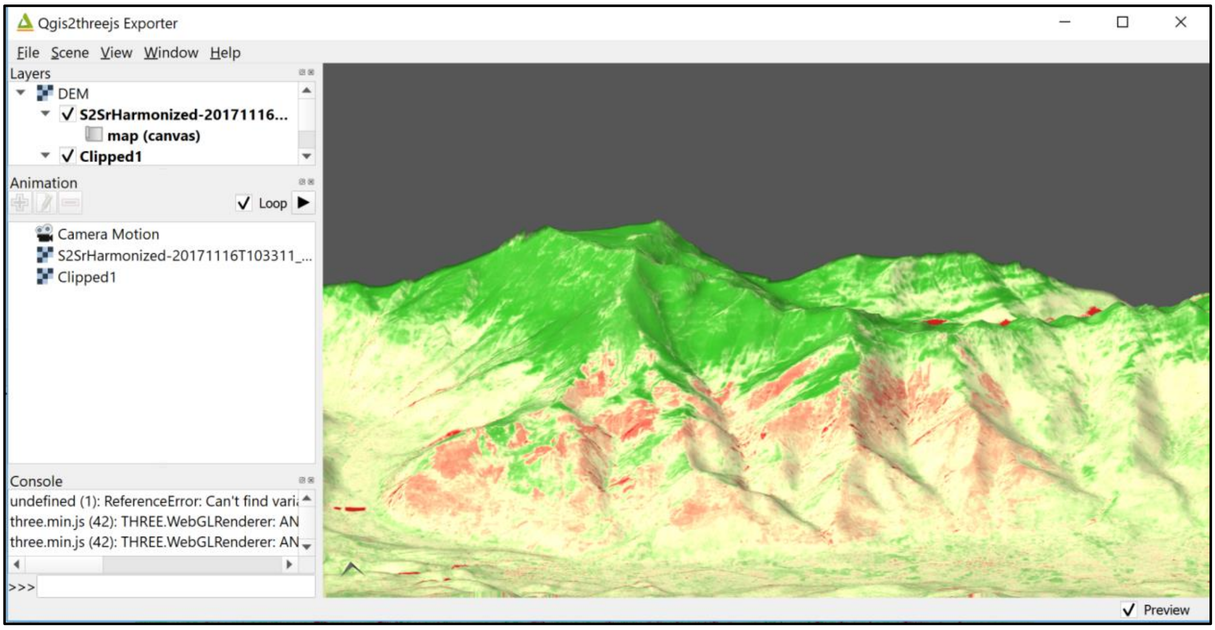


Fig.7-16.The 3D image preview, using Qgis2threejs performed on the SRTM layer_Source:(Author)

Finally the results are exported in different formats. For the use-case of digital twin, *glTF and *glb and also *html files can be used. *glTF is an open standard file format used for 3D models and environments. It was intended for use with web-based graphics and apps as an effective, interoperable format. It supports a broad variety of features, including textures, materials, animations, and more. It is optimised for quick, simple loading and rendering of 3D content.

On the other hand, glb is the *glTF file in binary form. It is more effective for loading and transmission because it saves all of the *glTF data in a binary format. It is self-contained, which means that all of the information required to show the 3D model—including textures, materials, and other resources—is stored in a single file.

In fact, In 3D modelling and animation software, game engines, and web-based apps that demand 3D graphics, *glTF and glb are both frequently used in numerous programs and operating systems, such as Blender, Unity, Unreal Engine, Three.js, and A-Frame, enable them.

To make accurate representations of the wildfire area, including the terrain, vegetation, buildings, and other features, 3D models in *glTF or *glb file formats can be used. This can assist in modelling the behaviour of wildfires accurately and estimating possible damages. The use of the 3D models to visualise the wildfire area both before and after the incident will improve management and planning of the wildfire reaction.

8.Main findings and conclusions

The current research began by gaining an understanding of the Italian and Piedmont region's wildfire management system, taking into account the major plans and reports on various planning, sociological, forestry, and management issues that may have an impact on wildfire and its management. By giving reference points and facilitating the creation of planning ideas for the AOI, these preliminary studies improved the accuracy of interpretations of the statistics and satellite images.
This chapter utilises all the previous steps in combination with the calculated indexes and the extracted statistics, to compare the results and interpret the pre-fire, post-fire and present situation focusing on burned area extraction, burn severity and vegetation recovery. The results are supplemented by further statistics and diagrams and different visualisations by specific band combinations and also 3D modelling to assist the interpretation.
The findings and the preliminary analysis lead to development of planning considerations and the potential stakeholders list for a wildfire assessment digital twin in case of Susa Valley, summarising the relevant sources and reports.
Finally, the study is concluded by a synthesis of the results and challenges faced during the research activity.

8.1.Results of automatization of the process

After performing the process of automation, the results are visualised. The outputs of GEE are interactive maps and the analysed data have also been exported in GeoTIFF format in order to create the 3D model.
This chapter describes the resulting maps and also discusses the accuracy of the results and usefulness of the automation process. Further on, it continues to talk about the planning suggestions for developing a wildfire digital twin.

8.1.1.Burnt Areas Extraction: Results and validation

The range of NBR results have been considered from -1 to 1. Values **close to 1 indicate healthy vegetation**(Green colour in the visualisation), since both the near-infrared and shortwave infrared bands are highly reflective.
Values **close to 0** indicate that the **spectral response** of the region has barely changed, which could indicate a **lack of vegetation** or **no disturbance**. Finally, values **close to -1** suggest **burned or charred areas** because the shortwave infrared band is extremely reflective and the near-infrared band is absorbed by damaged or destroyed vegetation.
While interpreting the NBR values, it has been taken into consideration that the interpretation of NBR values is context-dependent and has been done in conjunction with other sources of information, such as outdoor observations or other remote sensing data.
The **source image** for the validation in the case of burn area extraction, is the **Copernicus EMS Service delineation map (fig.8-2)** for the fire event of the 2017 in Susa Valley. This image has done analysis for the fire event, marking up the burned areas in the time of analysis (2017/11/03). Furthermore, a comparison is done with another dataset in **GEE (FireCCI51: MODIS Fire_cci Burned Area)** , to show the better accuracy of the resulting image in this research.
Figure 8-1 is the pre-fire image resulting from Burned area extraction to get a snapshot of the pre-fire condition. As it is evident in the image, all the pixels represent unburned areas (orange) and healthy vegetation (green).

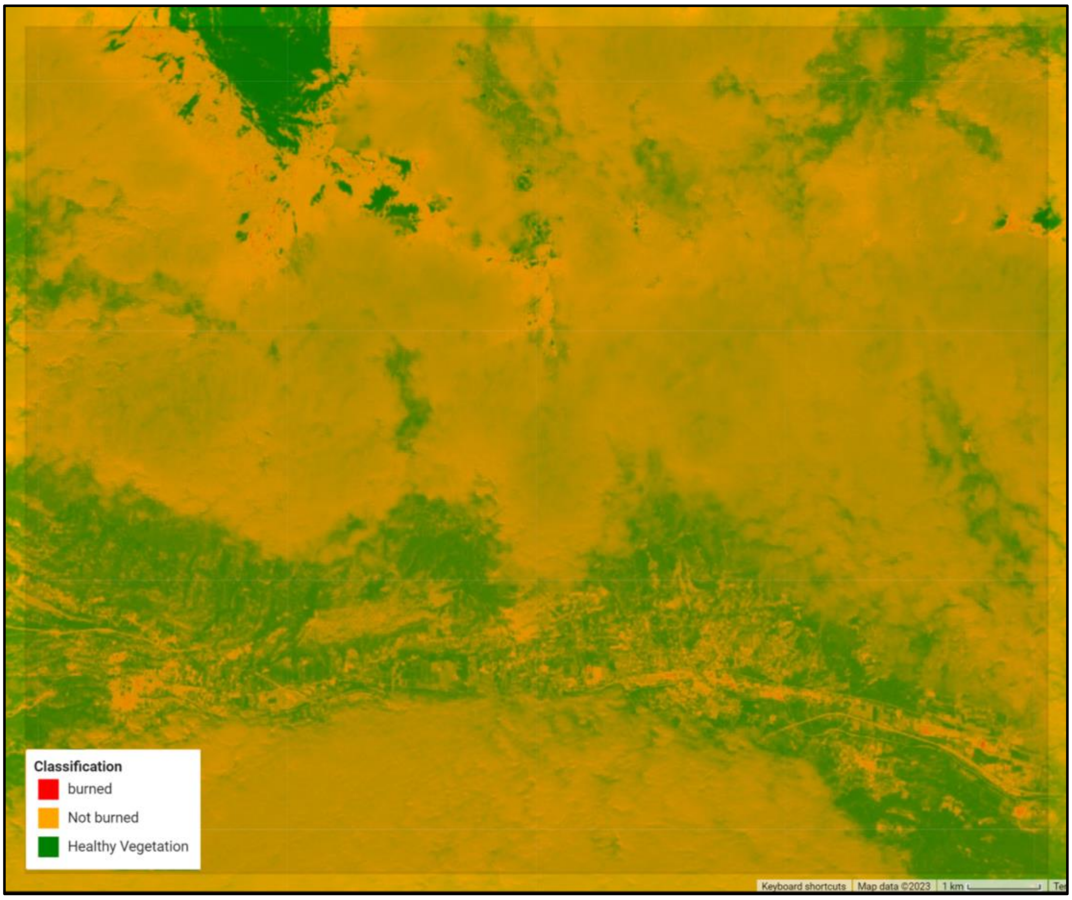


Fig.8-1.NBR calculation performed on pre-fire Sentinel 2 image sensed on the date of 2017/06/19_Source:(Author)

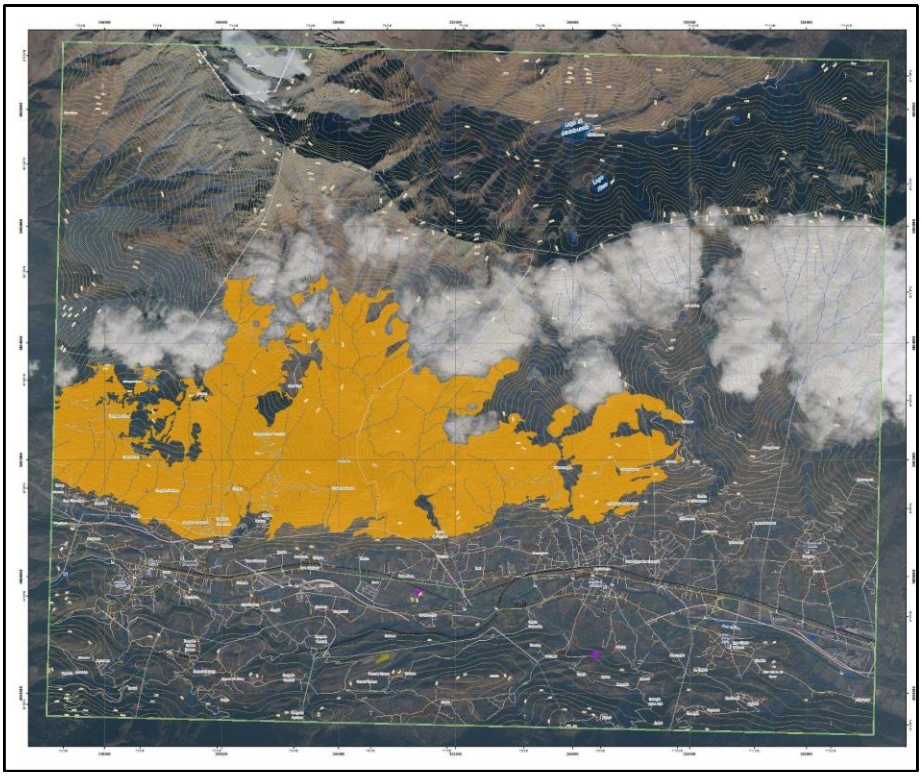


Fig.8-2.Source Image for comparison_Source:(Copernicus Website)

According to the results of the analysis (Fig.8-3), the areas in the centre of the AOI have been identified as burned areas, however, as the altitude increases, there is more healthy vegetation than the burned areas.

As it can be seen that according to the CEMS delineation map of the event, there are some false values also at the bottom and north-east of the AOI, mostly related to shadowed areas (identifiable in the false colour image), which could be because water bodies/waterways and also shadowed areas sometimes can have similar spectral values to burned areas in NBR analysis. Water bodies and shadowed areas can have similar NBR values to burned areas in Sentinel-2 imagery because they also have low reflectance in the SWIR band (B12) due to high absorption of the radiation by water molecules or shadows. This low reflectance in the SWIR band could possibly result in negative NBR values, also observed in burned areas. It is usually because shadowed areas also absorb near-infrared light and reflect green light, resulting in a low NBR value that could be misinterpreted as a burned area.

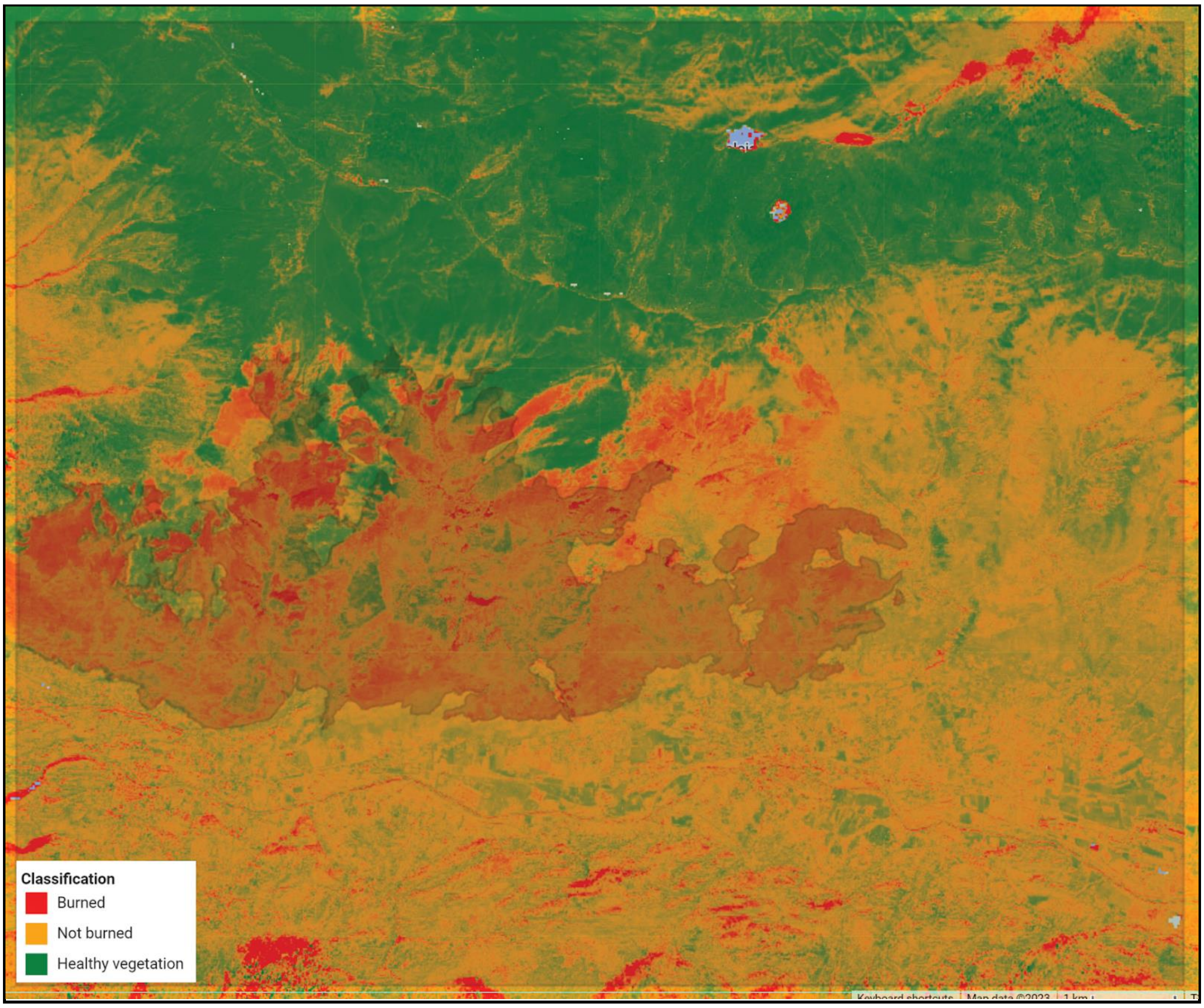


Fig.8-3.Burn Severity NBR calculation performed on post-fire Sentinel 2 image sensed on the date of 2017/11/16_Source:(Author)

Zooming-in on the AOI, setting a lower opacity of the NBR image, we can observe the Google Earth Map and identify the settlements that were somehow affected by the fire. As it can be seen areas in the north of Bussoleno, Borgata Bianchi Inferiori, Borgata Pietra Bianca and Lorano have been involved in the wildfire.

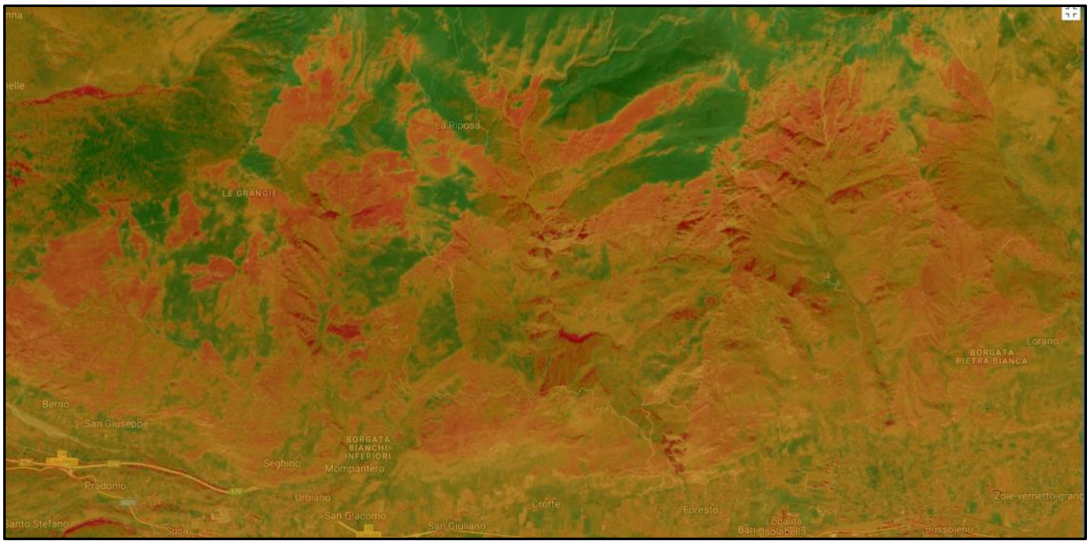


Fig.8-4.Zoomed image of Burn Severity NBR calculation performed on post-fire Sentinel 2 image sensed on the date of 2017/11/16_Source:(Author)

In order to verify the hypothesis about the presence of shadowed areas and water bodies, a false colour image has been created out of the post-fire sentinel2 image with band combination of B12, B8 and B4, decided specifically for the case of detecting burned areas and shadowed and waterbodies. As it can be observed in **Figure 8-5**, the area with red tones shows the central areas that were involved in the wildfire. The areas starting from north-east continued towards central-north of the image, and the areas on the southern segments of the image have been identified as shadows and waterways because they all have low reflectance in the visible bands (B4 and B8) and high absorption in the SWIR band (B12). This results in low values for all three bands, which are interpreted as black by the display settings. Finally, healthy vegetation, on the other hand, appears green in this false colour image because it exhibits high reflectivity in the visible spectrum and low absorption in the SWIR band.

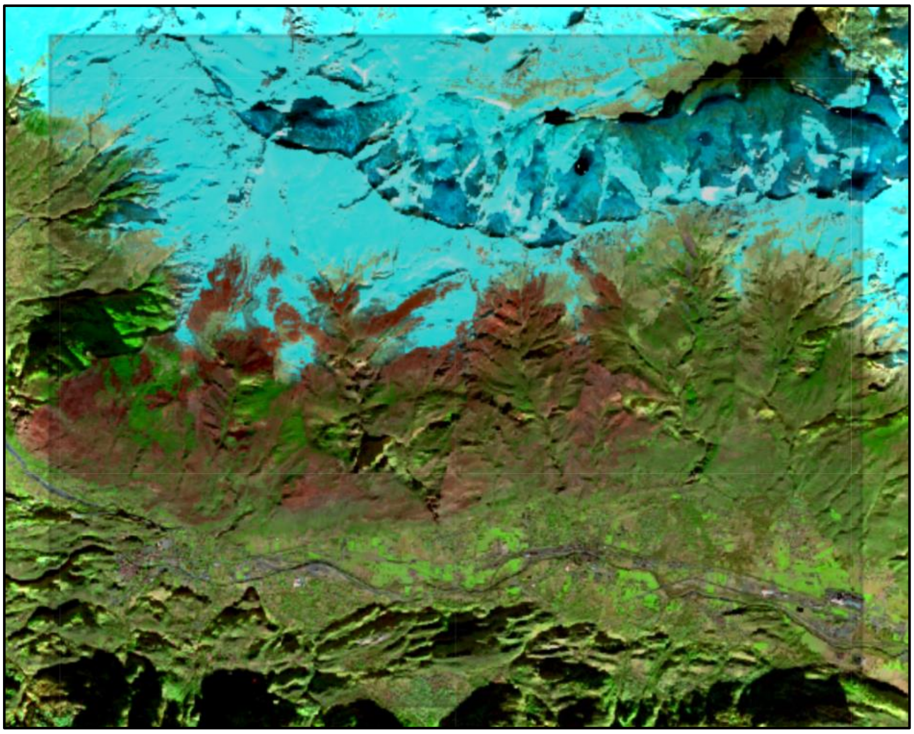


Fig.8-5.False Colour visualisation with band combinations of R:B12, G:B8, B:B4 and Gamma 1.55 on the post-fire Sentinel 2 image in date of 2017/11/16_Source:(Author)

If we compare the obtained results to the ***"FireCCI51: MODIS Fire_cci Burned Area Pixel Product, Version 5.1"*** dataset, available in GEE for burned area extraction, it is clear that the results of the calculation provide more accurate estimation of burned areas, also considering the categorisation of the remaining areas. This, of course, also depends on the difference in the spatial resolution between the two data (Sentinel2 vs. MODIS, i.e. 10m vs. 250m) Below there is an image of MODIS burned area for the area of analysis.

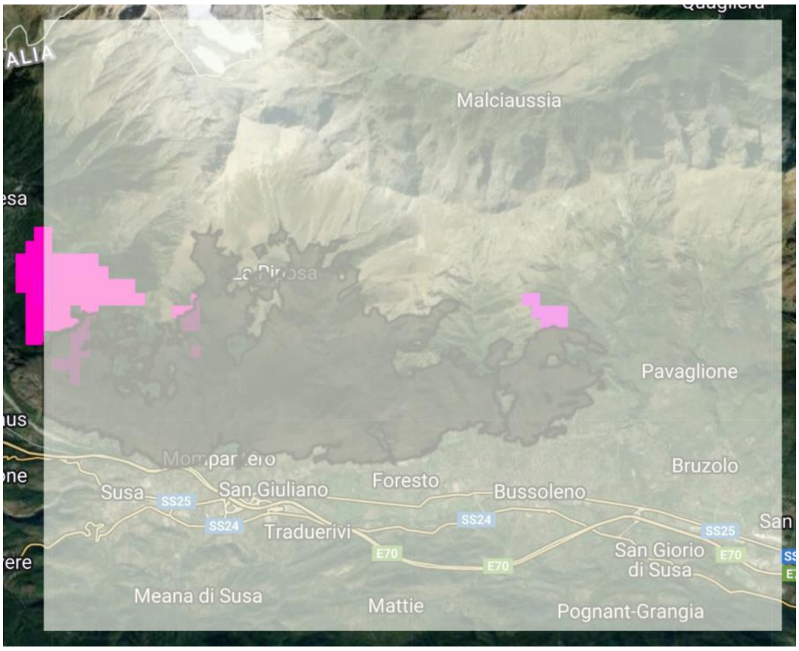


Fig.8-6.MODIS Fire_cci Burned Area for the area of analysis for the date of 2017/11/01_Source:(Google Earth Engine Website)

8.1.1.1.Statistics on Accuracy Assessment

In order to do verifications, the statistics acquired from the performed operations and calculations have been compared to the two main sources available publicly: The Copernicus Emergency Service report for the wildfire event of 2017 and also the archive of Wildfires in Piedmont Region “Sistema Piemonte-Banca Dati Incendi Boschivi”.

In order to get our results of statistics related to the burned area, an algorithm has been developed to automate the process of calculation (refer to **point 7.4.6** In **chapter 07** for further details on the process).

In short, the process included using a geometry object as an AOI which focuses on the burned areas, on which the algorithm is performed. The logical basis of the algorithm was to count the pixels that were identified as burned areas, and then the calculation of the area covered by such pixels and finally conversion into the unit of measurement (hectares). The obtained result by this methodology has been **2537.46** hectares of burned areas, which amounts to roughly **15% (15.4% precisely)** of the total area (ROI), being **16529.42** hectares.

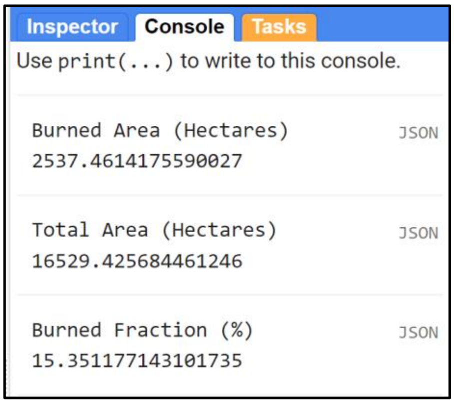


Fig.8-7.The results of the automated calculations printed in the console_Source:(Author)

The report in the Copernicus EMS included 17 municipalities in Piedmont and it stated the total burned areas to be **2451,2** (ha). On the other hand, investigating **the Regional archive** for the fire event of 2017, there is data available for 14 municipalities (3 of which do not exist in the CEMS report), and also from the municipalities that there are in the CEMS report, 5 of them do not have data associated to them regarding with that fire event of 2017. The results of this investigation in the regional archive have been reported below in table (8-1).

Another document backing up the findings of the research, is the **Piano AIB of the Piedmont Region(2021-2025)**, demonstrating a diagram of the annual area covered in the period 2000-2019 by small-scale events and large-scale events (Fig.6-26), where for the year 2017, almost **12000** hectares were involved in fire, most of them in the Turin and Cuneo provinces, in the Susa Valley zone.

Code	Date	Locality	Comune	Forested Surface(ha)	Non-forested Surface(ha)	Total Surface (ha)
2017_000196	22/10/2017	CALUSETTO	BUSSOLENO (TO)	3102,91	915,66	4,018.57
2017_000184	15/10/2017	MONTABONE	VENAUS (TO)	0,69	0,0	0.69
2017_000172	07/10/2017	STRADA DELLA MONTAGNA	BRUZOLO (TO)	0,11	0,0	0.11
2017_000188	18/10/2017	PEROLDRADO	CAPRIE (TO)	256,0	0,0	256.00
2017_000239	28/10/2017	GIORDA SUPERIORE	RUBIANA (TO)	0,06	0,0	0.06
2017_000201	22/10/2017	GIANGALLO	RUBIANA (TO)	35,22	0,0	35.22
2017_000200	22/10/2017	NON DISPONIBILE	RUBIANA (TO)	0,0	0,0	0.00
2017_000199	22/10/2017	SAGNERA	RUBIANA (TO)	0,05	0,0	0.05
2017_000180	13/10/2017	MONTE GIORANO	RUBIANA (TO)	19,53	0,0	19.53
2017_000222	25/10/2017	SALAMOCCA/TRAUNT	TRAVERSELLA (TO)	250,95	372,97	623.92
2017_000198	22/10/2017	PIU LOCANA E SPARONE	RIBORDONE (TO)	1440,56	129,2	1,569.77
2017_000244	31/10/2017	STRADA PROVINCIALE 166	SAN GERMANO CHISONE (TO)	0,05	0,0	0.05
2017_000221	25/10/2017	BORGATA BALMASSI	SAN GERMANO CHISONE (TO)	1,23	0,0	1.23
2017_000170	05/10/2017	MURET	PERRERO (TO)	499,6	169,03	668.63
2017_000222	25/10/2017	SALAMOCCA/TRAUNT	TRAVERSELLA (TO)	250,95	372,97	623.92
2017_000186	17/10/2017	CUMIANA 10040	CUMIANA (TO)	1818,25	0,0	1,818.25

2017_000182	15/10/2017	PIANTERO-CASTELMARTINO	CORTEMILIA (CN)	6,01	0,0	6.01
2017_000209	23/10/2017	PONTE BOFFA	CASTELDELFINO (CN)	378,02	0,0	378.02
2017_000207	23/10/2017	BRICCO LA PELATA	BARGE (CN)	2,08	0,0	2.08
					TOTAL BURNT AREAS(ha)	**10,022.11**

Table 8-1.Wildfire Data for the event of 2017 available in the regional Archive_Source: (Sistema Piemonte Website- Banca dati incendi boschivi)

The result of these comparisons have been concluded with some challenges related to incongruency in the data available in the Regional archive, and the report done by the Copernicus EMS service. This problem has been explained in more detail regarding the missing data in both sources, and continues to persist when it comes to the final statistics about the fire event of 2017 (**10,022.11** hectares in the regional archive and **2451,2** hectares in the CEMS). The same problem exists with the AIB plan reports about the fire event of 2017 and the municipalities involved.

In any case, considering the fact that the area of analysis is the same as the area of analysis for the Copernicus CEMS maps, also the results of Burned Surface area calculation is very close to the Copernicus product. Even though the calculations obtained a higher value, it is justifiable because of the existence of shadowed areas and waterways areas that resulted in similar values as in the burned areas. Table 8-2 summarises the results of different sources for burned area surface and percentage of burned area.

	Copernicus Delineation Map	**Piano AIB**	**Regional Archive**	**Calculation of the research in GEE**
Total Burnt Area(ha)	2451,2	12000	10,022	**2537.46**

Table 8-2.Wildfire Data for the event of 2017 available in the regional Archive_Source: (Author)

8.1.1.2.Statistics on Data Analysis

In order to depict NBR values distribution, histograms are developed for pre-fire and post-fire NBR images (explanation of methods in point 7.2.6.1.Statistics on NBR_Burned Area Extraction). The information in the diagram **(Fig.8-8)** indicates that the majority of the pixels have values in the range of 0.1 to 0.3 in the pre-fire histogram; this finding would suggest that the study area's pre-fire vegetation was primarily made up of healthy, green vegetation before the fire.

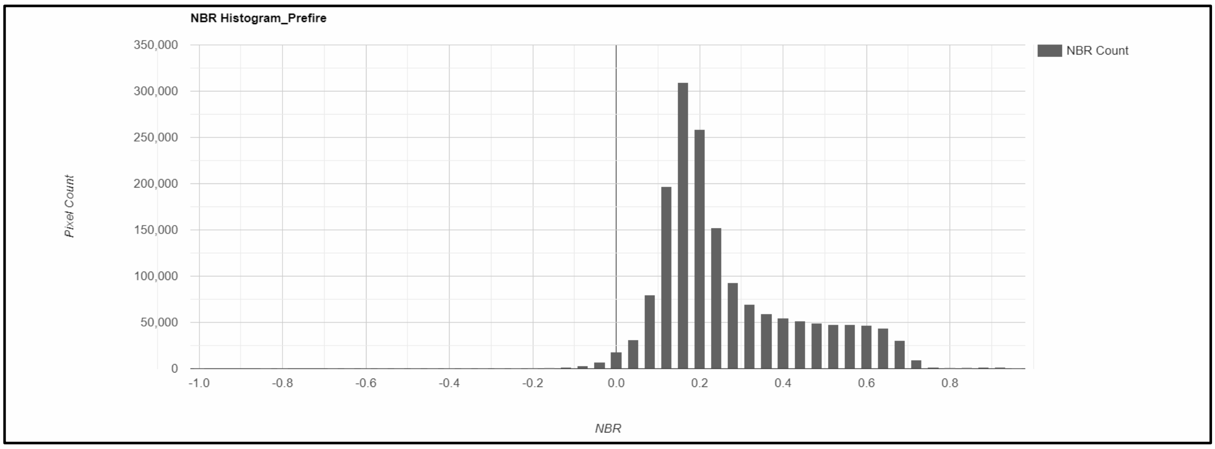


Fig.8-8.Pixel Distribution Histogram for pre-fire NBR image_Source:(Author)

On the other hand, The Normalised Burn Ratio (NBR) histogram for the post-fire image illustrates the highest pixel count in the range of -0.2 to 0.2 (Fig.8-9). We know that the negative values indicate burned areas and positive values of NBR indicate unburned areas, and so healthy vegetation.
Taking a general look, it may be said that a burn area with an NBR value in the range of -0.2 to 0.3 is considered to be of relatively low severity and to have a mixture of burned and unburned vegetation. This might be the outcome of a low intensity fire or a mosaic burn pattern, where different vegetation patches have undergone varying degrees of severe burning.

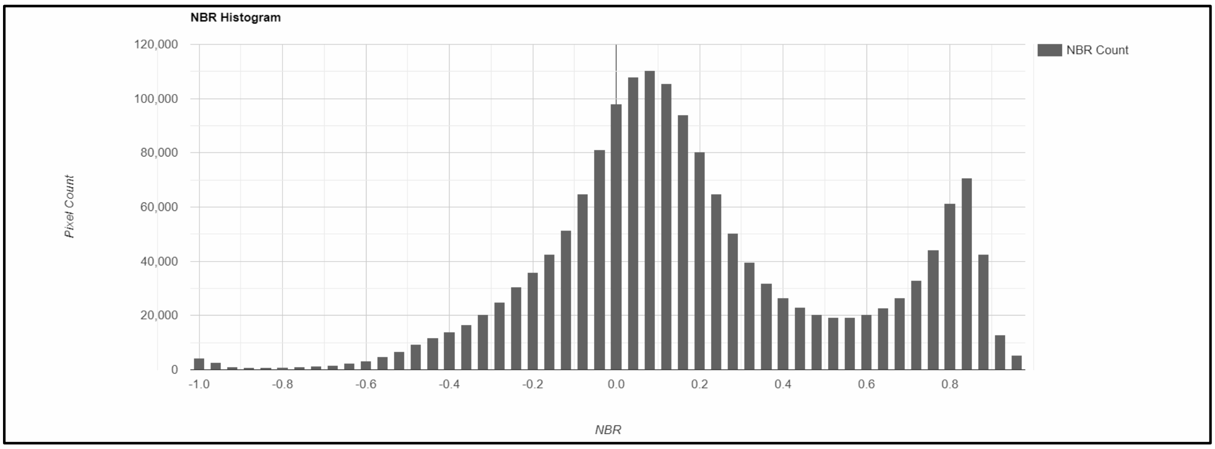


Fig.8-9.Pixel Distribution Histogram for post-fire NBR image_Source:(Author)

In order to have a more clear understanding of the situation of the burned areas and the characteristics of the fire, a histogram specifically for the burned area mask was calculated. A closer inspection of the diagram suggests that the number of pixels starts to have an increasing trend from -0.7, with a peak in -0.2. A moderate to high severity burn is typically characterised by NBR values in the range of -0.2 to -0.4, with the vegetation in the burned areas suffering severe damage. Additionally, NBR readings between -0.2 and -0.1 point to low severity burns in the burned areas with little to no impact on the vegetation. The burned regions have generally lost some of their greenness, according to the negative NBR readings, but there may still be a lot of green vegetation there.
This diagram will get us a more holistic picture by incorporating another diagram that illustrates the burn severity histogram and statistics.

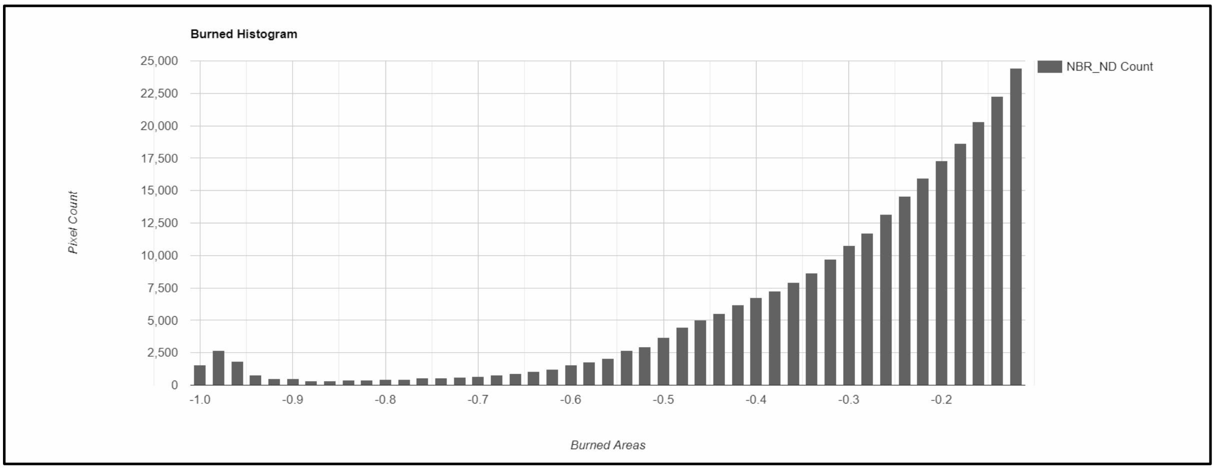


Fig.8-10.Pixel Distribution Histogram for post-fire Burned Areas Mask image_Source:(Author)

8.1.2.Burn Severity Result

The differenced Normalised Burn Ratio (dNBR) is a commonly used index for assessing burn severity in remote sensing. It is calculated by subtracting the post-fire NBR (Normalised Burn Ratio) from the pre-fire NBR (to see details, refer to 7.2.4.2.Burn Severity Analysis section). The image (see Figure 8-11 below) has been classified into 7 categories based on the values of dNBR for each pixel. The areas of CEMS delineation are also present in the image. The northern areas have been identified as areas with "high-enhanced regrowth" (army green) which refers to the post-fire vegetation response in burned areas. In this specific case, it represents the vegetation not involved in the fire event, so perfectly healthy.
The burned area in the centre of the image (contained in the CEMS delineation), is concentrated mostly on the southern part of the delineation area, focused towards western edges and is characterised by moderate-high burn severity and high severity. In general, after a fire, different tree plant species or vegetation types may respond differently to the disturbance, depending on their ability to regenerate and grow back.

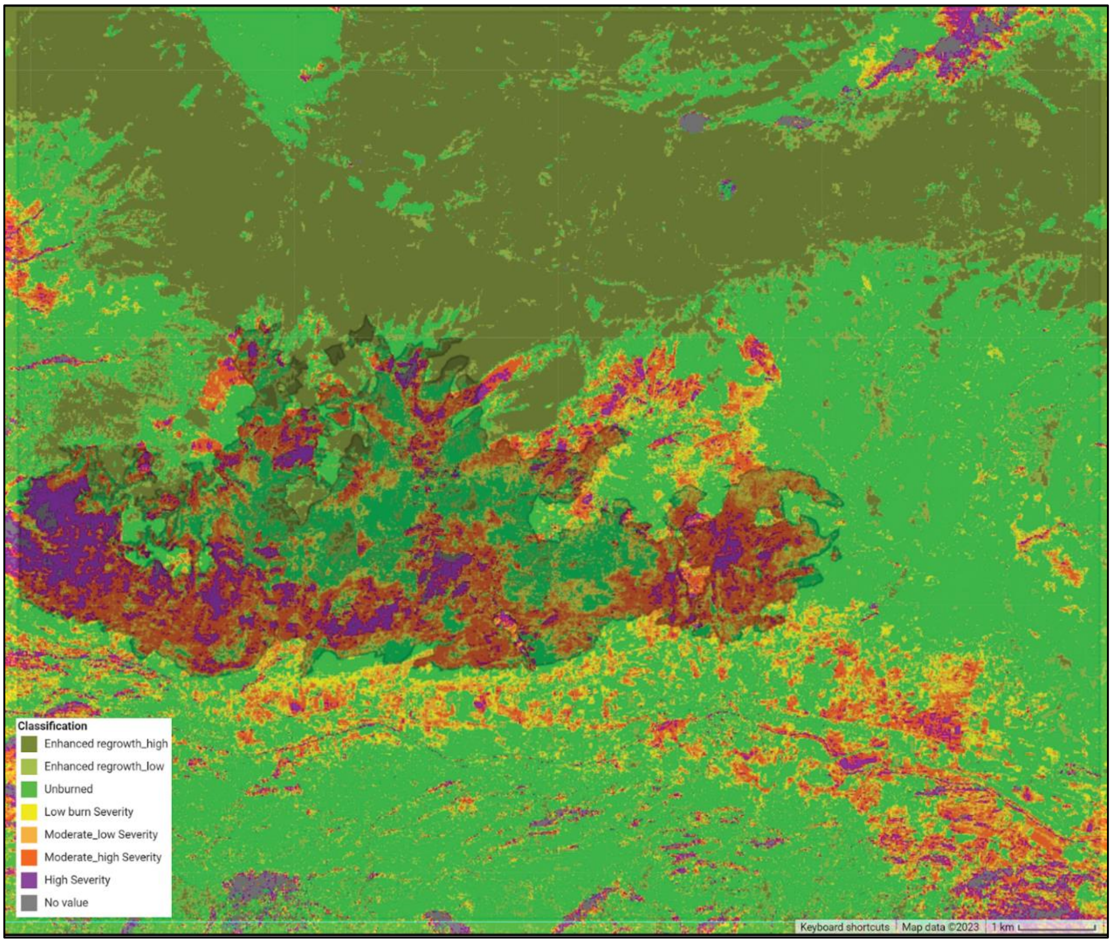


Fig.8-11.Burn Severity Calculation performed on Sentinel 2 images (pre-fire and post-fire) sensed on the dates of 2017/06/19_Source:(Author)

8.1.2.1.Statistics of Burn Severity

The delta Normalised Burn Ratio (dNBR) index computes the difference in the NBR between two time periods by comparing an area's pre-fire and post-fire spectral reflectance values.
Positive dNBR readings show an increase in post-fire reflectance relative to pre-fire reflectance, which can be attributed to a decrease in live vegetation and an increase in exposed soil, ash, and char. This signifies a more severe burn and more damage to the grass cover. In addition, burn severity criteria are often determined based on field observations of vegetation and soil conditions in burned regions, and they are frequently calibrated to specific fire regimes and vegetation species. Higher dNBR values are generally

related with more severe fire effects, such as increased tree death, soil erosion, and loss of vegetation cover.
Negative dNBR readings show a decrease in post-fire reflectance when compared to pre-fire reflectance, which can be produced by the existence of unburned vegetation or by vegetation regrowth following the fire. Negative dNBR values imply that the fire was less severe and caused less damage to the vegetation cover.
The histogram in fig.8-14 depicts the distribution of the pixels for each NBR value/range. As it can be observed, there are two peaks, one lower, with the peak between -0.75 and -0.50 dNBR, indicating moderate burn severity; and the other that encompasses a larger number of pixels from 0.00 and 0.25 which are signs of higher burn severity.

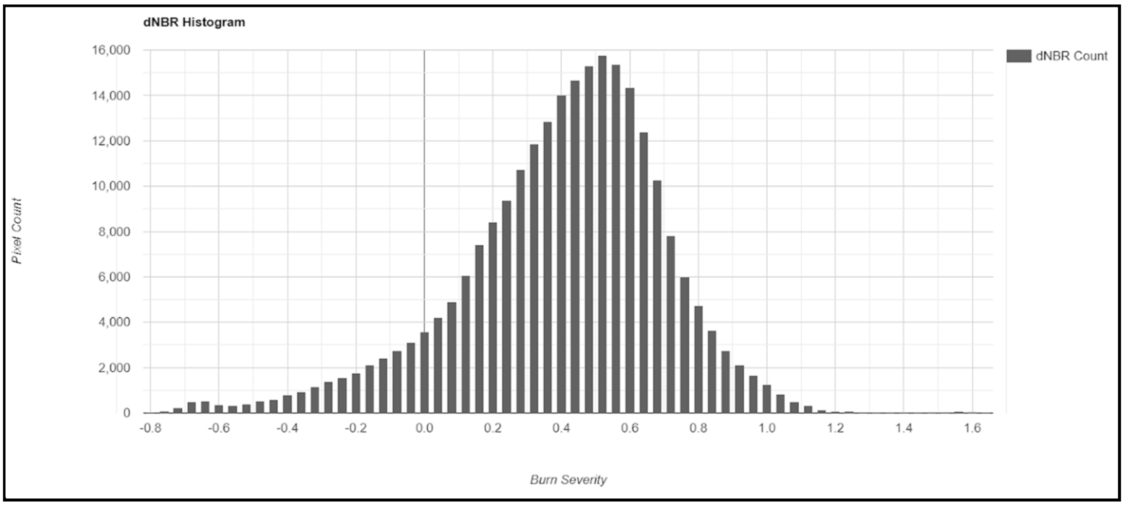


Fig.8-12.Pixel Distribution Histogram for dNBR(Burn Severity) image_Source:(Author)

Figure 8-13 shows the pixel distribution of dNBR, this time for each category. This diagram also demonstrates what the map had depicted earlier. Most of the areas are classified as unburned and enhanced regrowth category, which when referring back to the image and to the 3D model, we realise those areas belong to the peaks which are frequently covered by snow. The burned areas including low severity, moderate low severity, moderate high severity and high severity have similar distributions. Among the burned areas, moderate-high severity areas had the most number of pixels allocated to it, followed by low severity, moderate-low severity and high severity respectively. In order to explain the statistics better, the area covered by each category has been calculated.

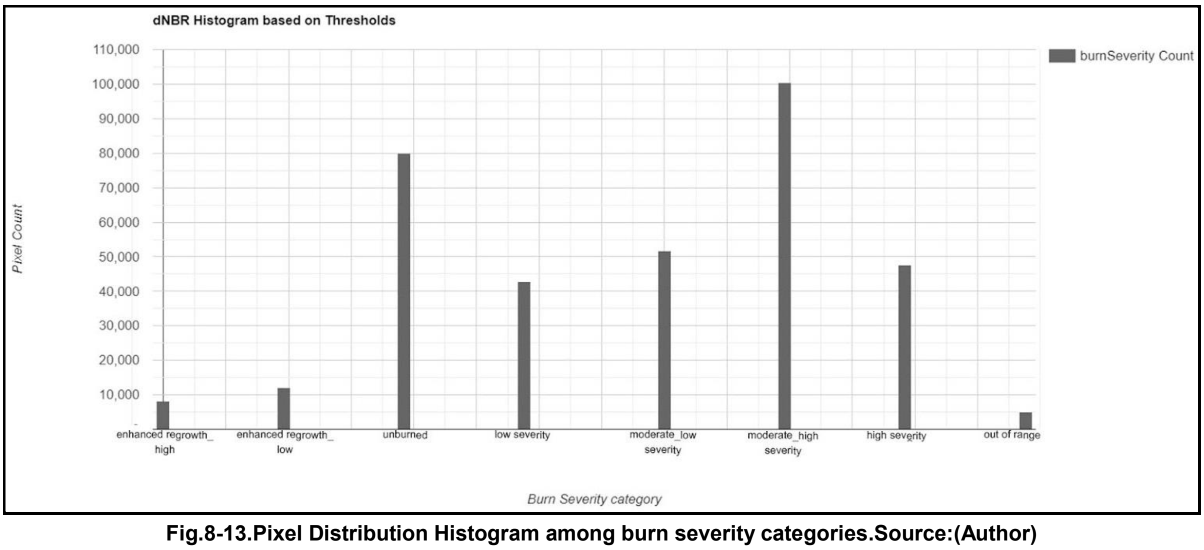


Fig.8-13.Pixel Distribution Histogram among burn severity categories.Source:(Author)

Table 8-3 summarises the statistics of the surface area and the percentage of the area covered by each burn severity category.

Severity grade	High severity	Moderate-High Severity	Moderate-Low Severity	Low Severity	Total Burned Area (ha)	Total Area (ha)
Area(ha)	513.10	983.29	528.24	577.71	**2,602**	16678.29
Percentage(%)	3.07%	5.89%	3.16%	3.4%	**15.5%**	

Table 8-3.Statistics on the surface area covered by different burn severity category_Source:(Author)

8.1.3.Vegetation Recovery (NDVI)

The difference in reflectance of near-infrared and red light is used to calculate NDVI, which is heavily impacted by the quantity of green vegetation present. A high NDVI number suggests that the vegetation is healthy and green, whereas a low NDVI value indicates that the vegetation is stressed or scarce. NDVI is excellent for monitoring vegetation health and detecting changes over time, but it is less useful for assessing fire damage, which usually results in full loss of vegetation. In this research, it was used in order to monitor the vegetation recovery over the years.

In order to achieve a proper vegetation recovery analysis, the trend of NDVI index was considered and consequently NDVI values were computed for the three different periods of analysis, i.e., pre-fire (2017), post-fire (2019) and present (2022). Relative statistics were also computed for the 3 considered years, and compared, thus allowing the assessment of the vegetation status in the study area.

Regarding the pre-fire period (July 2017), as the map illustrates the northern part of the area (which encompass mountainous area), the vegetation cover is sparse vegetation such as grassland/shrubland (dark red) or vegetation that has newly grown or that is in a degraded state (red). The outskirts and the areas along the river seem to have very high vegetation cover (yellow) and the further we get from the outskirts, the vegetation cover gets denser categorised as extremely dense and near optimal vegetation which is for forested area.

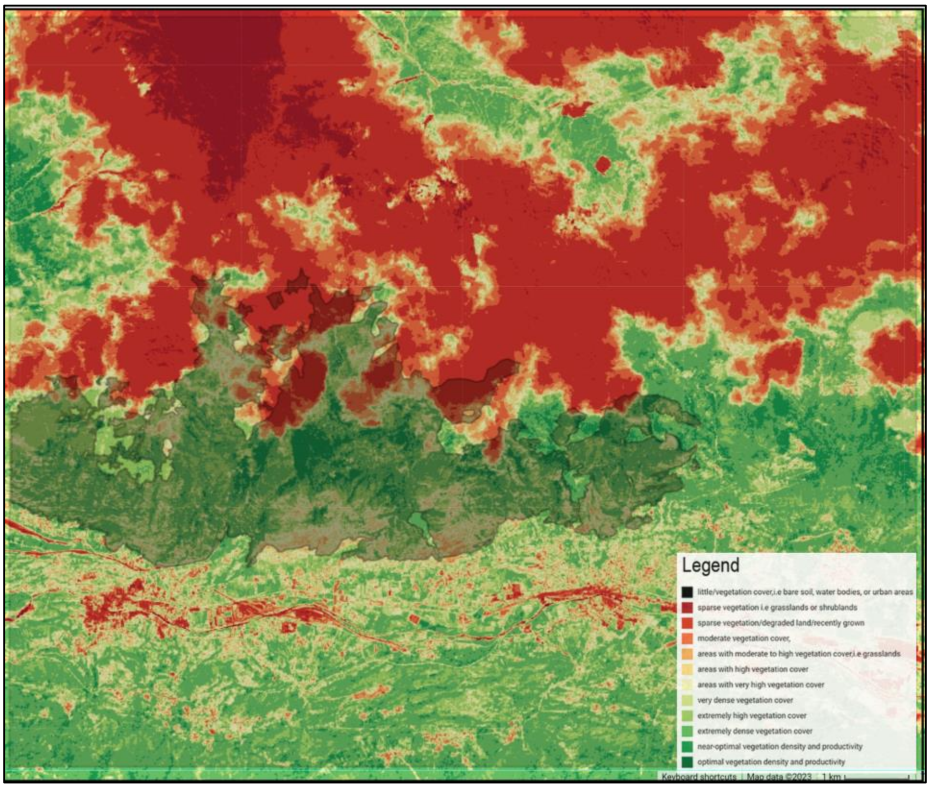


Fig.8-14.Normalised difference Vegetation Index(NDVI) calculated for vegetation recovery analysis for pre-fire period_ calculation performed on pre-fire Sentinel 2 image sensed on the date of 2017/07/04_Source:(Author)

The generated true colour band combination visualisation (Fig.7-04) demonstrates the presence of clouds in the areas identified with low NDVI values. We also can observe areas with no vegetation (areas in the peak) and the ones covered by the snow.

Taking a look at the histograms of the pre-fire also it is evident that the NDVI values range from 0 to 0.85, with peak values in the range of 0.7 and 0.8, meaning that all the pixels had a positive value. For pixels having 0 and positive values however, the distribution is more even and the number of the pixels starts to have a decreasing trend from values around 0.1 to 0.25.

The areas with moderately dense and robust vegetation are shown by the **peak at 0.7 and 0.8**, which represent extremely dense vegetation cover such as **older forests with high biomass**.

The presence of this distinct peak in the NDVI histogram suggests that for the most part, the area was characterised by healthy and dense vegetation, and less number of pixels having moderate health/density, identifiable as patches of different categories (less gradual values).

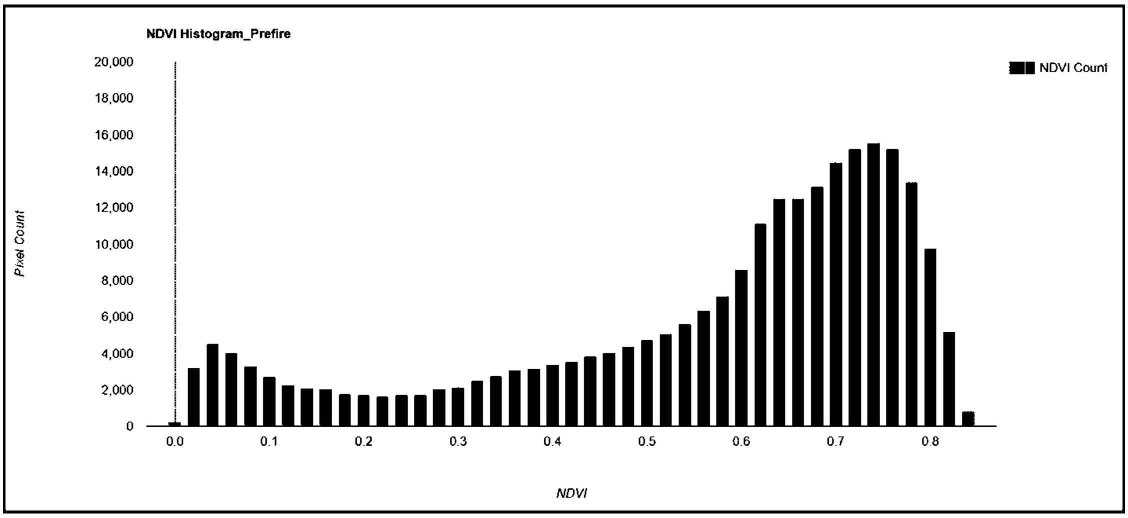


Fig.8-15.Pixel Distribution Histogram for pre-fire NDVI image_Source:(Author)

The next histogram (Fig.8-16) which categorises the pixel distribution based on the thresholds (vegetation category) also confirms the existence of two peaks at the two ends of spectrum. It is also evident that even though a large number of pixels (around 620,000 pixels) were categorised as degraded vegetation cover or recently grown vegetation, the maximum number of pixels in the image (over 690,000 pixels) were in the category of extremely dense vegetation (such as forest).

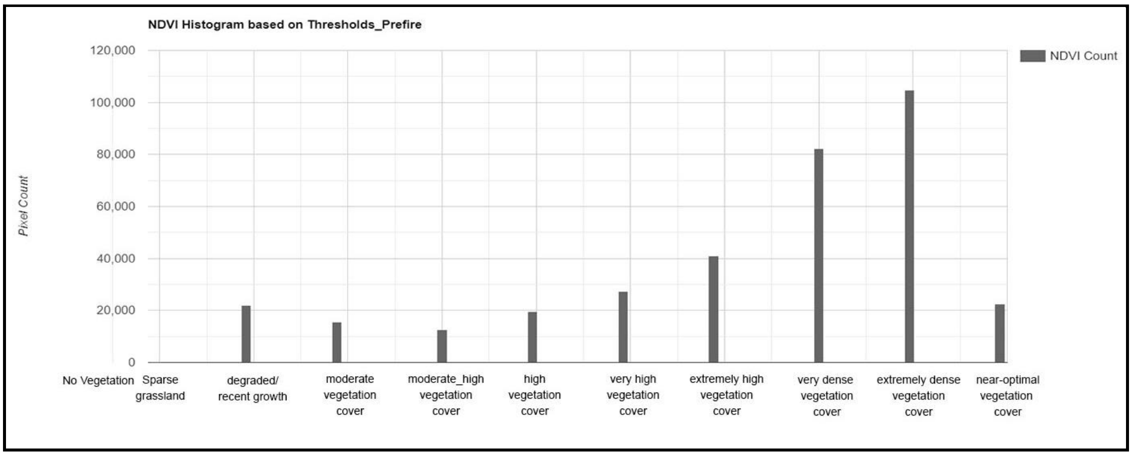


Fig.8-16.Pixel Distribution Histogram for pre-fire NDVI image categorised by vegetation cover type_ Source:(Author)

The post-fire situation, looking at the NDVI image, might seem similar to the pre-fire situation, so we have to get better insights looking more closely into the statistics to find out the differences.

We know for a fact that fire can alter the structure of vegetation, resulting in changes to the canopy cover, leaf area index, and other factors that can affect NDVI values. For example, if the fire removed a significant amount of vegetation, this could result in a lower pre-fire NDVI value in some areas. Basically, if the fire created gaps in the canopy that allowed more light to reach the ground, this could result in a higher post-fire NDVI value. So the areas that seem to have higher NDVI values on the post-fire image, can be in fact the areas that the canopy has experienced some vegetation loss.

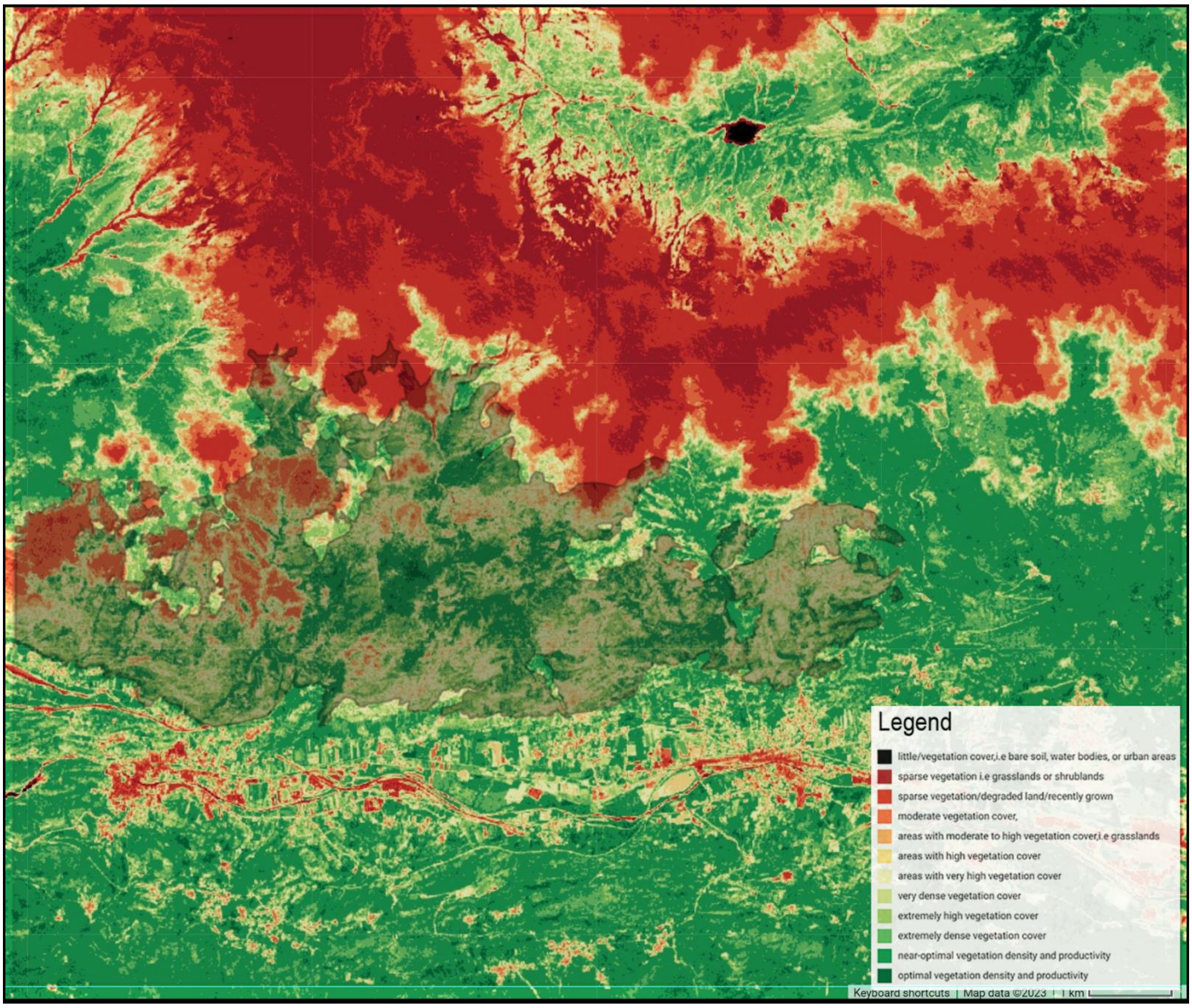


Fig.8-17.Normalised difference Vegetation Index(NDVI) calculated for vegetation recovery analysis for post-fire period_ calculation performed on post-fire Sentinel 2 image sensed on the date of 2018/06/19_Source:(Author)

With the true colour band combination visualisation (Fig.8-18) it can be concluded that the low-NDVI areas include cloudy areas, snow-covered areas and arid lands (in central-left side of the image) and water bodies with very low NDVI values, and some waterways such as Dora river with some vegetation elements in them (such as algae and other vegetation types being in water). In the post-fire true colour image, the patches of burned areas are also visible in reddish colour (mostly concentrated on the central-left section of the image).

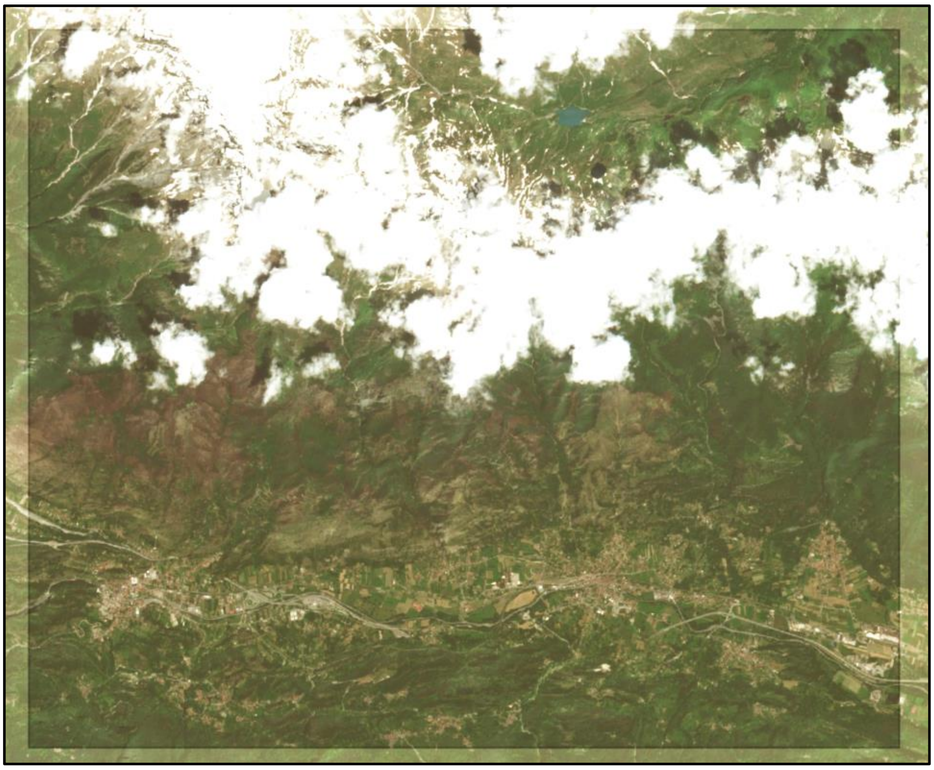


Fig.8-18.True colour visualisation of the post-fire image_ calculation performed on post-fire Sentinel 2 image sensed on the date of 2018/06/19_Source:(Author)

Taking a look at the histograms of the post-fire also it is evident that the NDVI values range from -0.1 to 0.9, with peak values in point 0.8. The post-fire pixel distribution diagram demonstrates less sudden fluctuations in the values compared to the pre-fire condition and the peak for the dense vegetation does not exist anymore. In addition, we have some negative values too. Overall, post-fire situation has positive values for NDVI, but less number of pixels for dense vegetation. The positive value of NDVI could be associated with the higher soil moisture in 2018 compared to 2017 despite the extensive fire.

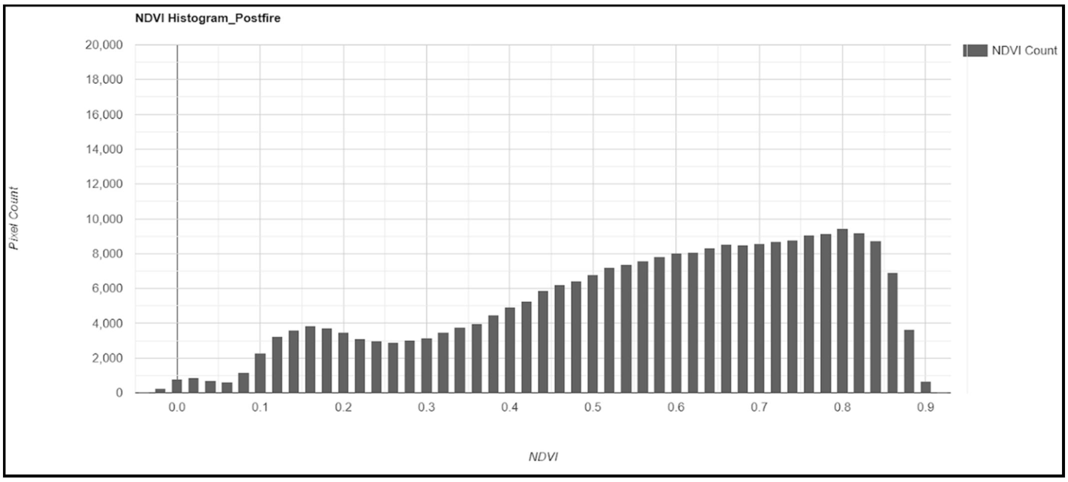


Fig.8-19.Pixel Distribution Histogram for post-fire NDVI image_Source:(Author)

Fig.8-20 illustrates the NDVI categories histogram, highlighting the same extreme behaviour of pixel distribution for different NDVI values. According to this diagram, the majority of pixels had NDVI values referring to near-optimal vegetation cover which are characterised by near-optimal vegetation density and productivity, such as highly productive croplands or other ecosystems with high biomass. For other NDVI classes there are comparatively very less number of pixels.

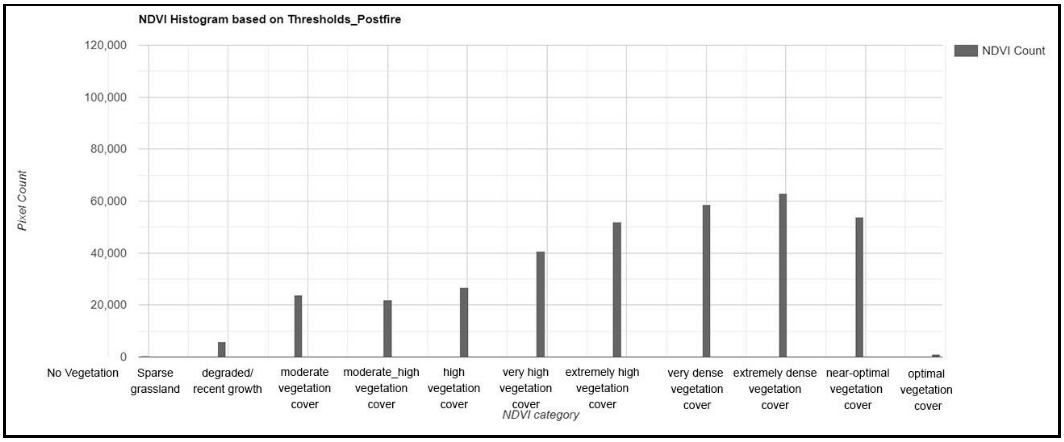


Fig.8-20.Pixel Distribution Histogram for post-fire NDVI image categorised by vegetation cover type_Source:(Author)

The present (2022) NDVI analysis map (Fig.8-21) suggests that vegetation recovery following the wildfire is showing promising signs. In fact, more pixels are classified as having a very high vegetation cover (yellow areas), extending their reach on higher altitudes, where previously was categorised as sparse vegetation/grassland or degraded land with recently grown vegetations.

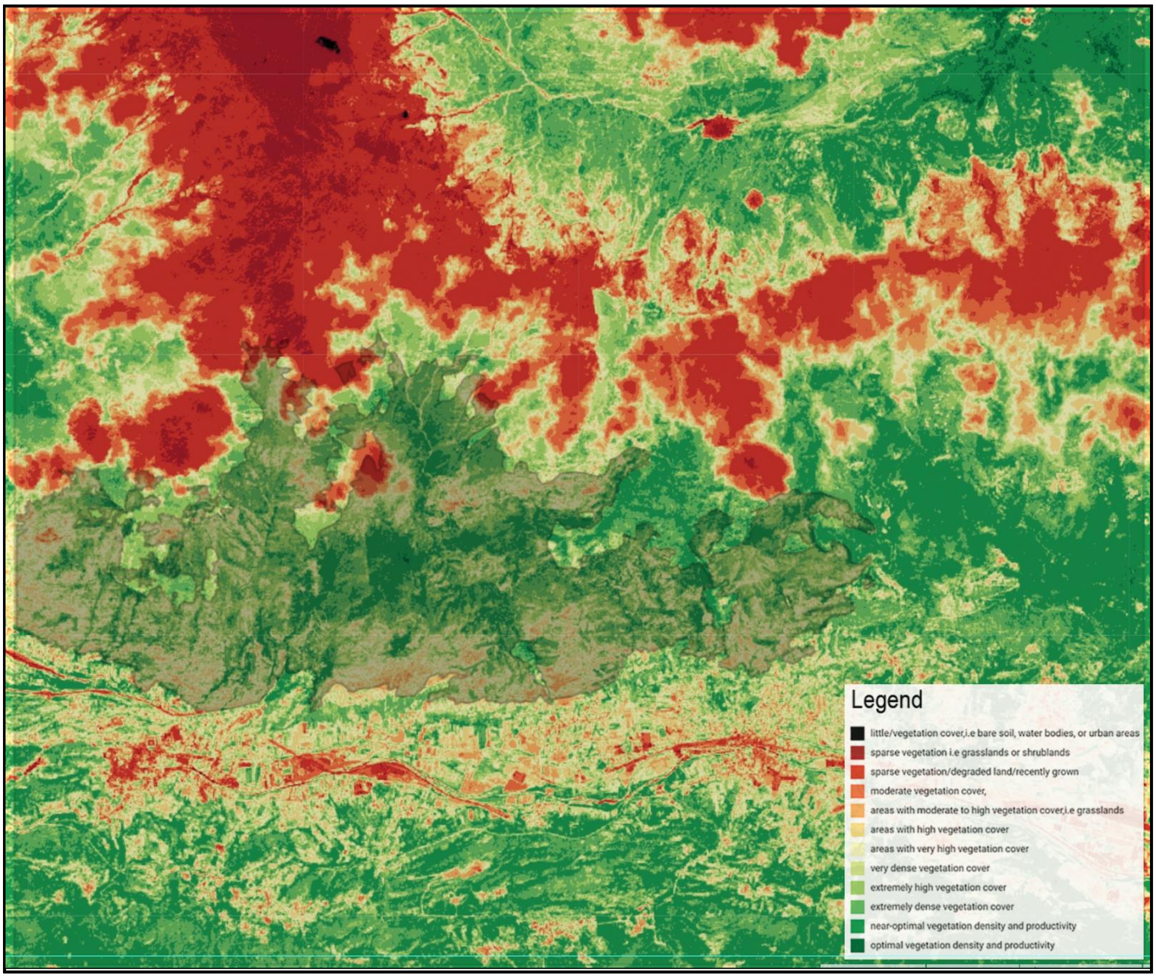


Fig.8-21.Normalised difference Vegetation Index(NDVI) calculated for vegetation recovery analysis for post-fire period_ calculation performed on post-fire Sentinel 2 image sensed on the date of 2022/06/18_Source:(Author)

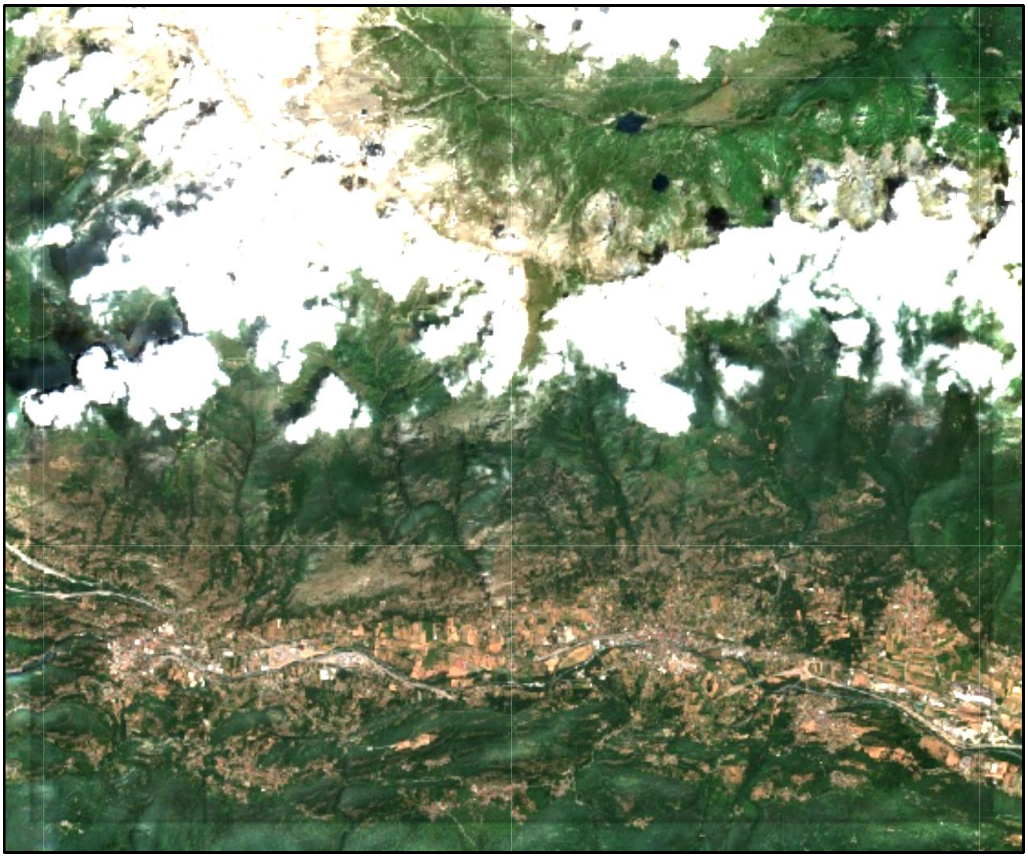


Fig.8-22.True colour visualisation of the present (2022) image_ calculation performed on present (2022) Sentinel 2 image sensed on the date of 2022/06/19_Source:(Author)

The pixel distribution histogram of the present situation NDVI analysis (Fig.8-24) depicts smoother changes between different values of NDVI. The number of pixels with higher NDVI value are clearly higher than the post-fire situation, with a no negative pixels, indicating healthier state of vegetation and higher soil moisture with respect to previous conditions.

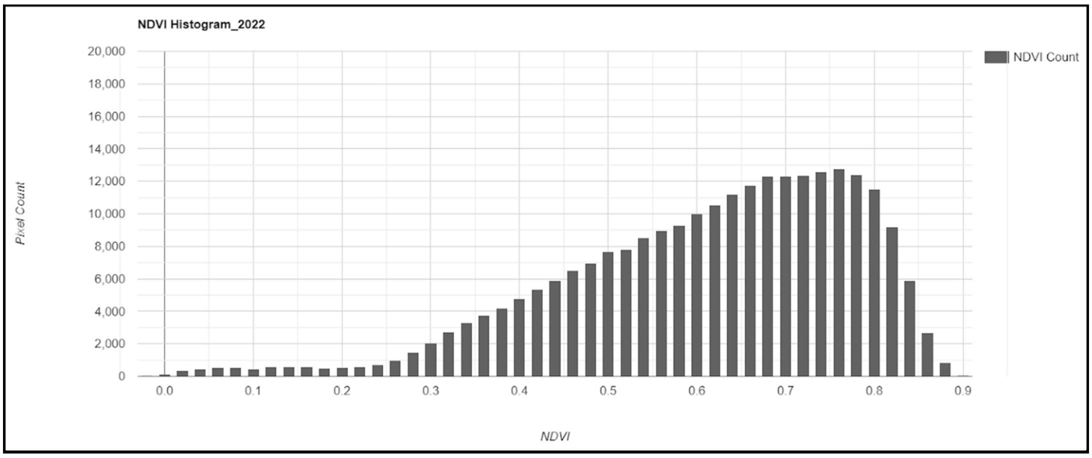


Fig.8-23.Pixel Distribution Histogram for present NDVI image(2022)_Source:(Author)

(Fig.8-24) illustrates the NDVI categories histogram, characterised by a more uniformed distribution for different NDVI values. In this diagram the pixel distribution is more homogeneous with a majorly ascending trend, having a peak for extremely dense vegetation (such as old forests and high biomass ecosystems) cover and near-optimal vegetation cover such as highly productive croplands or other ecosystems with high biomass.

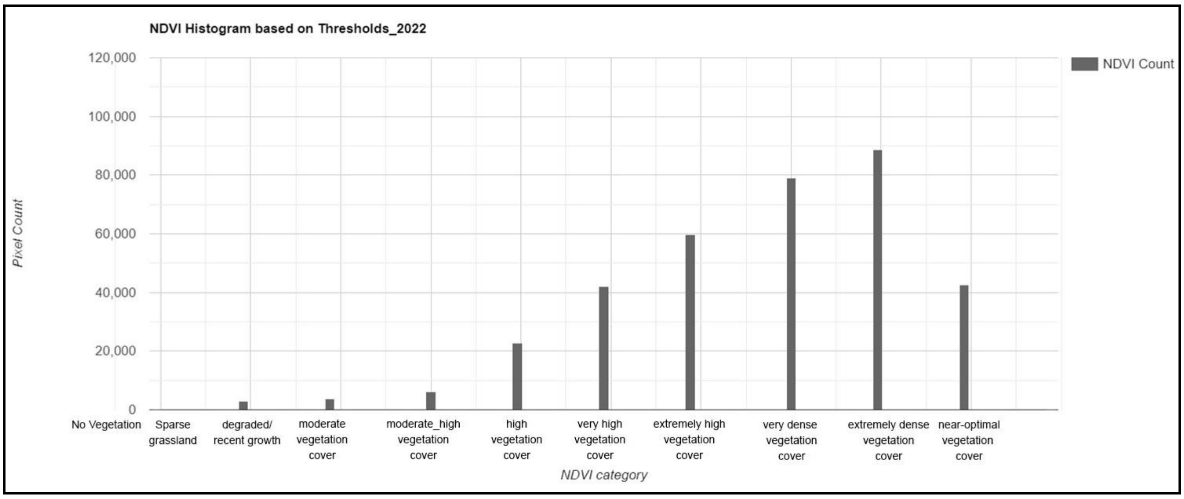


Fig.8-24.Pixel Distribution Histogram for present NDVI image(2022)_Source:(Author)

The following scatter plot (Fig.8-25) demonstrates the vegetation recovery trend using NDVI index, considering pre-fire, post-fire and present (2022) allowing us to assess the vegetation dynamics in the study area.

The scatter plot displays three data points, one for each year (2017, 2018, and 2022), with NDVI values drawn on the y-axis and years plotted on the x-axis. The graphic indicates a clear pattern of dropping of NDVI values from 2017 to 2018, followed by a sharp increase from 2018 to 2022. The NDVI score in 2017 was 0.574, then fell to 0.568 in 2018, before rising to 0.622 in 2022.

The scatter plot indicates that there was some variance in the health and vigour of the vegetation in the study region over the three-year period following the wildfire. The drop in NDVI values from 2017 to 2018 could be attributed to wildfire effects on plants, such as reduced vegetation cover or damage to photosynthetic tissues. The subsequent rise in NDVI values from 2018 to 2022 may indicate that the vegetation in the study area is recovering from the effects of the wildfire, as new growth and regrowth occur. However, it is crucial to remember that other factors, such as changes in land use, soil conditions, or other environmental factors, could have contributed to the changes in NDVI values.

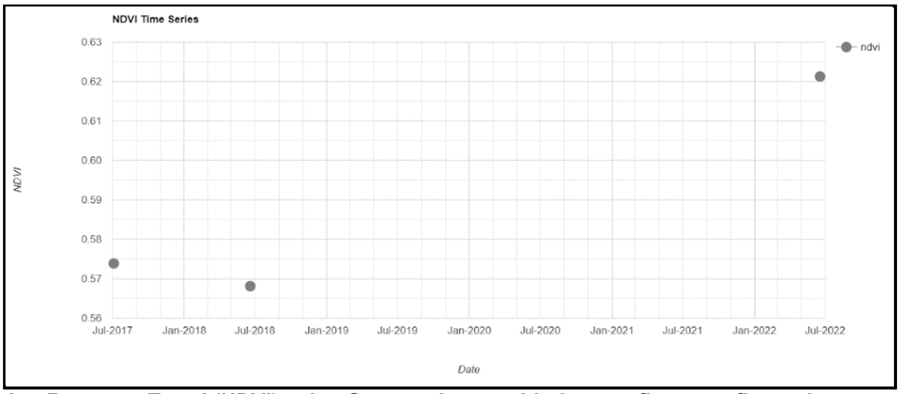


Fig.8-25.Vegetation Recovery Trend (NDVI) using Scatter plot considering pre-fire, post-fire and present (2022) images_ Source:(Author)

8.2.Three Dimensional Models

The 2D analysed satellite images are a valuable source of information on their own. However, 3D models might offer extra insights, thanks to the immersive visualisation they offer, that are not immediately obvious in a 2D image. Namely, 3D models can provide us with immediate understanding of the spatial context, topographic information while improving and complementing the 2D visualisation. This section presents some of the added values and insights deriving from the visualisation of analysis results as a 3D model, one for considered years of analysis, i.e. one for pre-event, one for post-event and one for the present.

Each 3D model followed the same following development approach: the elevation data as the base layer (SRTM), overlaid by the specific analysis output and converted to 3D using the qgis2threejs plugin.

8.2.1.3D Model of Pre-event

This model highlights the lower NDVI values on the higher elevations and higher NDVI values for the lower elevations. As visible in the true colour visualisation **(Fig.7-5)**, on the peaks of the mountains where there was snow, non-vegetated area and sparse vegetation or the image had a few clouds, there were lower NDVI values.

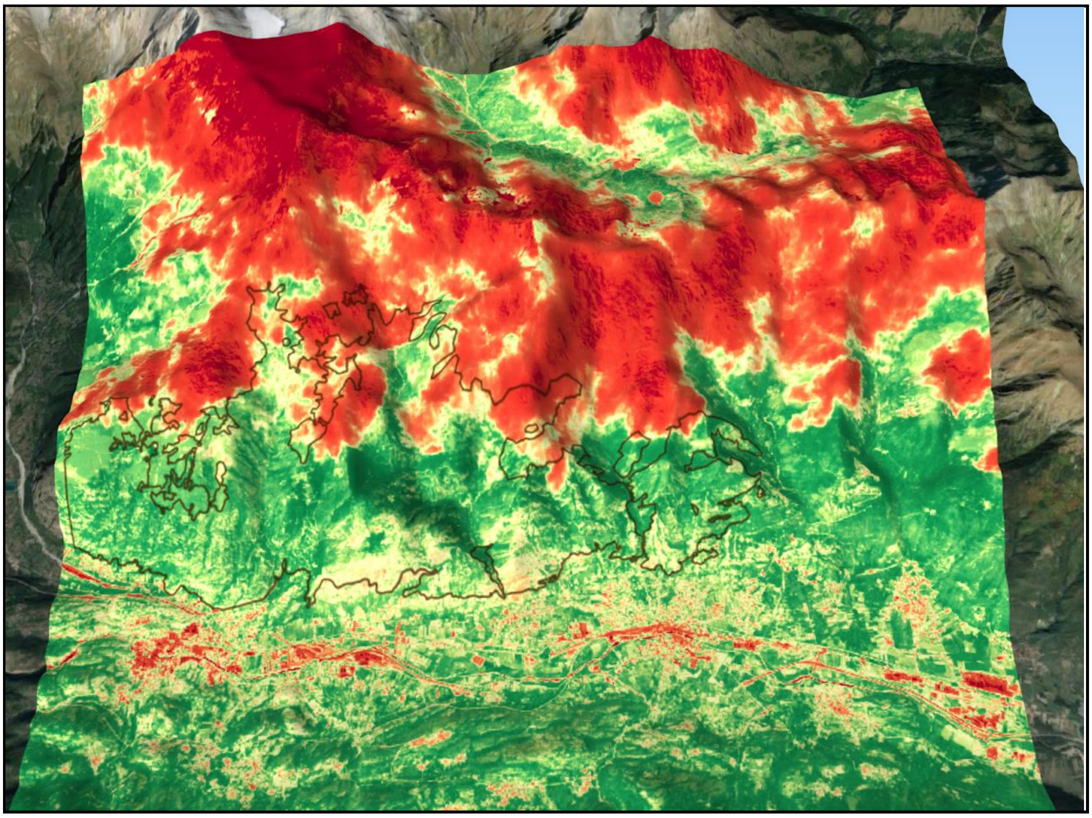


Fig.8-26.Vegetation Recovery NDVI pre-fire 3D model_Source:(Author)

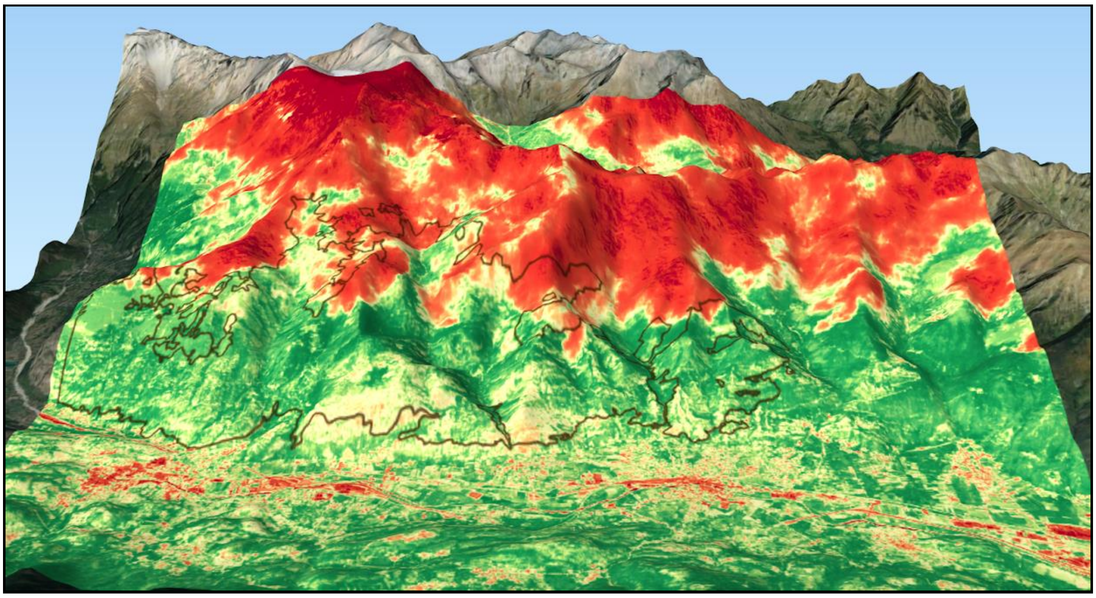


Fig.8-27.Vegetation Recovery NDVI pre-fire 3D model_Source:(Author)

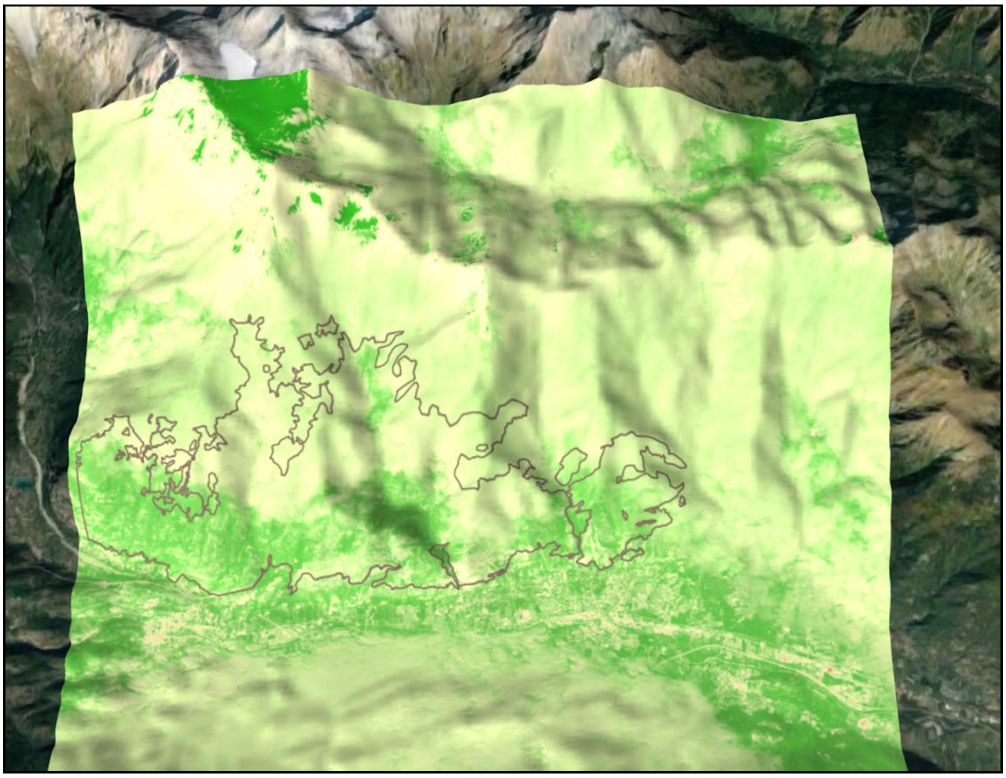


Fig.8-28.pre-fire NBR 3D model_Source:(Author)

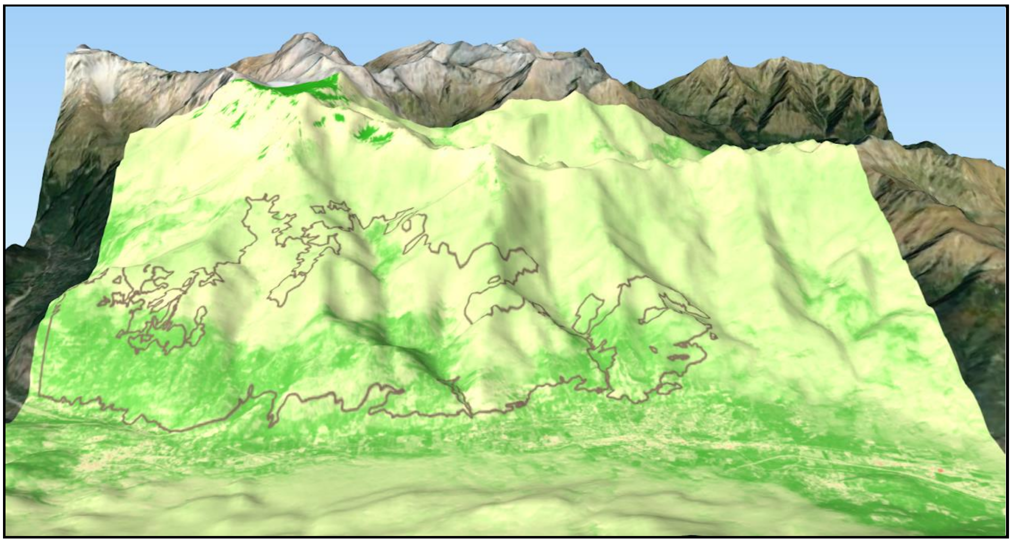


Fig.8-29.pre-fire Burned area extraction(NBR) 3D model_Source:(Author)

8.2.2.3D Model of the Post-event

Similar to the pre-fire image, this model highlights the lower NDVI values on the higher elevations and higher NDVI values for the lower elevations. As visible in the true colour visualisation (Fig.8-30), some parts of the low NDVI values were covered by the snow and non-vegetated areas and a big portion also belonged to the areas covered by the clouds. It is also evident that waterways show to have some minimum NDVI values (instead of values near -1 to appear black) so they appear red. It can be a sign of some vegetational life in those waterways.
Ascending from the mountain, near the mountain base, the vegetation health is in a better condition.

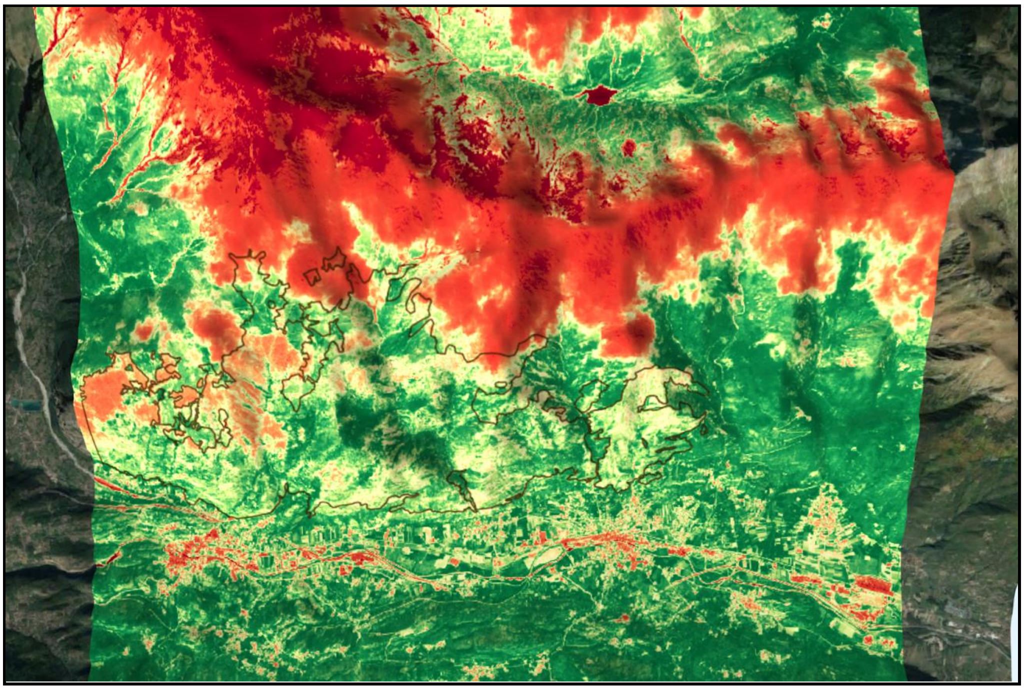


Fig.8-30.Vegetation Recovery NDVI post-fire 3D model_Source:(Author)

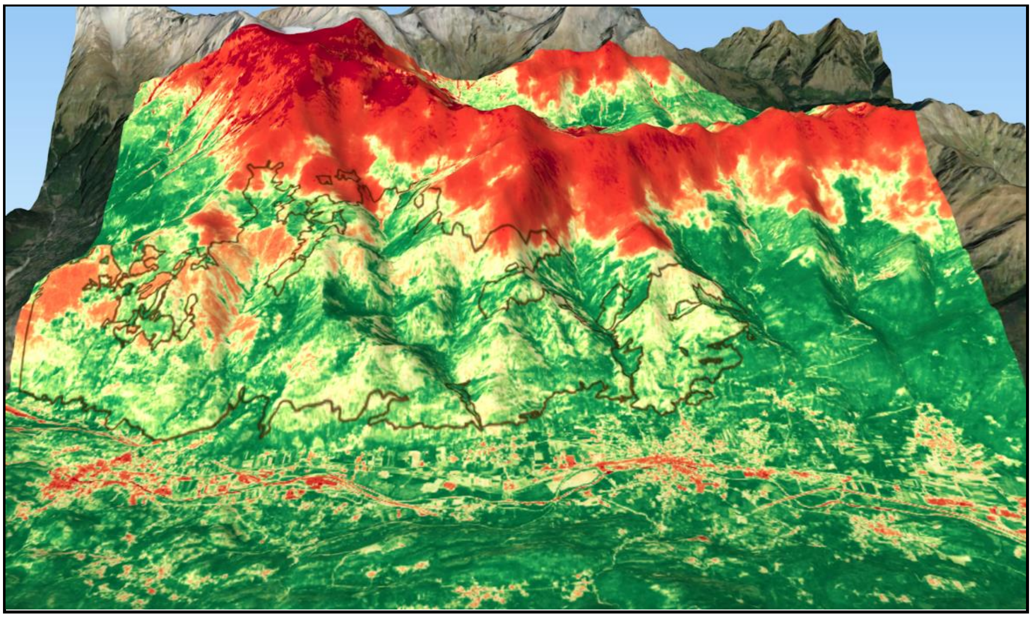


Fig.8-31.Vegetation Recovery NDVI post-fire 3D model_Source:(Author)

The post-fire burned area 3D model highlights the burned area being on the saddles and ridges especially at the base of the mountain. The southern side of the model identified as burned demonstrates to be mostly in the shadowed areas.

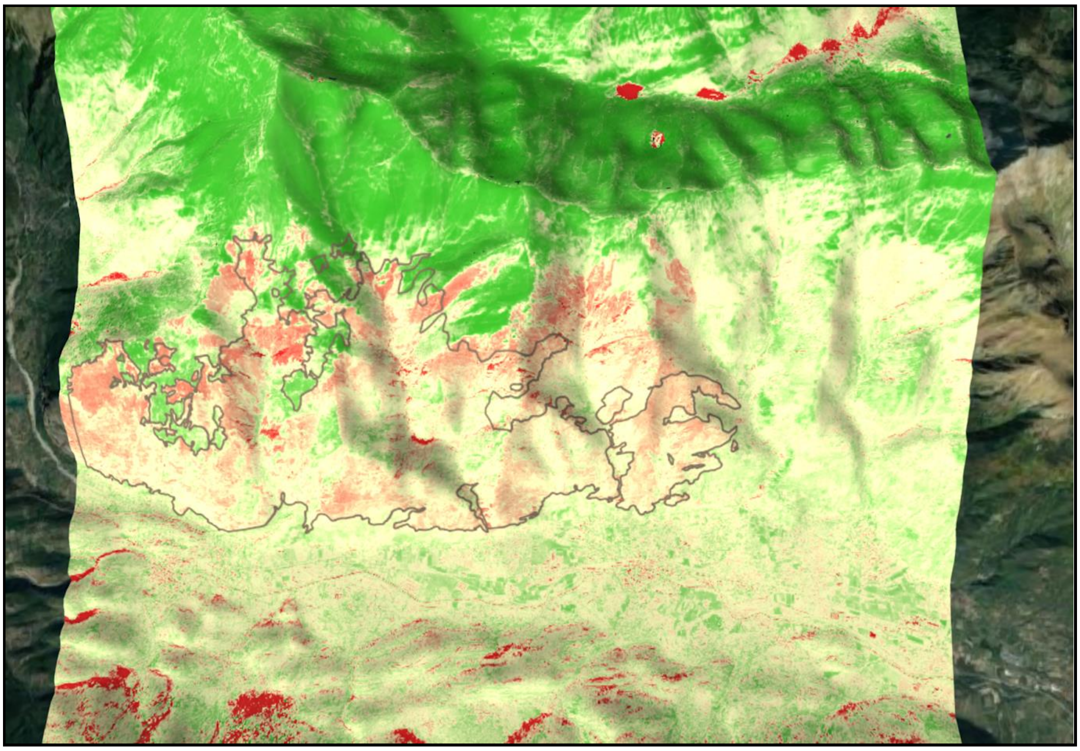


Fig.8.32.post-fire Burned area extraction(NBR) 3D model_Source:(Author)

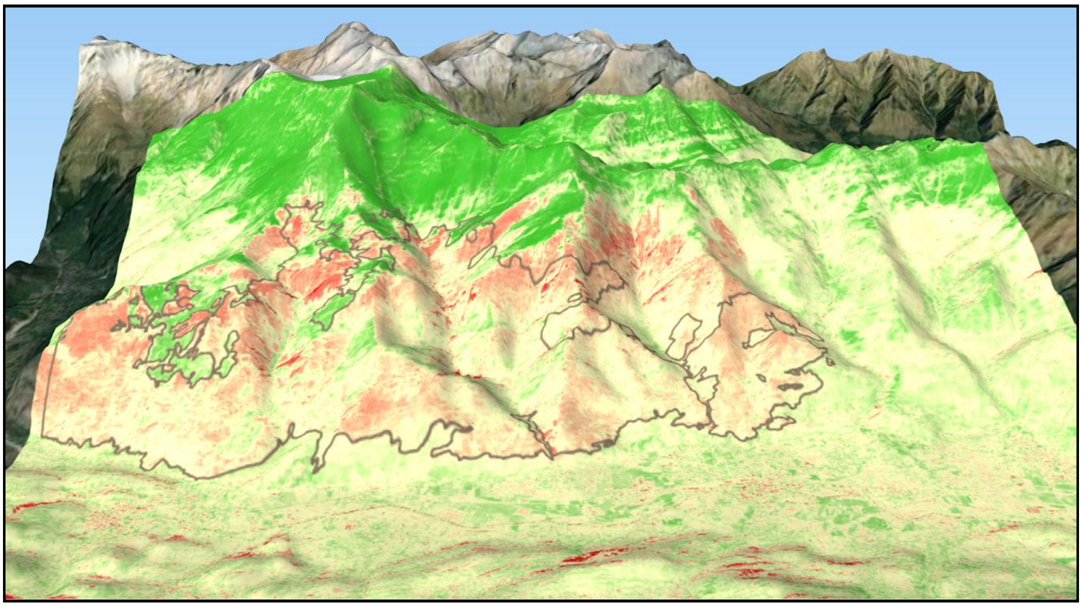


Fig.8.33.post-fire Burned area extraction(NBR) 3D model_Source:(Author)

8.2.3.3D Model of Burn Severity

Burn severity 3D model can be a complementary asset for interpretation of the burn severity image. As it can be noticed by the image, the mountain peaks demonstrate to experience very low burn severity, in fact those areas are areas covered with snow and less vegetation/biomass.

However it can be noticed that the fire had affected both ridges and saddles in the base of the mountain more than other areas, with the most severity in central west, extending towards central-eastern parts. The areas in the saddles (surface between two ridges on a mountain slope), seem to have higher burn severity than the areas in the ridges especially as the fire travels in higher altitudes. This could be because saddles may have steeper slopes or a more constrained path for the fire to travel, which can make the fire burn there more fiercely. Ridges may also have less vegetation or more exposed rocks, which might hinder a fire's ability to spread.

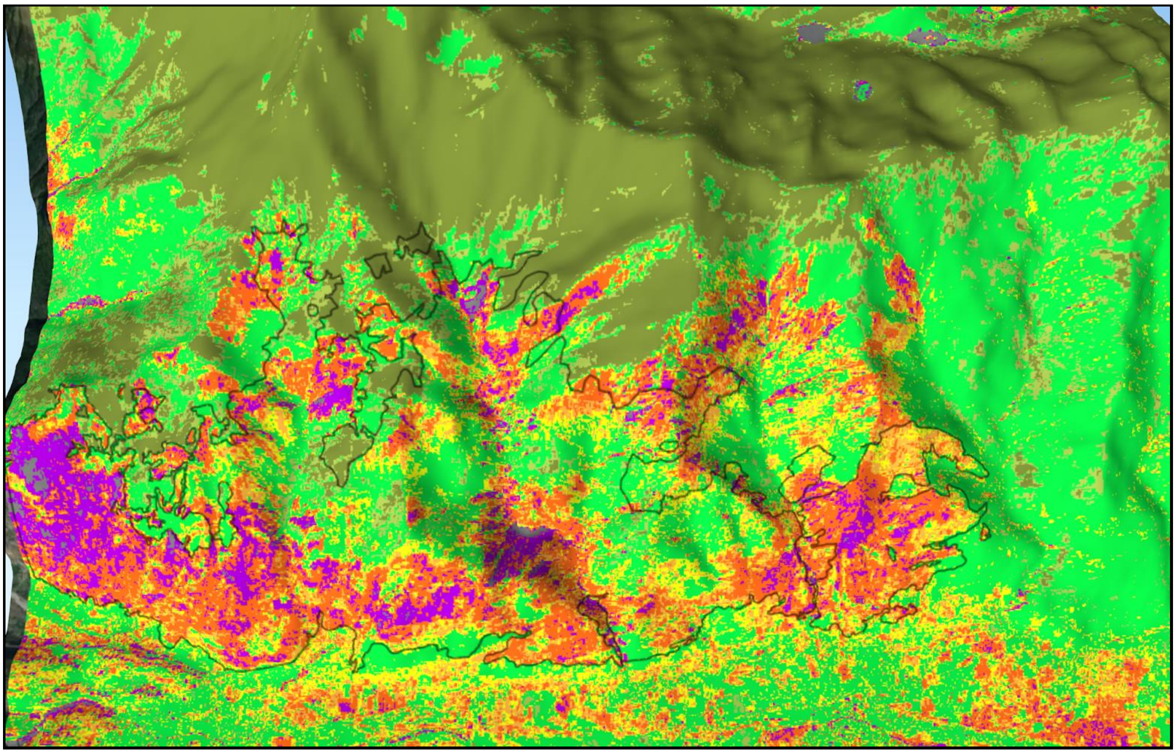


Fig.8-34.post-fire Burn Severity 3D model_Source:(Author)

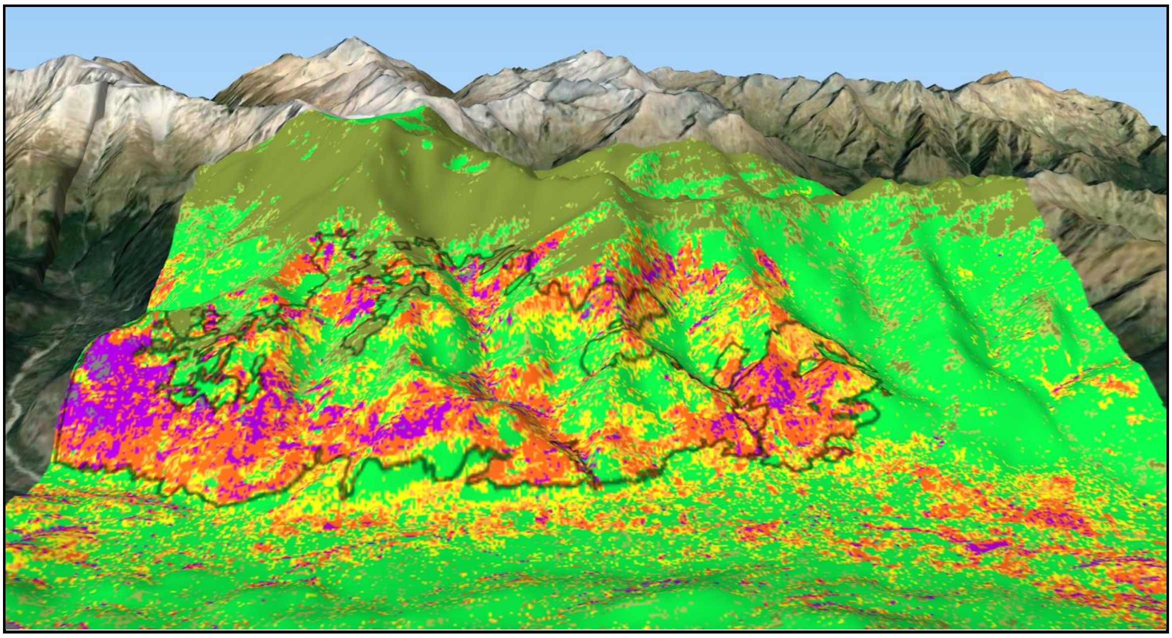


Fig.8-35.Vegetation Recovery NDVI post-fire 3D model_Source:(Author)

8.2.4.3D Model Present (2022)

Same as two previous NDVI images, the higher altitudes demonstrate lower NBR values as a result of snow and harsher climatic situations. However, the vegetation categories seem to be more uniformly distributed compared to other two models.

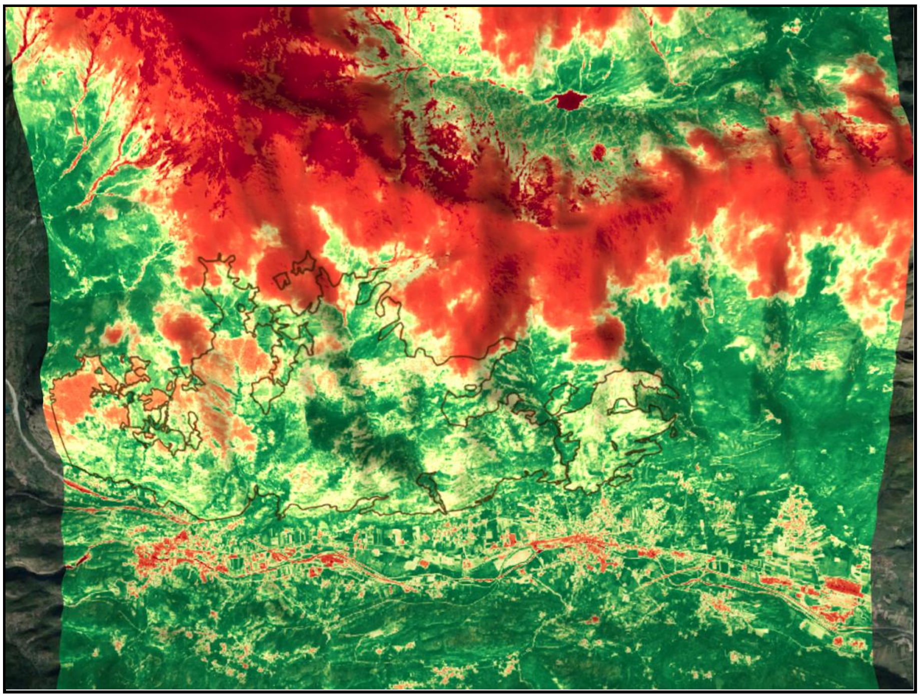


Fig.8-36.Vegetation Recovery NDVI Present (2022) 3D model_Source:(Author)

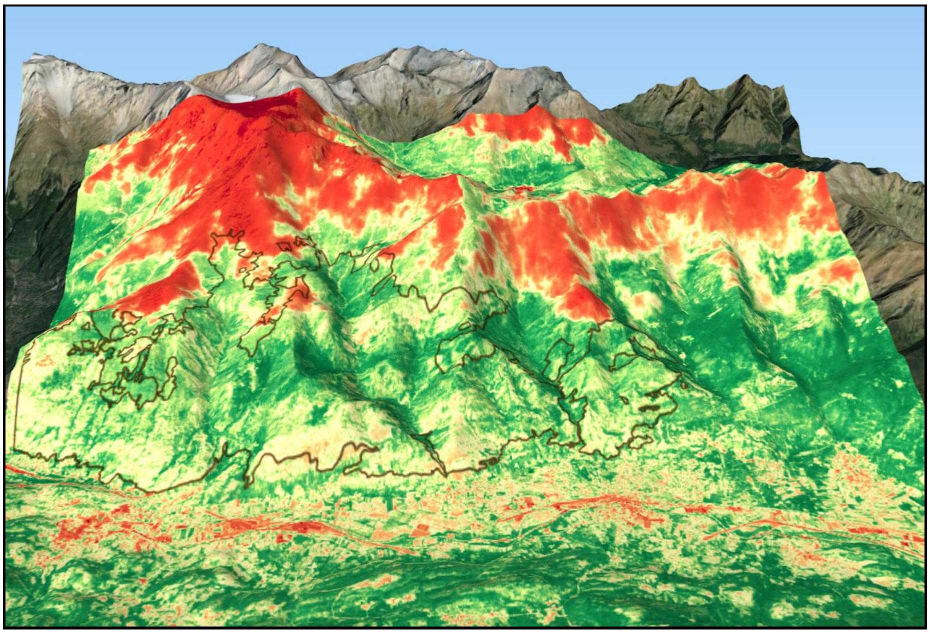


Fig.8-37.Vegetation Recovery NDVI Present (2022) 3D model_Source:(Author)

8.3.Planning suggestions

Planning has an essential role in managing wildfire issues in the Alpes area -here Susa Valley. After careful observation of the wildfire events over the years, there are various planning actions that can be taken for the area, and incorporated into the digital twin.

Planning activities take on different forms and treat different aspects of wildfire management activity. Usually the first thing to consider in this regard, would be developing a **comprehensive land-use plan that can** help identify areas of high wildfire risk and prioritise the allocation of resources and investments in wildfire management and prevention. Such a plan can include **implementation of zoning regulations that can** assist to prevent development in high-risk areas and promote responsible land use practices.

There seems to be a need for integration/coordination in fire management, at regional and national level, between the sectors dedicated to forecasting, prevention, information, training, fighting, investigation and post-fire recovery. Such integration should also lead to an increase of interaction with agricultural and forestry policy for planning in areas where agricultural activities are well-spread.

The situation would benefit from the integration of **urban planning** and **territorial forestry plans,** which identify the areas exposed to fire danger (probability of spreading large fires). The same attention must be directed to the road network which plays a fundamental role in guaranteeing the safety of the logistics of emergency vehicles in the event of high intensity fires. Having a common platform that integrates all the related information and would act as a reference tool where the reports and statistics and fire registers are all in the same space without parallelisation would improve the accuracy and efficiency of the administrational, governor and planning sources.

Additionally, the integration of **fire-related requirements for new construction** within the urban planning regulations, for example requiring the new buildings to be designed with fire-resistant materials and located in areas that provide adequate defensible space, would improve the effectiveness of the aforementioned land-use plan.
Moreover, there is a need **to invest in early warning systems** which provide critical information to emergency responders and residents in the event of a wildfire. Furthermore, **regularly assess and update of wildfire management plans** to reflect changes in the landscape, community demographics, and the latest wildfire management and prevention techniques.
Furthermore, it will help to elaborate a **comprehensive emergency response plan** which includes **provisions for evacuation procedures, communication protocols, and resource allocation** in the event of a wildfire. Such a plan needs to be coupled up with **conducting regular community outreach and education programs that** can help to inform residents about wildfire risks, prevention, and mitigation strategies. Moreover, **establishing partnerships with neighbouring communities** will facilitate coordinated efforts in wildfire management and prevention and ensure a comprehensive approach to managing wildfire risk. Citizens can take an active part, first of all by involving volunteers not only in the fight but also in prevention.
Last but not least, **involving the maximum number of stakeholders** in the process of creating the digital twin would increase the probability of accuracy and practicality of such a platform/product. **In the case of** Susa Valley, the stakeholders for a wildfire assessment digital twin are suggested in table (8-4).

8.3.1.Potential Stakeholders

With all these premises, first responders and other interested parties can adopt the wildfire DT as an instrument for decision-making to assess the damage and make recovery attempt plans. When deciding where to concentrate recovery efforts and distribute resources, the digital twin, for instance, can demonstrate the size of the burned area, the severity of the burn, and the locations of infrastructure that has been damaged. Table 8-4 summarises some of the potential stakeholders for a wildfire assessment DT.

Stakeholder	Relevance	Specific Stakeholder in Susa Valley
Public Organisations	Forest services, disaster management organisations, and local government officials are examples of the government entities in charge of managing and tackling wildfires.	In the context of Susa Valley, Civil Protection at the national level, Forestry corpse, local administrations including Administration of Turin which is responsible for the territory and Piedmont region, in addition, local municipalities within the boundaries of the Susa Valley have their own Civil Protection division are among the Public Organisations and legal bodies that

		could be potential stakeholders.
First Responders	The position and severity of a wildfire must be accurately known in order for firefighters and other first responders to plan their actions. The digital twin during a wildfire can offer real-time data about the fire's development, assisting firefighters in making choices about where to deploy resources and how to prioritise their efforts. Firefighters can anticipate where the fire will spread next by using the digital twin, which can display regions that have already burned as well as those that are still at risk of doing so.	In Susa Valley, Wildfire FireFighter from local and regional and national level are the corresponding bodies for this area.
Local People/Residents	Property owners and locals who have been impacted by the wildfire need to be aware of the extent of the destruction and any dangers to their homes and neighbourhoods.	
Service Providers	such as insurance firms, which must have precise knowledge of the damage's scope in order to handle claims.	
Researchers/Academics	experts and researchers who investigate the behaviour of wildfires and how they affect ecosystems and the environment. Some related disciplines include disaster management, Urban Planning, Forestry, Geospatial Science and Remote Sensing, Sociology, Economy etc.	All academic institutions covering relevant topics, especially the ones existing in the Piedmont region, or Alpine group.
NGOs	non-governmental organisation**s** (NGOs) can aid and help communities impacted by wildfires, especially when it comes to raising awareness and community programs.	

Table 8-4.Suggested Stakeholders for Susa Valley Digital Twin_Source:(Author)

Another key element to be considered in formation of the wildfire assessment DT, is to **aggregate the related documents** and **portals/platforms**. It helps to improve **data accessibility and facilitation** for the stakeholders and would eventually save time and effort in searching for relevant information, instead of having to access parallel platforms. Moreover, it would enhance the **quality of data analysis** about the wildfires in the area, because it would assist us in **more accurate pattern and trend identification** which would not be obvious when assessing individual reports in isolation and in the end it would lead to a **better-informed decision** making and better results. These aggregated reports and documents can improve the **collaboration among the stakeholders** in different fields by giving them a common ground. Finally, it would help to **improve transparency** by making the information available to all stakeholders and **build trust**. The following tables list the related existing platforms and reports and their functions.

Report	Organisation	Function
PianoAIB Regione Piemonte	Corpo AIB Piemonte	-
Arpa Piemonte_Wind Studies	Arpa Piemonte	The role of wind and its contribution in climatic situations
Arpa Piemonte_Idrologia	Arpa Piemonte	Information and policies about water bodies and waterways
Il Clima in Piemonte	Arpa Piemonte Dipartimento Rischi Naturali e Ambientali	Climatic information and report
Rapporto climatico annuale	Agenzia Regionale per la Protezione dell'Ambiente(Arpa Piemonte)	Climatic information and report
Direzione Pianificazione Risorse Idriche(2007). Piano di Tutela delle Aque.Rev03. Sottobacino: Dora Riparia(AI11)	Regione Piemonte	Information and policies about water bodies and waterways

La Carta Forestale del Piemonte	Regione Piemonte/ Istituto Per le Piante da Legno e l'ambiente IPLA Spa	Forest plan for piedmont
Piano Regionale Forestale(PFR)	L'Istituto per le Piante da Legno e l'Ambiente – IPLA spa.	Regional forest plan
Piano Regionale Per La Programmazione Delle Attività Di Previsione, Prevenzione E Lotta Attiva Contro Gli Incendi Boschivi 2021-2025	Regione Piemonte Settore Sistema Antincendi Boschivi.	-
Tipi forestali del Piemonte	Regione Piemonte	Forest categories in piedmont
Copernicus EMS report	Copernicus	Fire delineation report and map
Copernicus Land Monitoring Service	Copernicus	Tree cover density and tree cover change mask

Table 8-5.Existing related reports for a Wildfire Assessment Digital Twin (some elements are more detailed to susa valley)_Source: (Author)

8.4.Final considerations and Conclusion

The current study started by generating an understanding of the wildfire management system currently adopted in Italy and in the Piedmont region, followed by investigating the main plans and reports on different aspects of planning, climate, topography and hydrology, sociology, forestry and management, that possibly affect wildfires and its management. These preliminary studies helped in the f interpretations of the satellite images processing outputs (vegetation indexes) and of the derived statistics computations the identification of planning suggestions for the AOI. The uniqueness of the research is in suggesting a holistic solution for a wildfire assessment digital twin, by gathering the sources and documents customised and tailored for the specific area needed, coupled up with the automatic extraction of indexes using satellite images.
The technical activities included development of algorithms for automatic/semi-automatic extraction of the burned areas, burn severity and vegetation recovery, based on which the further statistical analysis and 3D model was elaborated to give a more holistic idea of the situation and ultimately be utilised as some building block in a Wildfire assessment digital twin platform.

In the process of conducting the research and especially in the case study and calculation phase, several problems were faced. For example, several times, the data needed for the analysis that was available on open source platforms, was not accurate for the specific location. For example the MODIS wildfire dataset, or the MODIS water surface datasets or even Global Surface Water by the EU, were not representative of all the existing elements for the Susa Valley, so in these cases the regional and local databases resulted more complete and accurate and could set a more trustable base for decision making and also academic efforts. In the case of waterways, even the Piedmont region Geoportale and Arpa piemonte did not have the related data for the Susa Valley area, while for other areas of Piedmont these data were available. A similar problem existed for statistics related to the wildfire event in Susa valley, which were sometimes contradicting or not coherent in different public sources available and demonstrates the importance of creation of an integrated platform for aggregation of the data sources and statistics, without inefficient parallelisation. Another challenge was to find images with the required criteria for the analysis in the GEE database. For example for the pre-fire situation, it was not possible to find images with optimal cloud cover, so being aware of this fact, the cloud effects have been considered when interpreting the images.

Regarding the calculations, the index calculations for Burn Area Extraction using NBR index using the automatic extraction method developed by GEE identify the burned area highlighted also by the CEMS product (Copernicus Emergency Management Service). Moreover, the comparison between the resulting images and the already available product from MODIS in GEE platform shows a higher accuracy for the wildfire of 2017 in Susa Valley. However, there are also some false values also at the bottom and north-east of the AOI, mostly related to shadowed areas (identifiable in the false colour image), which could be because water bodies/waterways and also shadowed areas sometimes can have similar spectral values to burned areas in NBR analysis. So it is necessary to control the false colour band combinations to verify the findings of the method and increase accuracy of interpretation. Further statistics are calculated about the burned area and area compared to different statistics of regional reports and CEMS and demonstrate the closeness of the obtained results to the CEMS reported statistics. Furthermore, for better understanding of the distribution of the areas, a histogram was created demonstrating burn with NBR value in the range of -0.2 to 0.3, considered to be of relatively low severity and to have a mixture of burned and unburned plants. This might be the outcome of a low intensity fire or a mosaic burn pattern, where different vegetation patches have undergone varying degrees of severe burning. Zooming on the histogram for only burned areas, it demonstrates in the NBR values from -4 which is an indication of higher severity of burn.

The study of the burn severity is complemented by adding the Burn Severity analysis calculated from the pre-fire NBR and post-fire NBR. The resulting image highlights the burned area in the centre characterised by lower burn severity on the edges, moving towards moderate-low burn severity, moderate-high burn severity and in the middle, the high burn severity that extends to the western edges. The calculations of the areas of burned areas resulting from the thresholds set for calculations, are almost equal to the percentage of the burned areas calculated in the burned areas image (15.6% vs 16% in NBR).

Since vegetation health condition has great influence on the occurrence of fire and its behaviour, and also is an indication of recovery after the fire, NDVI index has been calculated, coupled up with statistics for each vegetation category and a time series scatter plot highlighting the gradual increase of the NDVI values after the fire, and its drastic rise in 2022 as the years pass, indicating a healthier vegetation condition.

At the end of the analysis in GEE, all the results have been tested also in the QGIS application to be verified. However, the outputs of such processes also produce 3D files which are in optimal formats and size to be used in web platforms.

Additional insights that might not be immediately apparent in a 2D image could be provided by 3D models. In particular, 3D models can help us comprehend the topographic information and spatial context more clearly while enhancing and completing the 2D representation. The 3D models have been used to assist in a more complete and informed judgement in interpretation of the images and discuss the relationship of altitude and topography with the resulting analysis of indexes and the role of these factors in the occurred fire event.

The performed analysis demonstrates that the automatic extraction of images, image collections and index calculation using GEE and open source satellite data can function as building blocks for the creation of a wildfire assessment DT. The obtained images can be used in the web platforms, using the Google earth engine API, resulting in the interactive maps.

However, in order to analyse the images better, the indexes need to be combined with field data and observation. It's crucial to remember that to effectively estimate the harm caused by a wildfire and choose the best strategy for recovery and management activities, qualified professionals are still required to conduct field assessments and surveys.

In conclusion, using open source satellite data and in specific the GEE platform can be advantageous especially when attempting to assess the post-fire situations. Being an open source, the data on GEE are available and accessible to everyone, allowing researchers to analyse data without financial barriers, leading to opportunities for diverse methodologies and outcomes. Being a cloud-based platform it also allows for large-scale analysis, and it provides various datasets encompassing different fields such as satellite imageries, socio-economic and climatic data and facilitates the integration process. However, data availability and accuracy is usually the main issue especially considering more local data, or if there is a necessity for a specific period of time in which a service might not be active so the recalled datasets need to be carefully examined beforehand in terms of quality and accuracy which requires field knowledge and validation with ground truth data or reference datasets. In cases of manual calibrations such as atmospheric corrections, usually the memory management problems and efficiency can cause problems for further operations and calculations. In addition, in order to benefit from this platform, some technical expertise in different fields such as remote sensing, geospatial analysis and programming are needed.

A1.Pre-fire Burned Area(NBR)

Legend

- burned
- Not burned
- Healthy Vegetation

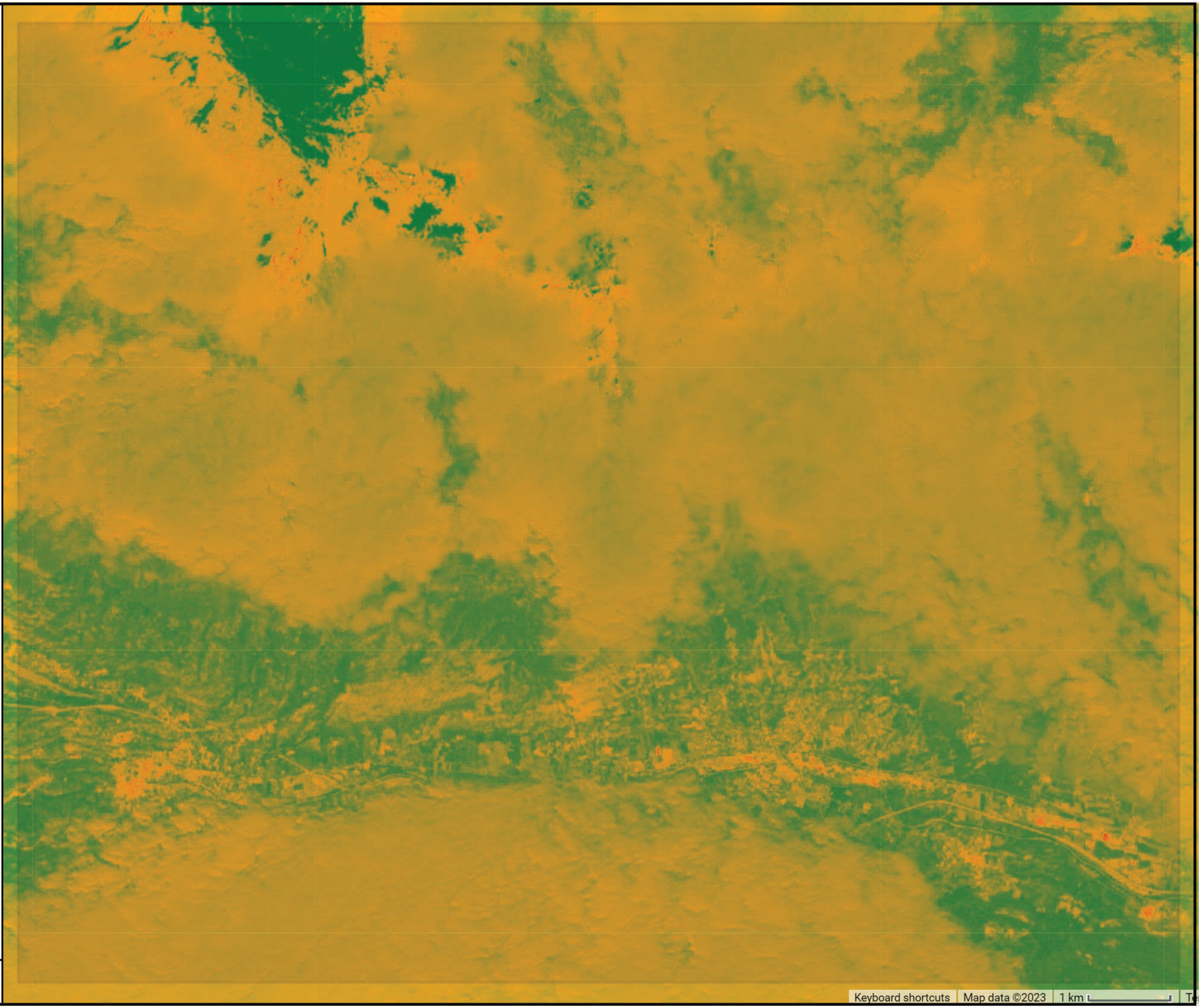


Image Resolution: 10

A

A2.Post-fire Burned Area(NBR)

Legend

- Burned
- Not burned
- Healthy vegetation
- Fire delineation area CEMS

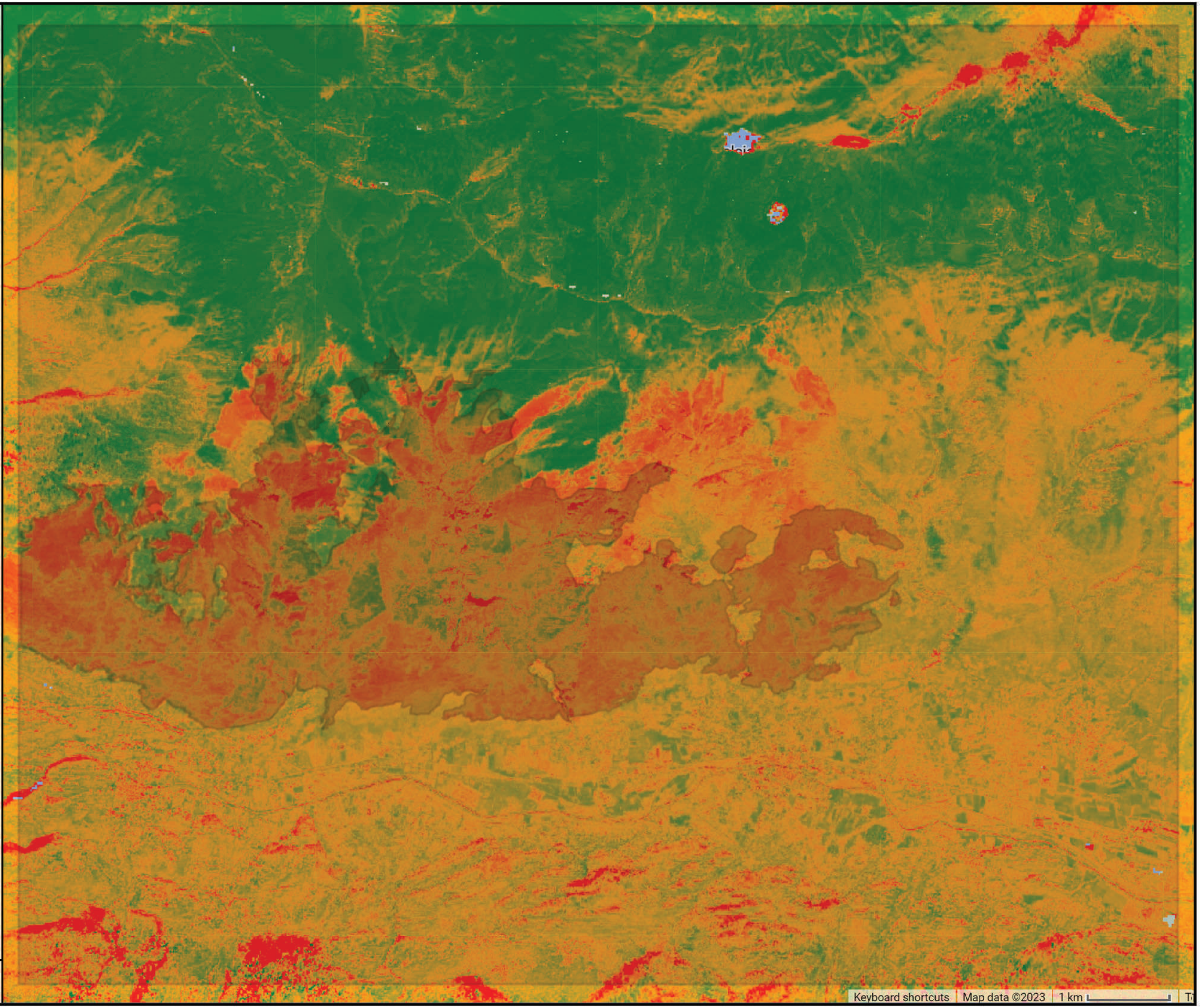
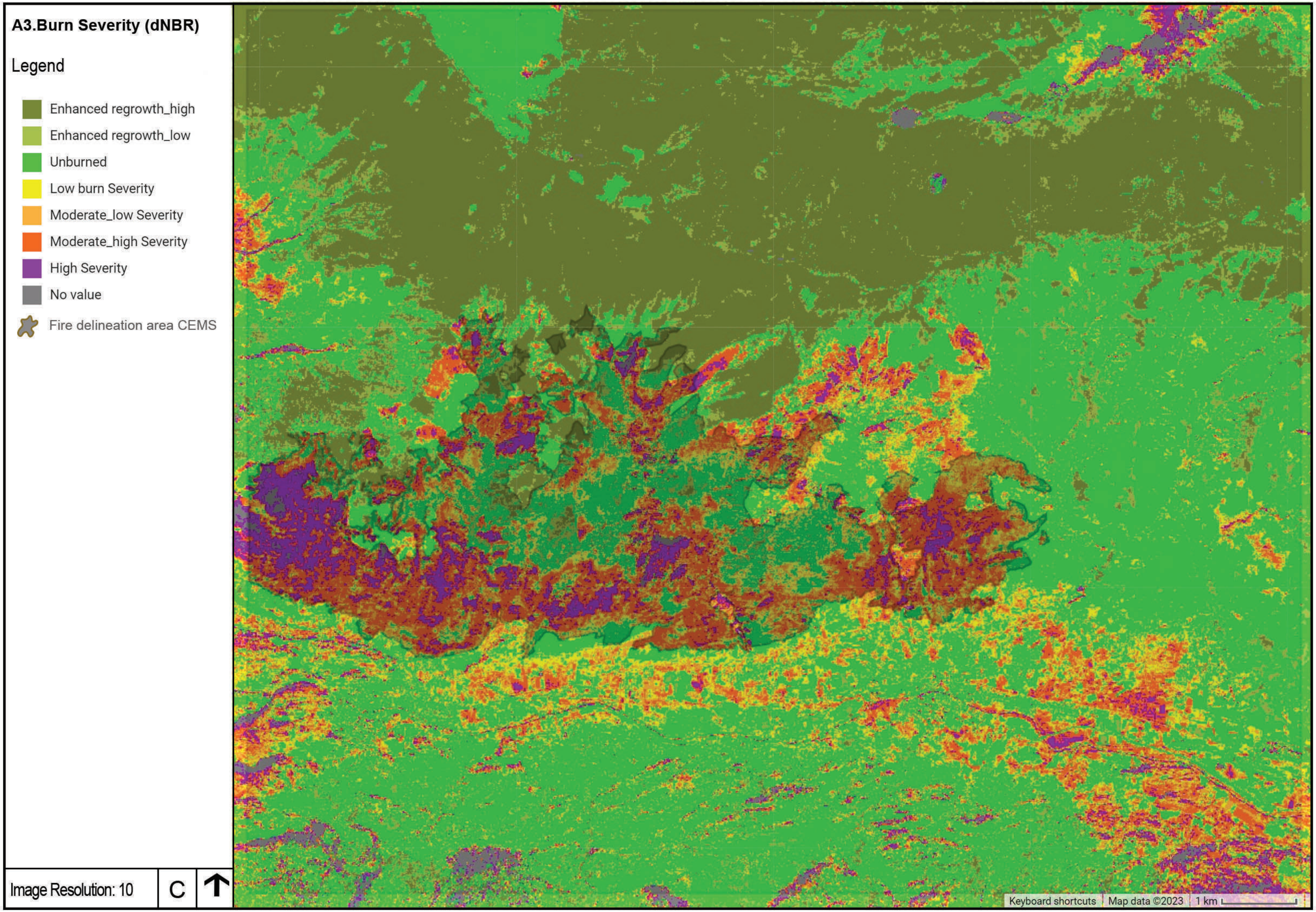
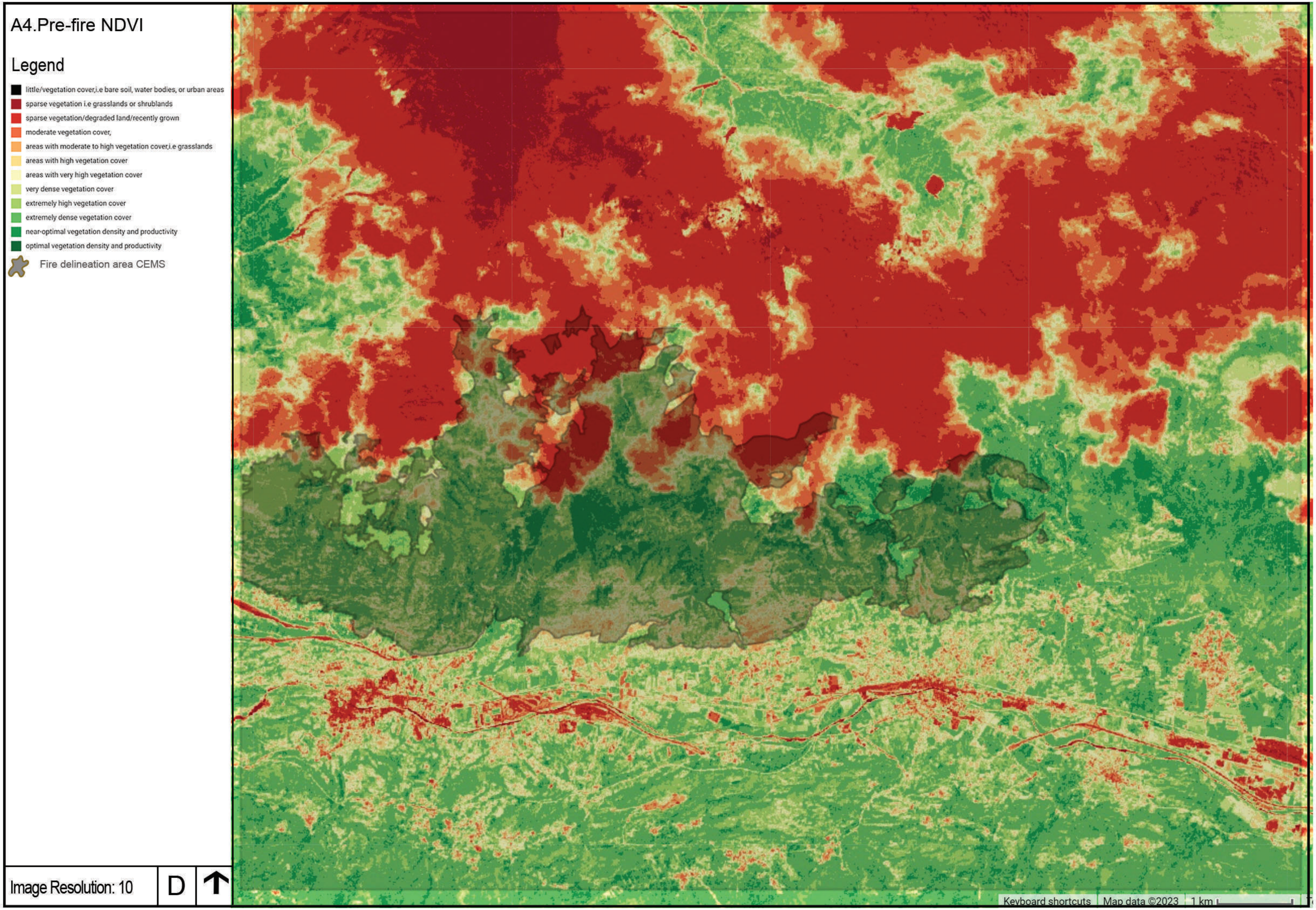


Image Resolution: 10 | B


A3.Burn Severity (dNBR)
Legend
Enhanced regrowth_high
Enhanced regrowth_low
Unburned
Low burn Severity
Moderate_low Severity
Moderate_high Severity
High Severity
No value
Fire delineation area CEMS
Image Resolution: 10
C
Keyboard shortcuts
Map data ©2023
1 km



A4.Pre-fire NDVI
Legend
little/vegetation cover,i.e bare soil, water bodies, or urban areas
sparse vegetation i.e grasslands or shrublands
sparse vegetation/degraded land/recently grown
moderate vegetation cover,
areas with moderate to high vegetation cover,i.e grasslands
areas with high vegetation cover
areas with very high vegetation cover
very dense vegetation cover
extremely high vegetation cover
extremely dense vegetation cover
near-optimal vegetation density and productivity
optimal vegetation density and productivity
Fire delineation area CEMS
Image Resolution: 10
D
Keyboard shortcuts
Map data ©2023
1 km

A5.Post-fire NDVI

Legend

- little/vegetation cover,i.e bare soil, water bodies, or urban areas
- sparse vegetation i.e grasslands or shrublands
- sparse vegetation/degraded land/recently grown
- moderate vegetation cover,
- areas with moderate to high vegetation cover,i.e grasslands
- areas with high vegetation cover
- areas with very high vegetation cover
- very dense vegetation cover
- extremely high vegetation cover
- extremely dense vegetation cover
- near-optimal vegetation density and productivity
- optimal vegetation density and productivity
- Fire delineation area CEMS

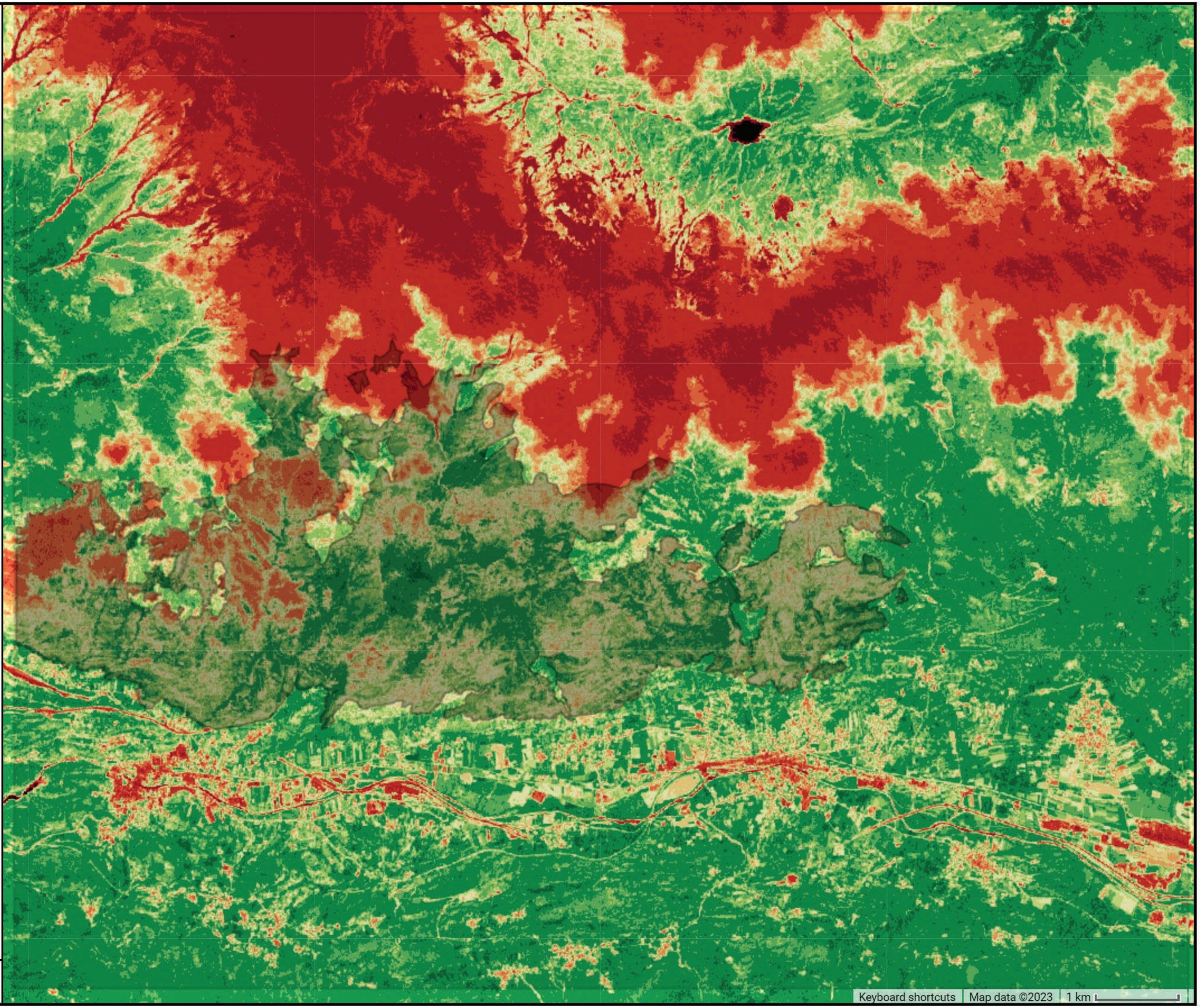


Image Resolution: 10 | E | ↑

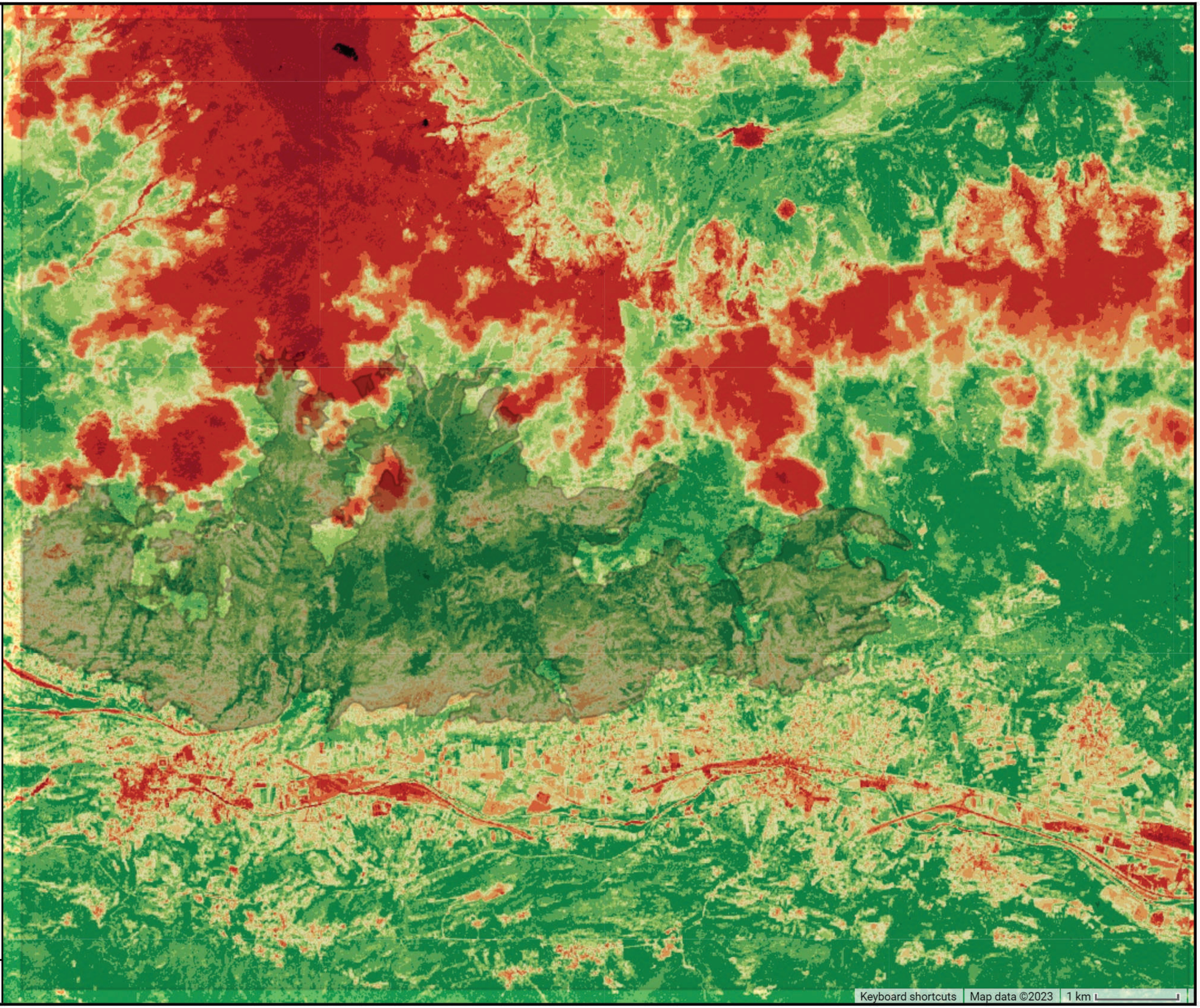
A6.Present NDVI (2022)

Legend

- little/vegetation cover,i.e bare soil, water bodies, or urban areas
- sparse vegetation i.e grasslands or shrublands
- sparse vegetation/degraded land/recently grown
- moderate vegetation cover,
- areas with moderate to high vegetation cover,i.e grasslands
- areas with high vegetation cover
- areas with very high vegetation cover
- very dense vegetation cover
- extremely high vegetation cover
- extremely dense vegetation cover
- near-optimal vegetation density and productivity
- optimal vegetation density and productivity
- Fire delineation area CEMS

Image Resolution: 10

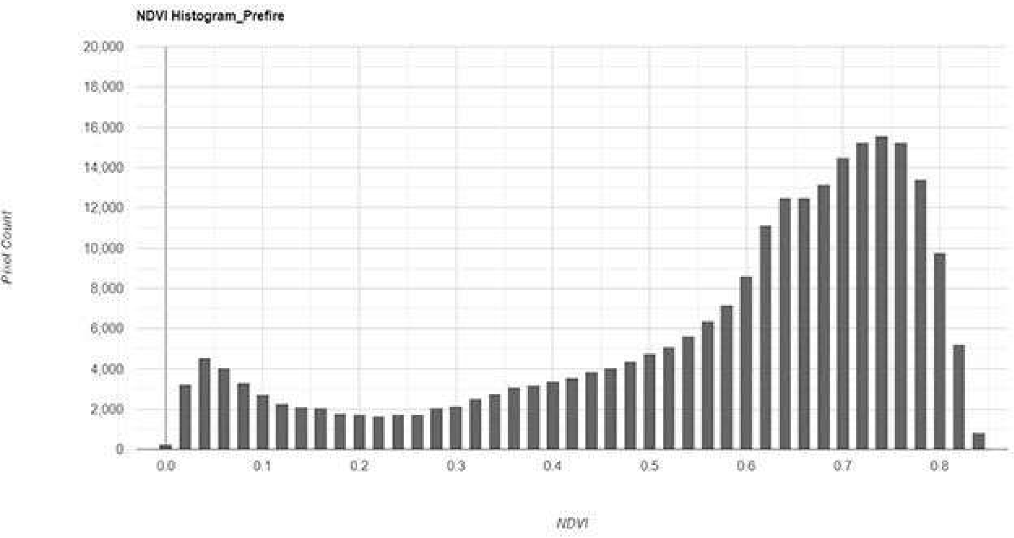
F

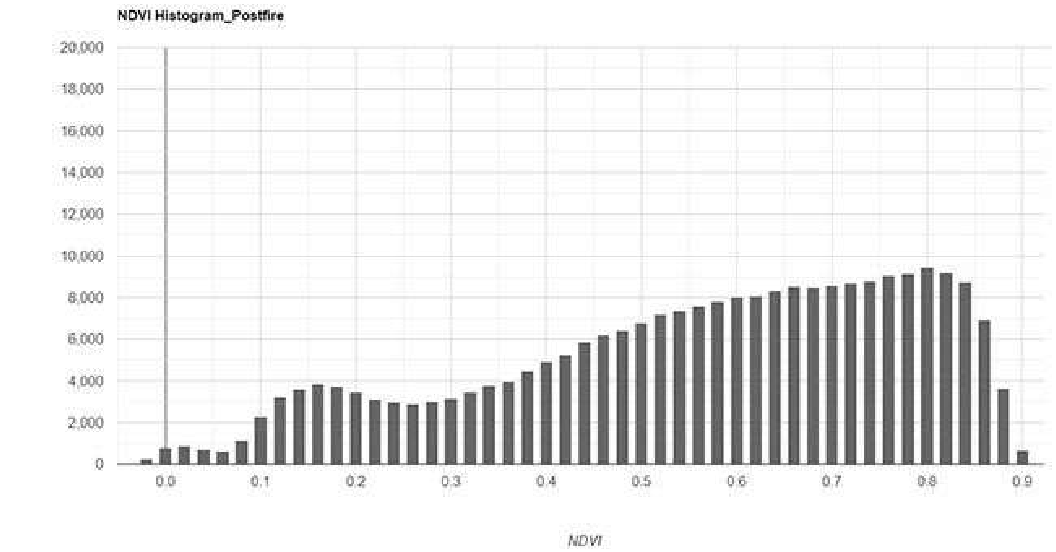


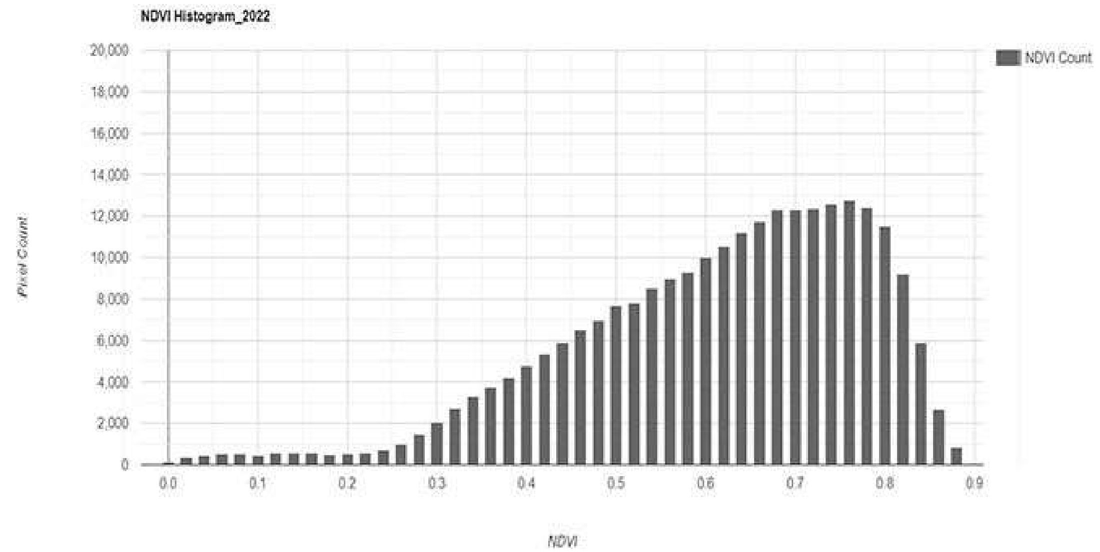
Pre-fire

Post-fire

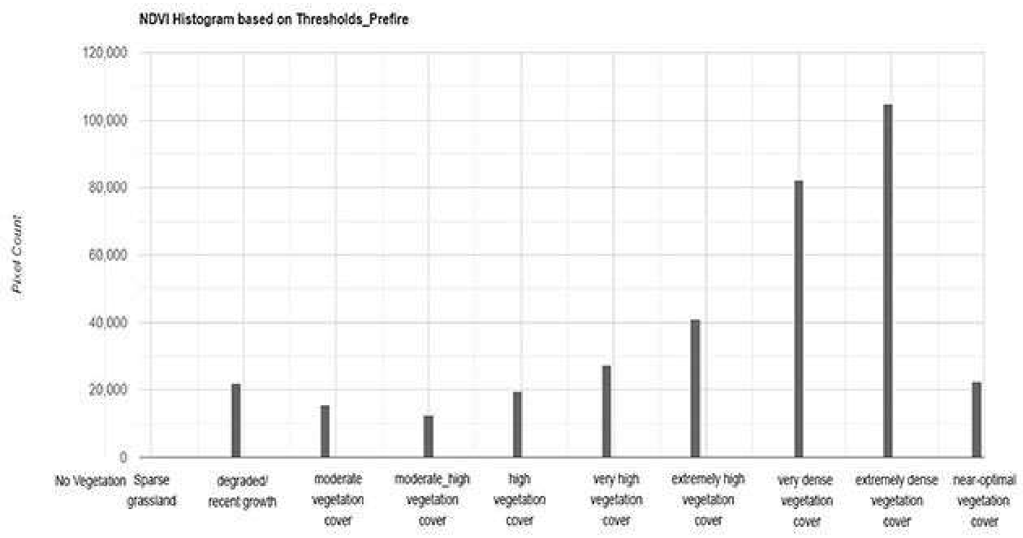
Present/2022

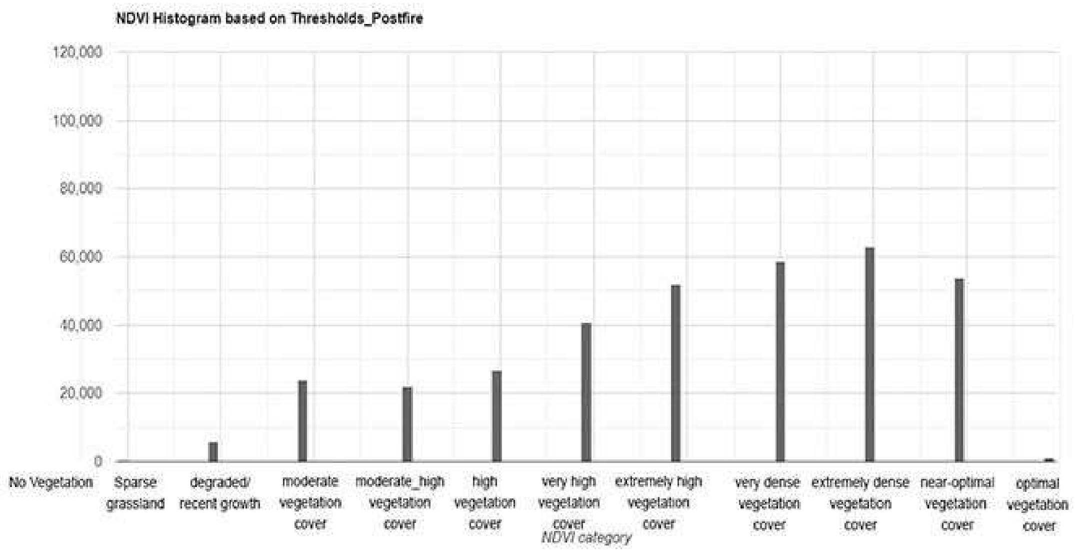


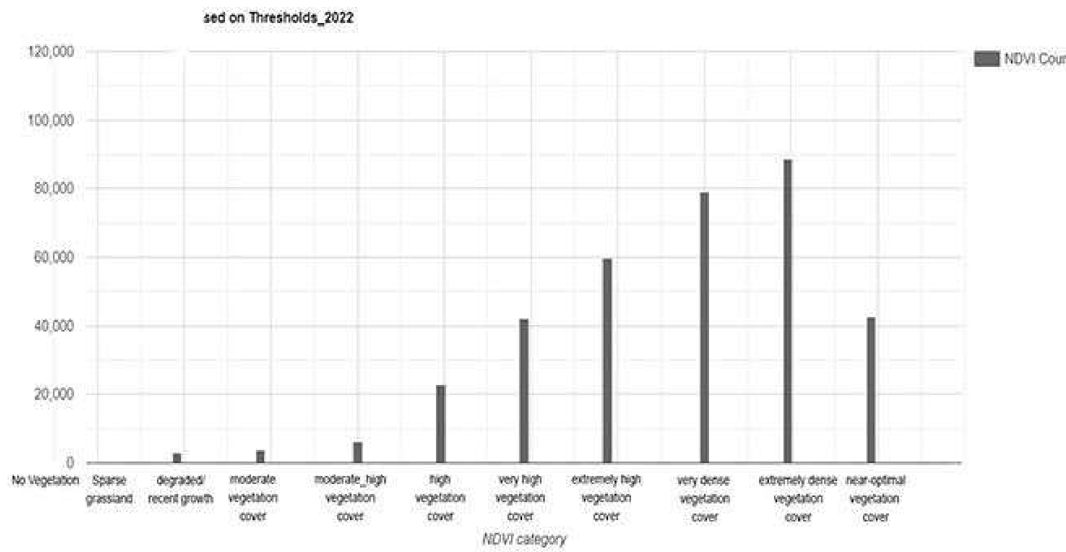




Comparison based on NDVI range







Comparison based on vegetation category

References

1. Yu, D., & He, Z. (2022). Digital twin-driven intelligence disaster prevention and mitigation for infrastructure: advances, challenges, and opportunities. Natural hazards, 1-36.
2. Disasters & Emergencies _ Training package_ WHO/EHA Panafrican Emergency Training Centre, Addis Ababa Updated March 2002 by EHA.
3. Assessment Of Forest Fire Risk In European Mediterranean Region: Comparison of satellite-derived and meteorological indices. 2008.
4. Kate Abnett. Mediterranean has become a 'wildfire hotspot', EU scientists say. 2021. Article on website of Reuters. Available at: https://www.reuters.com/business/environment/mediterranean-has-become-wildfire-hotspot-eu-scientists-say-2021-08-04/.[Last accessed: 18 July.2022].
5. Website of Copernicus Emergency Management Service_Mapping. Available at: https://emergency.copernicus.eu/mapping/list-of-components/EMSR213.[Last accessed: 18 July.2022].
6. FOREST FIRES IN THE ALPS, State of knowledge, future challenges and options for an integrated fire management. White Paper for policy makers. 06 February, 2020|Vienna . Available at : https://www.alpine-region.eu/sites/default/files/uploads/result/2233/attachments/200206_forestfires_whitepaper_final_online.pdf. [Last accessed: 18 July.2022].
7. Stroppiana, D., Bordogna, G., Carrara, P., Boschetti, M., Boschetti, L., & Brivio, P. A. (2012). A method for extracting burned areas from Landsat TM/ETM+ images by soft aggregation of multiple Spectral Indices and a region growing algorithm. ISPRS Journal of Photogrammetry and Remote Sensing, 69, 88-102.
8. Michetti, M., & Pinar, M. (2019). Forest fires across Italian regions and implications for climate change: a panel data analysis. Environmental and Resource Economics, 72(1), 207-246.
9. Cat Berro, Daniele and Mercalli,Luca.2017. Ottobre 2017 Al Nord-Ovest Italiano:Caldo, Siccita' E Incendi. Article on website of Nimbus Web. Available at: http://www.nimbus.it/clima/2017/171101SiccitaIncendiNordOvest.htm#:~:text=L'incendio%20pi%C3%B9%20grave%20ha,%2C%20Bussoleno%2C%20Mompantero%20e%20Venaus. .[Last accessed: 18 July.2022].
10. William L Bain. Digital Twins: a New Real-Time Data Analytics Technique that Boosts Disaster Response. 2020. Article on Website of SpiceWorks. Available at: https://www.spiceworks.com/tech/big-data/guest-article/digital-twins-a-new-real-time-data-analytics-technique-that-boosts-disaster-response/.[Last accessed: 18 July.2022].
11. EFFIS - European Forest Fire Information System Website. Available at : https://effis.jrc.ec.europa.eu/.[Last accessed: 18 July.2022].
12. e.g. Kok, E., Stoof, C., 2021. Country report for The Netherlands, in SanMiguel-Ayanz et al. (Eds), Forest Fires in Europe, Middle East and North Africa 2020, EUR 30862 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42351-5, doi:10.2760/216466, JRC1267665. Available at : https://effis.jrc.ec.europa.eu/reports-and-publications/annual-fire-reports.[Last accessed: 18 July.2022].
13. Euronews Website. 2022. Forest fires have burned a record 700,000 hectares in the EU this year. Available at: https://www.euronews.com/my-europe/2022/08/18/forest-fires-have-burned-a-record-700000-hectares-in-the-eu-this-year.[Last accessed: 20 July.2022].
14. Parmesan, Camille; Morecroft, Mike; Tri Surat, Yongyut; et al. "Chapter 2: Terrestrial and Freshwater Ecosystems and their Services' ' (PDF). Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change.
15. Transforming our World: THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT. 2015. United Nations. Available at: sustainabledevelopment.un.org.[Last accessed: 20 July.2022].
16. Website for Earth Systems Science for the Baltic sea Region. Available at : https://www.baltic-earth.eu/working_groups/natural_hazards/index.php.en.[Last accessed: 20 July.2022].
17. Stavrakoudis, D., Katagis, T., Minakou, C. and Gitas, I.Z. (2020) Automated Burned Scar Mapping Using Sentinel-2 Imagery. Journal of Geographic Information System, 12, 221-240. https://doi.org/10.4236/jgis.2020.123014.
18. Website for Centre of Climate and Energy Solutions. Wildfires and Climate Change Available at: https://www.c2es.org/content/wildfires-and-climate-change/.[Last accessed: 20 July.2022].
19. Website of World Meteorological Organisation. Number of wildfires forecast to rise by 50% by 2100. Available at: https://public.wmo.int/en/media/news/number-of-wildfires-forecast-rise-50-2100.[Last accessed: 20 July.2022].

20. Flannigan, M. D., Amiro, B. D., Logan, K. A., Stocks, B. J., & Wotton, B. M. (2006). Forest fires and climate change in the 21st century. Mitigation and adaptation strategies for global change, 11(4), 847-859.
21. United Nations, 2015. The 2030 Agenda and the Sustainable Development Goals.
22. European Environment Agency. 2021. Forest Fires in Europe. Available at: https://www.eea.europa.eu/ims/forest-fires-in-europe.[Last accessed: 20 July.2022].
23. How Does A Digital Twin Work?. Article On Ibm Website. Available At: Https://Www.Ibm.Com/Topics/What-Is-A-Digital-Twin.[Last accessed: 10 Aug .2022].
24. Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital Twin: Enabling Technologies, Challenges And Open Research. Ieee Access, 8, 108952-108971.
25. M. Grieves, "Digital Twin: Manufacturing Excellence Through Virtual Factory Replication,'' Nasa, Washington, Dc, Usa, White Paper 1, 2014.
26. Glaessgen, E., & Stargel, D. (2012, April). The Digital Twin Paradigm For Future Nasa And Us Air Force Vehicles. In 53rd Aiaa/Asme/Asce/Ahs/Asc Structures, Structural Dynamics And Materials Conference 20th Aiaa/Asme/Ahs Adaptive Structures Conference 14th Aiaa (P. 1818).
27. Y. Chen, ``Integrated And Intelligent Manufacturing: Perspectives And Enablers,'' Engineering, Vol. 3, No. 5, Pp. 588595, Oct. 2017.
28. Z. Liu, N. Meyendorf, And N. Mrad, ``The Role Of Data Fusion In Predictive Maintenance Using Digital Twin,'' In Proc. Annu. Rev. Prog. Quant. Nonde-Struct. Eval., Provo, Ut, Usa, 2018, Art. No. 020023.
29. Y. Zheng, S. Yang, And H. Cheng, ``An Application Framework Of Digital Twin And Its Case Study,'' J. Ambient Intell. Humanised Comput., Vol. 10,No. 3, Pp. 11411153, June. 2018.
30. R. Vrabi£, J. A. Erkoyuncu, P. Butala, And R. Roy, ``Digital Twins: Understanding The Added Value Of Integrated Models For Through-Life Engineering Services,'' Procedia Manuf., Vol. 16, Pp. 139146, Jan. 2018.
31. A. Madni, C. Madni, And S. Lucero, ``Leveraging Digital Twin Technology In Model-Based Systems Engineering,'' Systems, Vol. 7, No. 1, P. 7, Jan. 2019.
32. Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising The Digital Twin: A Systematic Literature Review. Cirp Journal Of Manufacturing Science And Technology, 29, 36-52.
33. Wright, L., & Davidson, S. (2020). How To Tell The Difference Between A Model And A Digital Twin. Advanced Modelling And Simulation In Engineering Sciences, 7(1), 1-13.
34. Walsh, Joe. (2020). 8 Myths About Digital Twins Exposed—Here's The Reality. Article On The Myengineering Website. Available At: Https://Www.Engineering.Com/Story/8-Myths-About-Digital-Twins-Exposedheres-The-Reality. .[Last accessed: 10 Aug .2022].
35. Ashton, K. (2009). That 'internet Of Things' Thing. Rfid Journal, 22(7), 97-114.
36. Ornes, S. (2016). The Internet Of Things And The Explosion Of Interconnectivity. Proceedings Of The National Academy Of Sciences, 113(40), 11059-11060.
37. Boyes, H., Hallaq, B., Cunningham, J., & Watson, T. (2018). The Industrial Internet Of Things (Iiot): An Analysis Framework. Computers In Industry, 101, 1-12.
38. An Official Website Of The European Union_ Available At : Https://Joint-Research-Centre.Ec.Europa.Eu/Scientific-Activities-Z/Earth-Observation_en. [Last accessed: 10 Aug.2022].
39. Geo_group On Earth Observations. Website Available At: Https://Www.Earthobservations.Org/G_faq.Html.[Last accessed: 10 Aug.2022].
40. Kansakar, P., & Hossain, F. (2016). A Review Of Applications Of Satellite Earth Observation Data For Global Societal Benefit And Stewardship Of Planet Earth. Space Policy, 36, 46-54.
41. Katherine Anderson, Barbara Ryan, William Sonntag, Argyro Kavvada & Lawrence Friedl (2017): Earth Observation In Service Of The 2030 Agenda For Sustainable Development, Geo-Spatial Information Science, Doi: 10.1080/10095020.2017.1333230. Available At: Http://Dx.Doi.Org/10.1080/10095020.2017.1333230. [Last accessed: 12 Aug.2022].
42. Deng, T., Zhang, K., & Shen, Z. J. M. (2021). A Systematic Review Of A Digital Twin City: A New Pattern Of Urban Governance Toward Smart Cities. Journal Of Management Science And Engineering, 6(2), 125-134.
43. Olivia Hudson.(2022). Article On AzoCleantech Website. Using Drones For Environmental Research. Available At: Https://Www.Azocleantech.Com/Article.Aspx?Articleid=1519.[Last accessed: 12 Aug.2022].
44. Lee, A., Lee, K. W., Kim, K. H., & Shin, S. W. (2022). A Geospatial Platform To Manage Large-Scale Individual Mobility For An Urban Digital Twin Platform. Remote Sensing, 14(3), 723.
45. Yun, S. J., Kwon, J. W., & Kim, W. T. (2022). A Novel Digital Twin Architecture With Similarity-Based Hybrid Modelling For Supporting Dependable Disaster Management Systems. Sensors, 22(13), 4774.
46. Nativi, S., Mazzetti, P., & Craglia, M. (2021). Digital Ecosystems For Developing Digital Twins Of The Earth: The Destination Earth Case. Remote Sensing, 13(11), 2119.

47. Chazdon, R. L., Brancalion, P. H., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., ... & Wilson, S. J. (2016). When Is A Forest A Forest? Forest Concepts And Definitions In The Era Of Forest And Landscape Restoration. Ambio, 45(5), 538-550.
48. Gabban ,A, San-Miguel-Ayanz, J, X. Viegas, D, Joined Research With European Commission Joint Research Centre Institute For Environment And Sustainability. 2008. Assessment Of Forest Fire Risk In The European Mediterranean Region: Comparison Of Satellite-Derived And Meteorological Indices.
49. Britannica. Available At : Https://Www.Britannica.Com/Science/Wildfire.[Last accessed: 13 Aug.2022].
50. Claire Wolters, 2019. Article On National Geographic Website: Here's How Wildfires Get Started—And How To Stop Them. Available At: Https://Www.Nationalgeographic.Com/Environment/Article/Wildfires.[Last accessed: 13 Aug.2022].
51. Idaho Firewise Website. Fire Ecology & Management. Fire Ignition, Behaviour & Effects. Available At: Https://Idahofirewise.Org/Fire-Ecology-And-Management/Wildfire-Ignition-Behavior-And-Effects/#:~:Text=The%20three%20sides%20of%20the,And%20wildfires%20to%20burn%20rapidly. [Last accessed: 13 Aug.2022].
52. SDG indicator metadata (Harmonised metadata template - format version 1.0) . 2022.
53. Natasha Gilbert. 2009. Forest definition comes under fire. Article on Nature website. Available At: https://www.nature.com/articles/news.2009.842#:~:text=The%20UNFCCC%20defines%20a%20forest,forest%20from%20within%20those%20ranges.[Last accessed: 13 Aug.2022].
54. USGS Website.What is remote sensing and what is it used for? Available At: https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used.[Last accessed: 13 Aug.2022].
55. Leblon, B., Bourgeau-Chavez, L., & San-Miguel-Ayanz, J. (2012). Use of Remote Sensing in Wildfire Management. In (Ed.), Sustainable Development - Authoritative and Leading Edge Content for Environmental Management. IntechOpen. https://doi.org/10.5772/45829. Available At: https://www.intechopen.com/chapters/38093. [Last accessed: 13 Aug.2022].
56. P. P. Shinde and S. Shah, "A review of machine learning and deep learning applications," in Proc. 4th Int. Conf. Comput. Commun. Control Autom.(ICCUBEA), Aug. 2018, pp. 16.
57. A. S. Modi, "Review article on deep learning approaches" in Proc.2nd Int. Conf. Intell. Comput. Control Syst. (ICICCS), Jun. 2018,pp. 16351639.
58. European Space Agency(ESA). 2021. Working towards a Digital Twin of Earth. Available at: https://www.esa.int/Applications/Observing_the_Earth/Working_towards_a_Digital_Twin_of_Earth.[Last accessed: 13 Aug.2022].
59. European Centre for Medium-Range Weather Forecasts(ECMWF)website.Destination Earth. Available at: zttps://www.ecmwf.int/en/about/what-we-do/environmental-services-and-future-vision/destination-earth.[Last accessed: 13 Aug.2022].
60. Buonocore, L., Yates, J., & Valentini, R. (2022). A Proposal for a Forest Digital Twin Framework and Its Perspectives. *Forests*, *13*(4), 498.
61. CORDIS Website. Digital twins for understanding forest disturbances and recovery from space. Available at: https://cordis.europa.eu/project/id/101039795 . [Last accessed: 14 Jan.2023]
62. VisualSweden Website(2022). Smart Twins for Forest Environment. Project by RISE Research Institutes of Sweden. Available at: https://www.visualsweden.se/en/aktuella-projekt/smart-twin-for-forest-environment/ .[Last accessed: 14 Jan.2023]
63. KAUPPI, ANNA (2021). Finnish Forest Association WEbsite. Digital twin of forests commissioned by European Space Agency – new tools for carbon calculations are hoped for . Available at: https://forest.fi/article/digital-twin-of-forests-commissioned-by-european-space-agency-new-tools-for-carbon-calculations-are-hoped-for/#69b78345 . [Last accessed: 14 Jan.2023]
64. Brook, Robert(2022). T & D World Website. Get Ahead of Wildfires with a Digital Twin. Available at: https://www.tdworld.com/wildfire/article/21236131/get-ahead-of-wildfires-with-a-digital-twin . [Last accessed: 14 Jan.2023]
65. Zohdi, T. I. (2020). A machine-learning framework for rapid adaptive digital-twin based fire-propagation simulation in complex environments. *Computer Methods in Applied Mechanics and Engineering*, *363*, 112907.
66. Yun, S. J., Kwon, J. W., & Kim, W. T. (2022). A Novel Digital Twin Architecture with Similarity-Based Hybrid Modeling for Supporting Dependable Disaster Management Systems. *Sensors*, *22*(13), 4774.
67. Wallgrün, Jan Oliver; Huang, Jiawei; Zhao, Jiayan et al. 2021. UC Santa Barbara _ GIScience 2021 Short Paper Proceedings _ Embodied digital twins of forest environments. Available at: https://escholarship.org/uc/item/0kb4z5hq . [Last accessed: 14 Jan.2023]
68. Jiang, X., Jiang, M., Gou, Y., Li, Q., & Zhou, Q. (2022). Forestry digital twin with machine learning in Landsat 7 data. *arXiv preprint arXiv:2204.01709*.

69. andy castillo. (2021). For public agencies, the proposed ‘metaverse’ has implications beyond social media—like predicting the spread of wildfire. *The American City & County,* Available at: https://www.proquest.com/trade-journals/public-agencies-proposed-metaverse-has/docview/2595465021/se-2 . [Last accessed: 14 Jan.2023]
70. Zhang, C., Cheng, S., Kasoar, M., & Arcucci, R. (2022). Reduced order digital twin and latent data assimilation for global wildfire prediction. *EGUsphere*, 1-24.
71. Kramer, R. (2012). Wildfire. NASA Earth Observatory. Available at: https://earthobservatory.nasa.gov/features/wildfire. [Last Accessed: 06 March 2023].
72. Gatto, M., Lafortezza, R., & Sanesi, G. (2018). Wildfire management in Mediterranean Europe: a governance perspective. International Journal of Disaster Risk Reduction, 27, 538-548. https://doi.org/10.1016/j.ijdrr.2017.12.003.
73. T. G. Filley, B. W. Weber, W. Mell, A. Linn, J. Bevins, and R. Barowy (2015).National Institute of Standards and Technology (NIST). Wildland-Urban Interface Fire Dynamics Simulations Using Coupled Atmospheric-Fire Model. Available at: https://www.nist.gov/publications/wildland-urban-interface-fire-dynamics-simulations-using-coupled-atmospheric-fire-model. Report URL URL: https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1907.pdf. [Last Accessed: 06 March 2023].
74. Jolly, W.M., et al. (2013). Climate-induced variations in global wildfire danger from 1979 to 2013. Nature Communications, 4, 2892. https://doi.org/10.1038/ncomms3892. [Last Accessed: 06 March 2023].
75. National Interagency Fire Center (NIFC). NIFC_Fire_Management_Response. Available at: https://www.nifc.gov/fireInfo/fireInfo_documents/NIFC_Fire_Mgmt_Resp.pdf.[Last Accessed: 06 March 2023].
76. Koutsias Nikos, Xanthopoulos Gavriil, Founda Dimitra, Xystrakis Fotios, Nioti Foula, Pleniou Magdalini, Mallinis Giorgos, Arianoutsou Margarita (2013) On the relationships between forest fires and weather conditions in Greece from long-term national observations (1894–2010). International Journal of Wildland Fire 22, 493-507. Available at: https://www.publish.csiro.au/wf/fulltext/WF12003.[Last Accessed: 06 March 2023].
77. US National Park Service Website. Post-fire Assessment. Available at: https://www.nps.gov/articles/post-fire-assessment.htm . [Last Accessed: 06 March 2023].
78. Hassani, H., Huang, X., & MacFeely, S. (2022). Enabling Digital Twins to Support the UN SDGs. Big Data and Cognitive Computing, 6(4), 115.
79. European commission website. A European Green Deal. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.[Last accessed: 10 Dec.2022].
80. Zanasi and partners website. SILVANUS: the new European Green Deal project launched for wildfire management, forest resilience and climate change. Available at: https://www.zanasi-alessandro.eu/news/silvanus-the-new-european-green-deal-project-launched-for-wildfire-management-forest-resilience-and-climate-change/.[Last accessed: 10 Dec.2022].
81. European Commission. Article published for project calls.2020. Preventing and fighting extreme wildfires with the integration and demonstration of innovative means .https://ec.europa.eu/info/sites/default/files/research_and_innovation/green_deal/gdc_stakeholder_engagement_topic_01-1_fighting_wildfires.pdf.[Last accessed: 10 Dec.2022].
82. Fetting,C and Esdn Office. 2020. The European Green Deal. Available at: https://www.esdn.eu/fileadmin/ESDN_Reports/ESDN_Report_2_2020.pdf .[Last accessed: 10 Dec.2022].
83. World Health Organisation Website. Millennium Development Goals (MDGs). Available at : https://www.who.int/news-room/fact-sheets/detail/millennium-development-goals-(mdgs).[Last accessed: 10 Dec.2022].
84. Focus2030 Website.2019.What Are The Sustainable Development Goals? Available at: https://focus2030.org/What-are-the-Sustainable-Development-Goals.[Last accessed: 12 Dec.2022].
85. PreventionWeb website. SDGs With Targets Related To Disaster Risk. Available at: . https://www.preventionweb.net/sustainable-development-and-drr/sdgs-targets-related-disaster-risk.[Last accessed: 12 Dec.2022].
86. United Nations Office for Disaster Risk Reduction (UNDRR Website) .What is the Sendai Framework for Disaster Risk Reduction? Available at:https://www.undrr.org/?_gl=1*frwf89*_ga*MTcyNzc0MzUwMi4xNjY5NzE3NjA5*_ga_T3RWEE6Z0J*MTY3MDQxMzI3Ny4yLjEuMTY3MDQxNDUxMS4wLjAuMA.[Last accessed: 12 Dec.2022].
87. European Commission Website.2021. Article: European Green Deal: Commission proposes new strategy to protect and restore EU forests. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3723.[Last accessed: 12 Dec.2022].

88. Paul Voosen. 2020.Europe builds 'digital twin' of Earth to hone climate forecasts Ingesting more data than ever before, exascale model will simulate the impact of climate change on humans. American Association for the Advancement of Science(AAAS). VOL. 370, NO. 6512, pp. 16-17. DOI: DOI: 10.1126/science.370.6512.16. . Available at: https://www.science.org/doi/full/10.1126/science.370.6512.16.[Last accessed: 12 Dec.2022].
89. European Space Agency(ESA). Destination Earth. Available at: https://www.esa.int/Applications/Observing_the_Earth/Destination_Earth.[Last accessed: 12 Dec.2022].
90. European Commision Website. Digital Earth. Available At: https://joint-research-centre.ec.europa.eu/scientific-activities-z/digital-earth_en.[Last accessed: 12 Dec.2022].
91. Marconcini, M., Esch, T., Bachofer, F., & Metz-Marconcini, A. (2020). Digital earth in Europe. In Manual of digital earth (pp. 647-681). Springer, Singapore.
92. CORDIS, European Commission Website.Integrated Technological and Information Platform for wildfire Management, Climate resilient forest management platform to prevent and suppress forest fire. Available at: https://cordis.europa.eu/project/id/101037247.[Last accessed: 12 Dec.2022].
93. Ganteaume, A., Camia, A., Jappiot, M. *et al.* A Review of the Main Driving Factors of Forest Fire Ignition Over Europe. *Environmental Management* 51, 651–662 (2013). DOI: https://doi.org/10.1007/s00267-012-9961-z Available at: https://www.degruyter.com/document/doi/10.1515/geo-2019-0033/html?lang=en.[Last accessed: 28 Dec.2022].
94. The European Environment Agency Website. 2022. Urban areas at risk of forest fire. Available at:. https://www.eea.europa.eu/data-and-maps/figures/forest-fire-risk-affecting-urban-areas.[Last accessed: 28 Dec.2022].
95. Morgan Stanley. National Geographic Website.Wildfires . Available at: https://education.nationalgeographic.org/resource/wildfires.[Last accessed: 28 Dec.2022].
96. National Geographic Website.Wildfires . Wildfires: How They Form, and Why They're so Dangerous. Available at: https://education.nationalgeographic.org/resource/wildfires-how-they-form-and-why-theyre-so-dangerous.[Last accessed: 28 Dec.2022].
97. The Conversation Website. Rao et al. 2022. The fastest population growth in the West's wildland-urban interface is in areas most vulnerable to wildfires. Available at: 28 Dec.2022. https://theconversation.com/the-fastest-population-growth-in-the-wests-wildland-urban-interface-is-in-areas-most-vulnerable-to-wildfires-173410.[Last accessed: 28 Dec.2022].
98. Leslie A. Richardson; Patricia A. Champ; John B. Loomis (2012). The hidden cost of wildfires: Economic valuation of health effects of wildfire smoke exposure in Southern California. , 18(1), 0–35. doi:10.1016/j.jfe.2011.05.002 . Available at: https://www.sciencedirect.com/science/article/abs/pii/S1104689911000444. [Last accessed: 28 Dec.2022].
99. Matthew Wibbenmeyer and Anne McDarris. 2021. Article published in Explained Publication. Resources for the Future Website. Wildfires in the United States 101: Context and Consequences: An overview of the context and consequences of wildfires in the United States, from trends and causes to impacts on the economy, the environment, and human health. 2021. Available at: https://www.rff.org/publications/explainers/wildfires-in-the-united-states-101-context-and-consequences/?gclid=CjwKCAiA76-dBhByEiwAA0_s9cf-f1TsbV9A7yDVEFDVY7xlwRQh0JxHQ_ttE2W6O9mdWWLQdaeUUBoC6nIQAvD_BwE.[Last accessed: 28 Dec.2022].
100. Chen, G., Guo, Y., Yue, X., Tong, S., Gasparrini, A., Bell, M. L., … Zanobetti, A. (2021). Mortality risk attributable to wildfire-related PM2·5 pollution: a global time series study in 749 locations. The Lancet Planetary Health, 5(9), e579–e587. doi:10.1016/s2542-5196(21)00200-x . Available at: https://www.sciencedirect.com/science/article/pii/S254251962100200X . [Last accessed : 29 Dec.2022].
101. Ciciretti, R., Barraza, F., De la Barrera, F., Urquieta, L., & Cortes, S. (2021). Relationship between Wildfire Smoke and Children's Respiratory Health in the Metropolitan Cities of Central-Chile. Atmosphere, 13(1), 58. https://doi.org/10.3390/atmos13010058 . Available at: https://www.mdpi.com/2073-4433/13/1/58 . [Last accessed : 29 Dec.2022].
102. The International Association of Wildland Fire (IAWF) Website . Available at: https://www.iawfonline.org/about-us/ .[Last accessed : 30 Dec.2022].
103. UNDDR. Fire Ecology Research Group website. The Global Fire Monitoring Center (GFMC). 2017. Available at: https://gfmc.online/intro/About1.html . [Last accessed : 30 Dec.2022].
104. Global Wildfire Information System (GWIS) website. Available at: https://gwis.jrc.ec.europa.eu/. [Last accessed : 30 Dec.2022].
105. Artés, T., Oom, D., de Rigo, D., Houston-Durrant, T, Maianti, P., Liberta, G., San-Miguel-Ayanz, J. (2019) A global wildfire dataset for the analysis of fire regimes and fire behaviour. Sci Data 6,

296 https://doi.org/10.1038/s41597-019-0312-2 . Available at: https://www.nature.com/articles/s41597-019-0312-2.[Last accessed : 30 Dec.2022].
106. US Fish and Wildlife Service Website. Fire Management Program. Available at: https://www.fws.gov/program/fire-management .[Last accessed : 30 Dec.2022].
107. National Interagency Fire Center Website (NIFC). Mobilisation. Available at: https://www.nifc.gov/resources/mobilization. [Last accessed : 30 Dec.2022].
108. National Interagency Fire Center Website (NIFC). Interagency Fire Program Management. Available at: https://www.nifc.gov/programs/interagency-fire-program-management. Last accessed : 30 Dec.2022.
109. U.S. Department of the Interior Website . Addressing the Drought Crisis. Available at: https://www.doi.gov/priorities/addressing-the-drought-crisis. Last accessed : 30 Dec.2022.
110. U.S. Department of the Interior Website. Wildfire Management . Available at: https://www.doi.gov/ocl/wildfire-management .[Last accessed : 30 Dec.2022].
111. National Integrated Drought Information System(NIDIS) Website. Wildfire Management. Available at: https://www.drought.gov/sectors/wildfire-management. [Last accessed : 30 Dec.2022].
112. Tidwell,Tom. 2009. World Forestry Congress 2009. Published on Forest Service _ U.S. Department Of Agriculture. U.S. Forest Landownership and the Role of the Forest Service. Available at: https://www.fs.usda.gov/speeches/building-global-partnerships-wildfire-management. [Last accessed : 30 Dec.2022].
113. National Interagency Fire Center Website. Fire Enterprise Geospatial Portal. Available at: https://egp.nwcg.gov/egp/ . [Last accessed : 30 Dec.2022]
114. Forest Service _ U.S. Department Of Agriculture Website .Fire Information. Available at: https://www.fs.usda.gov/science-technology/fire/information. [Last accessed : 30 Dec.2022].
115. Forest Service _ U.S. Department Of Agriculture Website . Fire Forcasting. Available at: https://www.fs.usda.gov/science-technology/fire/forecasting.[Last accessed : 30 Dec.2022].
116. National Interagency Coordination Center Website(NICC). National Interagency Fire Center. Predictive Services Program Overview. Available at: https://www.predictiveservices.nifc.gov/predictive.htm . [Last accessed : 30 Dec.2022].
117. National Wildfire Coordinating Group(NWCG) Website. The National Predictive Services Oversight Group (PSOG). Available at: https://www.nwcg.gov/partners/fmb/psog .[Last accessed : 30 Dec.2022].
118. National Interagency Fire Center Website. National Wildfire Coordinating Group. Available at: https://www.nifc.gov/programs/national-wildfire-coordinating-group#:~:text=The%20National%20Wildfire%20Coordinating%20Group,interagency%20wildland%20fire%20operations%20standards.[Last accessed : 30 Dec.2022].
119. U.S. Department Of Agriculture Website. Managing Fire. Available at: https://www.fs.usda.gov/science-technology/fire.[Last accessed : 30 Dec.2022].
120. European Forest Fire Information System(EFFIS) Website. Applications. Available at: https://effis.jrc.ec.europa.eu/applications.[Last accessed : 30 Dec.2022].
121. European Union. Global Wildfire Information System (GWIS) Website. Applications. Available at: https://gwis.jrc.ec.europa.eu/.[Last accessed : 02 Jan.2023].
122. European Union. Atmosphere Monitoring Service Website. Global Fire Emissions. Available at: https://atmosphere.copernicus.eu/global-fire-emissions .[Last accessed : 02 Jan.2023].
123. Global Fire Monitoring Center (GFMC) Website. 2017. Available at: https://gfmc.online/intro/about1.html. [Last accessed : 02 Jan.2023].
124. The International Association of Wildland Fire (IAWF) Website. Available at: https://www.iawfonline.org/. [Last accessed : 02 Jan.2023].
125. Wildfire Risk to Communities Website. USDA Forest Service. Available at: https://wildfirerisk.org/. [Last accessed : 02 Jan.2023].
126. National Interagency Fire Center (NIFC) Website. National Wildland Fire Preparedness Levels. A Summary of the Nation's Wildfire Response Stages. Available at: https://www.nifc.gov/sites/default/files/2020-09/National_Preparedness_Levels.pdf . [Last accessed : 04 Jan.2023].
127. California Department of Forestry and Fire Protection (Cal Fire) Website. Working Together To Create Healthy Forests. Available at: https://www.fire.ca.gov/programs/resource-management/resource-protection-improvement/wildfire-resilience/forest-stewardship/partners-agencies/ . [Last accessed : 04 Jan.2023].
128. California Department of Forestry and Fire Protection (Cal Fire) Website. Wildfire Prevention Grants Program. Available at: https://www.fire.ca.gov/grants/wildfire-prevention/ . [Last accessed : 04 Jan.2023].
129. University of California_Agriculture and Natural Resources Website. Forest Research and Outreach, California Forests. Available at: https://ucanr.edu/sites/forestry/California_forests/. [Last accessed : 04 Jan.2023].

130. California Fire Safe Council Website. Available at: https://cafiresafecouncil.org/resources/fire-safe-councils/#:~:text=Fire%20Safe%20Councils%20throughout%20California,wildfire%20survivability%20of%20their%20communities. [Last accessed : 04 Jan.2023].
131. University of California_Agriculture and Natural Resources Website. Fire in California_Evacuation. Available at: https://ucanr.edu/sites/fire/Safety/Evacuation/ . [Last accessed : 04 Jan.2023].
132. Wanger et al (Action Group 8_Risk Governance). 2020. EUSALP EU Strategy for the Alpine Region Website. Forest Fires In The Alps - State Of Knowledge And Further Challenges_White paper for policy makers. Available at: https://www.alpine-region.eu/results/forest-fires-alps-state-knowledge-and-further-challenges .[Last accessed : 04 Jan.2023.]
133. European Forest Fire Information System. (2021). EFFIS - Current Situation. Available at: http://effis.jrc.ec.europa.eu/static/effis_current_situation/public/index.html. [Last accessed : 26 Feb .2023].
134. European Commission. (2019). Forest Fires. Available at: https://ec.europa.eu/info/topics/environment-and-climate-change/forests/forest-fires_en.[Last accessed : 26 Feb .2023].
135. European Forest Institute. (2021). Wildfires. Available at: https://www.efi.int/wildfires. [Last accessed : 26 Feb .2023].
136. European Forest Fire Information System. (n.d.). EFFIS. Available at: https://effis.jrc.ec.europa.eu/. [Last accessed : 26 Feb .2023].
137. European Commission. (2014). Rural Development Policy. Available at: https://ec.europa.eu/agriculture/rural-development-2014-2020_en.[Last accessed : 26 Feb .2023].
138. Ganteaume, A., Jappiot, M., & Lampin, C. (2013). Analysing the spatiotemporal dynamics of southern France's forest fires between 1985 and 2011. Journal of Environmental Management, 127, 163-173.
139. Lombardi, G., Bertolini, G., & Sioni, S. (2019). Analysis of the Italian National Plan for the Prevention of Forest Fires (PNPFI): Strengths and weaknesses. Forest Policy and Economics, 101,
140. Alpine Convention. (2021). Forest Fire Protection. Available at: https://www.alpconv.org/en/tasks/forests/forest-fire-protection/. [Last accessed : 26 Feb .2023].
141. EEA. (2020). Wildfire in Europe - Executive summary. Available at: https://www.eea.europa.eu/publications/wildfire-in-europe-executive-summary. [Last accessed : 26 Feb .2023].
142. FAO. (2020). State of the World's Forests 2020. https://doi.org/10.4060/ca8643en.
143. Swissinfo.ch. (2020). Swiss fire detection system aims to combat alpine infernos. Available at: https://www.swissinfo.ch/eng/business/swiss-fire-detection-system-aims-to-combat-alpine-infernos/45803490. [Last accessed : 26 Feb .2023].
144. WWF. (2021). The Alpine Region. https://www.worldwildlife.org/places/alpine-region
145. San-Miguel-Ayanz, J., Schulte, E., Schmuck, G., Camia, A., Strobl, P., Liberta, G., Giovando, C., & Boca, R. (2013). Comprehensive monitoring of wildfires in Europe: the European Forest Fire Information System. Journal of Environmental Monitoring, 15(9), 1902-1912.
146. European Commission. (2018). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a renewed EU strategy 2018-2022 for tackling the risk of wildfires. Brussels: European Commission.
147. Bachmann, C. M., Mittermeier, L., & Wohlgemuth, T. (2013). Multi-level governance of forest resources. In European forests and global change: The likely impacts of rising CO2 and temperature (pp. 271-294). Cambridge University Press.
148. Moreno, J.M., Viedma, O., Moreno-Fernández, D., and Concha-Dimas, A. (2015). "Wildfire policies in Spain: integrating scientific knowledge into policy planning and implementation." Forest Systems 24(3), eRP-001. DOI: 10.5424/fs/2015243-07630.
149. Marzolini, E., Conedera, M., & Pezzatti, G. B. (2019). Swiss forest fire management: status, challenges and opportunities. Forest@, 16, 39-49. https://doi.org/10.3832/efor3209-016.
150. California Legislature. (2019). Assembly Bill No. 1054 - Wildfire prevention, safe drinking water, drought preparation, and flood protection bond act of 2019. Available at: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200AB1054.[Last accessed : 27 Feb .2023].
151. CALFIRE. (2022). About CAL FIRE. Available at: https://www.fire.ca.gov/about/. [Last accessed : 27 Feb .2023].
152. Marzelli, S., Pedrazzini, F., Conedera, M., & Niederhauser, P. (2019). The Federal Forest Fire Protection Act and forest fire management in Switzerland. Forest Policy and Economics, 100, 9-15. doi: 10.1016/j.forpol.2018.11.005.
153. National Interagency Fire Center. Available at: https://www.nifc.gov/. [Last accessed : 27 Feb .2023].

154.European Forest Fire Information System. (2021). EFFIS - Current Situation. Available at: http://effis.jrc.ec.europa.eu/static/effis_current_situation/public/index.html. [Last accessed : 26 Feb .2023].
155.European Commission. (2019). Forest Fires. Available at: https://ec.europa.eu/info/topics/environment-and-climate-change/forests/forest-fires_en.[Last accessed : 26 Feb .2023].
156.European Forest Institute. (2021). Wildfires. Available at: https://www.efi.int/wildfires. [Last accessed : 26 Feb .2023].
157.European Forest Fire Information System. (n.d.). EFFIS. Available at: https://effis.jrc.ec.europa.eu/. [Last accessed : 26 Feb .2023].
158.European Commission. (2014). Rural Development Policy. Available at: https://ec.europa.eu/agriculture/rural-development-2014-2020_en.[Last accessed : 26 Feb .2023].
159.Ganteaume, A., Jappiot, M., & Lampin, C. (2013). Analysing the spatiotemporal dynamics of southern France's forest fires between 1985 and 2011. Journal of Environmental Management, 127, 163-173.
160.Lombardi, G., Bertolini, G., & Sioni, S. (2019). Analysis of the Italian National Plan for the Prevention of Forest Fires (PNPFI): Strengths and weaknesses. Forest Policy and Economics, 101,
161.Alpine Convention. (2021). Forest Fire Protection. Available at: https://www.alpconv.org/en/tasks/forests/forest-fire-protection/. [Last accessed : 26 Feb .2023].
162.EEA. (2020). Wildfire in Europe - Executive summary. Available at: https://www.eea.europa.eu/publications/wildfire-in-europe-executive-summary. [Last accessed : 26 Feb .2023].
163.FAO. (2020). State of the World's Forests 2020. https://doi.org/10.4060/ca8643en.
164.Swissinfo.ch. (2020). Swiss fire detection system aims to combat alpine infernos. Available at: https://www.swissinfo.ch/eng/business/swiss-fire-detection-system-aims-to-combat-alpine-infernos/45803490. [Last accessed : 26 Feb .2023].
165.WWF. (2021). The Alpine Region. https://www.worldwildlife.org/places/alpine-region
166.San-Miguel-Ayanz, J., Schulte, E., Schmuck, G., Camia, A., Strobl, P., Liberta, G., Giovando, C., & Boca, R. (2013). Comprehensive monitoring of wildfires in Europe: the European Forest Fire Information System. Journal of Environmental Monitoring, 15(9), 1902-1912.
167.Yang, Z., Yu, X., Dedman, S., Rosso, M., Zhu, J., Yang, J., ... & Wang, J. (2022). UAV remote sensing applications in marine monitoring: Knowledge visualisation and review. *Science of The Total Environment*, 155939.
168.Government of Canada Website. Hyperspectral Remote Sensing. Available at: https://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-and-air-photos/sensors-and-methods/hyperspectral/10970. [Last Accessed: 10.Jan.2023].
169.GISRS Study Website (2022).Sensor. Available at: https://gisrsstudy.com/types-of-sensor/. [Last Accessed: 10.Jan.2023].
170.Kogut, Peter. 2020. Types Of Remote Sensing: Technology Changing The World. EOS Data Analytics,Inc Website. Available at: https://eos.com/blog/types-of-remote-sensing/#:~:text=There%20exist%20two%20main%20types,rely%20on%20the%20reflected%20one. [Last Accessed: 10.Jan.2023].
171.Zhu, L., Suomalainen, J., Liu, J., Hyyppä, J., Harri Kaartinen, H., & Haggren, H. (2017). A Review: Remote Sensing Sensors. In R. B. Rustamov, S. Hasanova, & M. H. Zeynalova (Eds.), Multi-purposeful Application of Geospatial Data. IntechOpen. https://doi.org/10.5772/intechopen.71049. Available at: https://www.intechopen.com/chapters/57384. [Last Accessed: 10.Jan.2023].
172.Bedolla, Azarely(2022). Wildfire Detection Technologies. Article on Roboticscats Website. Available at: https://roboticscats.com/2022/07/27/wildfire-detection-technologies/?utm_source=rss&utm_medium=rss&utm_campaign=wildfire-detection-technologies.[Last Accessed: 17.Jan.2023].
173.NASA EarthData Website. What is Remote Sensing? Available at: https://www.earthdata.nasa.gov/learn/backgrounders/remote-sensing.[Last Accessed: 17.Jan.2023].
174.European Commission. Copernicus Website. Emergency Management Service - Mapping_ RRM PORTFOLIO - P16. Available at: https://emergency.copernicus.eu/mapping/ems/rrm-portfolio-p16. [Last Accessed: 10.Jan.2023].
175.European Commission. Copernicus Website. Emergency Management Service - Mapping_ RRM PORTFOLIO - P15.Available at: https://emergency.copernicus.eu/mapping/ems/rrm-portfolio-p15. [Last Accessed: 09.Jan.2023].
176.European Commission. Copernicus Website. Emergency Management Service - Mapping_ RRM PORTFOLIO - P07.Available at: https://emergency.copernicus.eu/mapping/ems/rrm-portfolio-p07. [Last Accessed: 09.Jan.2023].

177. European Commission. Copernicus Website. Emergency Management Service - Mapping_ RRM PORTFOLIO - P14.Available at: https://emergency.copernicus.eu/mapping/ems/rrm-portfolio-p14. [Last Accessed: 09.Jan.2023].
178. European Centre for Medium-Range Weather Forecasts(ECMWF) Website.Copernicus Emergency Management Service. Available at: https://www.ecmwf.int/en/about/what-we-do/environmental-services-and-future-vision/copernicus-emergency-management-service . [Last Accessed: 27.Jan.2023].
179. European Commission. Copernicus Website. Emergency Management Service. Risk and Recovery Mapping Portfolio.Available at: https://emergency.copernicus.eu/mapping/ems/risk-and-recovery-mapping-portfolio#FLEX.
180. Remote Sensing: Meaning, Concept and Components | Geography. Available at: https://www.geographynotes.com/topography/remote-sensing/remote-sensing-meaning-concept-and-components-geography/5958 . [Last Accessed: 18.Jan.2023].
181. StudyProbe Website(2020). Remote Sensing – Definition, Basic Concept, and Components. Available at: https://www.studyprobe.in/2020/06/remote-sensing.html.[Last Accessed: 18.Jan.2023].
182. The University of Texas at Austin, Texas_ Center for Space Research. Hyperspectral Remote Sensing. Available at: https://www.csr.utexas.edu/projects/rs/hrs/hyper.html#background. [Last Accessed: 20.Jan.2023].
183. Esri Website.GIS Dictionary Beta. Ground Receiving Station. Available at: https://support.esri.com/en/other-resources/gis-dictionary/term/1091da28-a1e5-455b-80a9-cd60b0e4a82e. [Last Accessed: 20.Jan.2023].
184. Subha(2020). Agira Innovation Engineering. Forest Fire Detection Using Remote Sensing Techniques. Available at: https://www.agiratech.com/forest-fire-detection-remote-sensing. [Last Accessed: 22.Jan.2023].
185. United Nations Website. Office for Outer Space Affairs. UN-SPIDER Knowledge Portal_ Normalised Burn Ratio (NBR). Available at: https://un-spider.org/advisory-support/recommended-practices/recommended-practice-burn-severity/in-detail/normalized-burn-ratio. [Last Accessed: 22.Jan.2023].
186. European Commission Website. Climate Change Service, Implemented by ECMWF. Fire Weather Index. Available at: https://climate.copernicus.eu/fire-weather-index. [Last Accessed: 26.Jan.2023].
187. Landsat Missions. U.S. Department of the Interior. USGS Website.Landsat Soil Adjusted Vegetation Index. Available at: https://www.usgs.gov/landsat-missions/landsat-soil-adjusted-vegetation-index. [Last Accessed: 27.Jan.2023].
188. Filipponi, F. (2018). BAIS2: Burned Area Index for Sentinel-2. The 2nd International Electronic Conference on Remote Sensing. https://doi.org/10.3390/ecrs-2-05177.
189. Chirici, Gherardo(2022). Sul monitoraggio degli incendi forestali. Quali le fonti di dati più attendibili? . Available at: https://sisef.org/2022/08/10/sul-monitoraggio-degli-incendi-forestali-quali-le-fonti-di-dati-piu-attendibili/.[Last accessed : 04 Jan.2023].
190. Pittarello, Fabio(2019). Modellazione Numerica Della Dinamica Di Colate Detritiche Post Incendio: Analisi Dell'evento Del 7 Giugno 2018 Nel Comune Di Bussoleno (TO). Masters Thesis Dissertation. Politecnico di Torino University. Available at: https://webthesis.biblio.polito.it/secure/11850/1/tesi.pdf . [Last accessed : 02.Feb.2023]
191. Fiorentini, Cristian.A.A. 2017-2018. Analisi Della Severità Dell'incendio Del Parco Regionale Campo Dei Fiori (VA, 2017).Università Degli Studi di Milano. Available at: https://www.researchgate.net/profile/Fiorentini-Christian/publication/332780888_ANALISI_DELLA_SEVERITA_DELL'INCENDIO_DEL_PARCO_REGIONALE_CAMPO_DEI_FIORI_VA_2017/links/5cc95cad299bf120978bd138/ANALISI-DELLA-SEVERITA-DELLINCENDIO-DEL-PARCO-REGIONALE-CAMPO-DEI-FIORI-VA-2017.pdf. [Last accessed : 02.Feb.2023]
192. Unione Amministrazioni Comunali Website. Unione Montana Valle Susa. Available at: https://www.amministrazionicomunali.it/unione/unione-montana-valle-susa. [Last accessed : 03.Feb.2023]
193. CAMERANO P., GOTTERO F., TERZUOLO P.G., VARESE P. - IPLA S.p.A., Tipi forestali del Piemonte. Regione Piemonte, Blu Edizioni, Torino 2008, pp. 216. PDF Available at: https://www.regione.piemonte.it/web/sites/default/files/media/documenti/2019-03/tipi_forestali_del_piemonte.pdf. [Last accessed : 03.Feb.2023]
194. Ministero dell'Ambiente e della Sicurezza Energetica Website. A website of the Italian Government .Environment and Energy Security Minister(2021). Attività Antincendi Boschivi. Available at: https://www.mase.gov.it/pagina/attivita-antincendi-boschivi. [Last accessed : 04.Feb.2023]
195. Presidency of the Council of Ministers of Italian Government. Department of Civil Protection Website. Rischio incendi boschivi. Le attività. Available at: https://rischi.protezionecivile.gov.it/it/incendi-boschivi/attivita. [Last accessed : 04.Feb.2023]

196. Geoportale Nazionale Website. PROGETTO INCENDI. La cartografia AIB (Anti Incendi Boschivi) del Geoportale a supporto della realizzazione dei piani antincendi boschivi dei Parchi nazionali. Available at: http://www.pcn.minambiente.it/mattm/progetto-incendi/. [Last accessed : 04.Feb.2023]
197. CIMA Foundation Website. Incendi Boschivi e Conservazione della Biodiversità Forestale. Available at: https://www.cimafoundation.org/ambito/incendi-boschivi-e-conservazione-della-biodiversita-forestale/.[Last accessed : 05.Feb.2023]
198. GEOVES Website.ALLARME INCENDI BOSCHIVI. Available at: https://www.geoves.it/index.php/it/applicazioni/276-micromet3-butterfly-incendi?gclid=Cj0KCQiA-JacBhC0ARIsAIxybyOldNVo6Ln8ILtE1QSf43Ol0FXf6rl7xm5_CeOM_7FFUEI1Jo8OImIaAt09EALw_wcB. [Last accessed : 05.Feb.2023]
199. Dipartimentodella Protezione Civile Website. Presidenza del Consiglio dei Ministri. Bollettino di previsione nazionale incendi boschivi. Available at: https://rischi.protezionecivile.gov.it/it/approfondimento/bollettino-di-previsione-nazionale-incendi-boschivi. [Last accessed : 05.Feb.2023]
200. Legambiente Website(2022). Italia in fumo: il nuovo report di Legambiente sugli incendi. Available at: https://www.legambiente.it/comunicati-stampa/italia-in-fumo-il-nuovo-report-di-legambiente-sugli-incendi/.[Last accessed : 06.Feb.2023]
201. Regione Piemonte Website. Il sistema operativo antincendi boschivi del Piemonte. Available at: https://www.regione.piemonte.it/web/temi/protezione-civile-difesa-suolo-opere-pubbliche/protezione-civile/incendi-boschivi/sistema-operativo-antincendi-boschivi-piemonte.[Last accessed : 06.Feb.2023]
202. Regione Piemonte Website. Piano regionale per la programmazione delle attività di previsione, prevenzione e lotta attiva agli incendi boschivi 2021-2025. Available at: https://www.regione.piemonte.it/web/temi/protezione-civile-difesa-suolo-opere-pubbliche/protezione-civile/incendi-boschivi/piano-regionale-per-programmazione-delle-attivita-previsione-prevenzione-lotta-attiva-agli-incendi.[Last accessed : 06.Feb.2023]
203. Ricaldone, C, del Negro,L, Murru, A et al(2021).Regione Piemonte Settore Sistema Antincendi Boschivi. Piano Regionale Per La Programmazione Delle Attività Di Previsione, Prevenzione E Lotta Attiva Contro Gli Incendi Boschivi 2021-2025 (2021). Available at: https://www.regione.piemonte.it/web/sites/default/files/media/documenti/2021-03/piano_aib_2021_2025.pdf.[Last accessed : 06.Feb.2023]
204. Corpo AIB Piemonte. Approvato piano regionale AIB. Available at: https://www.corpoaibpiemonte.it/approvato-piano-regionale-aib/.[Last accessed : 06.Feb.2023]
205. Agenzia Regionale per la Protezione dell'Ambiente(Arpa Piemonte) Website. Rapporto climatico annuale. Available at: https://www.arpa.piemonte.it/rischinaturali/tematismi/clima/rapporti-di-analisi/annuale.html#:~:text=L'apporto%20delle%20 precipitazioni%20 totali,piovoso%20a%20a partire%20dal%201958. [Last accessed : 09.Feb.2023]
206. Sistema Nazionale per la Protezione dell'Ambiente. Arpa Piemonte Sistemi Previsionali (2018). Il Clima in Piemonte l'anno 2017. Report PDF available at: https://www.arpa.piemonte.it/rischinaturali/tematismi/clima/rapporti-di-analisi/annuale_pdf/anno_2017.pdf. [Last accessed : 09.Feb.2023]
207. Sistema Nazionale per la Protezione dell'Ambiente. Arpa Piemonte Dipartimento Rischi Naturali e Ambientali (2020). Il Clima in Piemonte l'anno 2021. Report PDF available at: https://www.arpa.piemonte.it/rischinaturali/tematismi/clima/rapporti-di-analisi/annuale_pdf/anno_2021.pdf.[Last accessed : 09.Feb.2023]
208. Regione Piemonte Website.Portal for accessing forestry documents.Piano Regionale Forestale. Available at: https://www.regione.piemonte.it/web/temi/ambiente-territorio/foreste/gestione-bosco-taglio/piano-forestale-regionale-2017-2027.
209. Licini, Franco In collaboration with L'Istituto per le Piante da Legno e l'Ambiente – IPLA spa. Piano Regionale Forestale(PFR) 2017_2027. PDFdocument Available at: https://www.regione.piemonte.it/web/sites/default/files/media/documenti/2018-11/piano_forestale_regionale_2017-2027_0.pdf.[Last accessed : 09.Feb.2023]
210. Copernicus Land Monitoring Service Website. Tree Cover Change Mask 2015 - 2018. Available at: https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/change-maps/tree-cover-change-mask-2015-2018?tab=mapview.[Last accessed : 10.Feb.2023]
211. Copernicus Land Monitoring Service Website. Tree Cover Density 2018. Available at: https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/tree-cover-density-2018.[Last accessed : 10.Feb.2023]

212. Copernicus Land Monitoring Service Website.Tree Cover Density 2015. Available at: https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/2015. [Last accessed : 10.Feb.2023]
213. Copernicus Emergency Service Website. EMSR253_02SUSA_01DELINEATION_MAP and Report. Available at: https://emergency.copernicus.eu/mapping/system/files/components/EMSR253_02SUSA_01DELINEATION_MAP_v2_100dpi.pdf. [Last accessed : 12.Feb.2023]
214. Copernicus Emergency Service Website(2017). Copernicus EMS Monitors the Impact of Forest Fire in Piedmont, Italy. Available at: https://emergency.copernicus.eu/mapping/list-of-components/EMSR253. [Last accessed : 12.Feb.2023]
215. Cat Berro, Daniele, Mercalli, Luca(2017), SMI. Nimbus Website. Ottobre 2017 Al Nord-Ovest Italiano: Caldo, Siccita' E Incendi. Available at: http://www.nimbus.it/clima/2017/171101SiccitaIncendiNordOvest.htm.[Last accessed : 13.Feb.2023].
216. Regione Piemonte, Direzione Pianificazione Risorse Idriche(2007). Piano di Tutela e delle Aque.Rev03. Sottobacino: Dora Riparia(AI11) PDF file Available at: https://www.regione.piemonte.it/web/sites/default/files/media/documenti/2018-11/ia01.pdf. [Last accessed : 14.Feb.2023].
217. USGS Website. Wildfires and Water Quality. Available at: https://www.usgs.gov/centers/california-water-science-center/science/science-topics/wildfires-and-water-quality#:~:text=Wildfires%20can%20compromise%20water%20quality,and%20drinking%2Dwater%20treatment%20processes.[Last accessed : 14.Feb.2023].
218. Environment Protection Agency(EPA) Website (2019).Wildfires: How Do They Affect Our Water Supplies? Available at: epa.gov/sciencematters/wildfires-how-do-they-affect-our-water-supplies.[Last accessed : 14.Feb.2023].
219. Regione Piemonte Website. GeoSpatial Dataset for Carta Forestale 2016 Shapefiles. Available at: http://www.sistemapiemonte.it/popalfa/indaginiPFT/indexCartaForAGG2016.do. [Last accessed : 16.Feb.2023].
220. Istituto Per le Piante da Legno e l'ambiente IPLA Spa. Regione Piemonte (2017). La Carta Forestale del Piemonte (Aggiornamento 2016). PDF Report Available at: http://www.sistemapiemonte.it/montagna/sifor/dwd/aggiornamenti2016/confronto_sup_boscate_2000_2016.pdf. [Last accessed : 16.Feb.2023].
221. Progetto ALP FFIRS: Alpine Forest Fire Warning System
222. Arpa Piemonte in collaborazione with Università degli studi di Torino(2007). , Collana Studi Climatologici in Piemonte, Volume 05. Il Vento In Piemonte. Available at: https://www.arpa.piemonte.it/pubblicazioni-2/pubblicazioni-anno-2007/pdf-il-vento-in-piemonte. [Last accessed : 16.Feb.2023].
223. Ferrentino, Antonio(2014). Consigliere Regionale. Morfologia Della Val Di Susa(Territorio; Dati economico-sociali; Cultura e Tradizioni). Available at: http://www.antonioferrentino.it/web/wp-content/uploads/2014/05/All1-MORFOLOGIAdelTERRITORIO.pdf. [Last accessed:19.Feb.2023].
224. Website of Tuscany Region. Centri Operativi Provinciali Antincendi Boschivi (COP AIB). Available at: https://www.regione.toscana.it/centri-operativi-provinciali-c.o.p.-. [Last accessed:21.Feb.2023].

225. GIS Geography Website (2022). What is NDVI (Normalised Difference Vegetation Index)? Available at: https://gisgeography.com/ndvi-normalized-difference-vegetation-index/. [Last accessed: 05 March 2023].
226. GIS Geography Website. Sentinel 2 Bands Combinations. Available at: https://gisgeography.com/sentinel-2-bands-combinations/. [Last accessed: 20 March 2023].
227. Google Earth Engine Documentation. Available at: https://developers.google.com/earth-engine. [Last accessed: 20 March 2023].
228. NASA's Earth Data Website. Available at: https://www.earthdata.nasa.gov/. [Last accessed: 28 March 2023].
229. Sentinel Hub Website by Synergis. Normalised difference vegetation index. Available at: https://custom-scripts.sentinel-hub.com/custom-scripts/sentinel-2/ndvi/. [Last accessed: 14 April 2023].
230. Regione Piemonte. Geoportale piemonte Website. Available at: https://www.geoportale.piemonte.it/geonetwork/srv/eng/catalog.search#/metadata/r_piemon:023ef6df-b781-4751-b5d2-a442427916d0. [Last Accessed: 05.Apr.2023]
231. Geoportale di Arpa Piemonte,I dati ambientali a portata di mappa. Available at:
232. https://geoportale.arpa.piemonte.it/app/public/ [Last accessed: 11. Apr. 2023].http://www.sistemapiemonte.it/dinvweb/base/HomePageCittadino.do Google Earth Engine Website. Documentation on Quantifying Forest Change. Available at: https://developers.google.com/earth-engine/tutorials/tutorial_forest_03. [Last accessed:: 11. Apr. 2023].

233. Regione Piemonte. Sistema Piemonte website. Banca Dati Incendi Boschivi. Available at: http://www.sistemapiemonte.it/incalfa/jsp/ricerca_inc/ricercaAvanzata.do . [Last Accessed: 12. Apr. 2023].
234. Available at: https://custom-scripts.sentinel-hub.com/custom-scripts/sentinel-2/ndvi/ . [Last Accessed: 12. Apr. 2023].
235. ArpaPiemonte Website. Raporto Climatico Annuale (2022). Available at: https://www.arpa.piemonte.it/rischinaturali/tematismi/clima/rapporti-di-analisi/annuale.html#:~:text=L'anno%202021%20in%20Piemonte,climatologia%20del%20periodo%201971%2D2000. [Last Accessed: 01. July. 2023].