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TERRITORIAL, URBAN, ENVIRONMENTAL AND LANDSCAPE PLANNING

FOREST FIRE RISK MAPPING USING GIS SPATIAL ANALYSIS IN ALPINE AREA

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ABSTRACT

In the last epoch there was an exponential growth of socio economic and earth-system trends that have led a rise of Earth temperature in correlation with drought particularly during warmer months, has intensified summer fires. Especially in the last decades and in cold months, higher temperature, stronger winds and the absence of precipitation, dried up the lands leading fires in woods, especially in the Alpine territory in the north of Italy. Forests are an important terrestrial biome, covering large areas of Earth surface and providing important ecosystem services like climate change mitigation, erosion reduction and more. Every year wildfires burn thousands of hectares of Mediterranean countries' forest and grassland, giving rise to landscape, ecology, economic, and public safety concerns. Since this trend will grow, a possible solution must be the limit of this ecosystem's vulnerability. This thesis combines weighted open data of social, environmental, geo-physical and fuel fields to extract factor that determine wildfires' risk; like terrain slope orientation and elevation and climate factor like precipitation, temperature and wind speed .These geospatial data were used for developing of a multi-criteria analysis thought an analytic hierarchy process (AHP) creating a spatial model of fire risk of Turin Province, that is focusing on the static and structural component of risk assessment. Historic Fire data incident have been collected from Fire Fighting database, They were compared with probable fire location predicted by the GIS model to evaluate the effectiveness and the accuracy of proposed methodology . Forest fire risk maps are vital to reduce the negative impacts of fire and facilitate planning for the protection of forested areas, so the aim of this work is not only to quantify the losses and the impact on ecosystems after wildfire occurrences, but also understand essential information that has potential operational application in protected and forested areas.

ASTRATTO

Nell'ultimo periodo c'è stata un crescita esponenziale dei processi socio-economici ed ecologici del pianeta terra che hanno portato ad un aumento dei gas serra nell'atmosfera con la conseguente crescita della temperatura terrestre ed dei periodi di siccità , che hanno intensificato il problema già esistente degli incendi estivi. Negli ultimi decenni anche nei mesi più freddi, le temperature più elevate , i venti più forti e l'assenza di precipitazioni hanno inaridito terreni hanno portato ad un incremento degli incendi invernali, specialmente nel territorio forestale alpino del nord Italia. Le foreste sono un importante bioma, che coprono vaste aree della superfice terrestre , che forniscono importati servizi ecosistemici, come la mitigazione dei cambiamenti climatici, la riduzione dell'erosione del suolo ed alto ancora. Ogni anno queste foreste ed i pascoli vengono distrutte da enormi incedi soprattutto nei paesi mediterranei, causando problemi paesaggistici, ecologici, economici e di sicurezza pubblica: Poiché questa tendenza e destinata a crescere a causa del cambiamento climatico, la possibile soluzione deve essere il limite della vulnerabilità di questi ecosistemi. Questa tesi combina dati open source, che rappresentano gli aspetti geofisici, socioeconomici ed ambientali, pesati in base al loro rischio di scaturire in incendio. Questi dati geospaziali sono stati utilizzati per lo sviluppo di un analisi multicriteriale basato su un processo di gerarchia analitica (AHP) per creare un modello spaziale del rischio di incedi boschivi nella Provincia di Torino, che si concentra sulla componente statica e strutturale della valutazione del rischio. I dati storici sugli incedi raccolti dai vigili del fuoco subito dopo ogni evento, sono stati confrontati con i modello di previsione elaborato in GIS per valutare l'efficacia e l'accuratezza della metodologia proposta. Le mappe del rischio di incendio boschivo sono fondamentali per ridurre gli impatti negativi degli incendi e facilitare la pianificazione per la protezione delle aree boschive; pertanto, l'obiettivo di questo lavoro non è solo quello di capire le possibili perdite e gli impatti nell'ecosistema forestale a seguito di incendi boschivi, ma anche di comprendere informazioni essenziali che hanno una potenziale applicazione operativa nelle aree protette e boschive.

SUMMARY

1 INTRODUCTION

Forests like all natural areas on earth perform numerous ecological and environmental functions. In fact, these regulate rainfall, temperature, reduce soil erosion and stabilize the atmospheric cycle of greenhouse gases. At the same time, they provide a variety of recreational opportunities and numerous other ecosystem services. Forest paths have a significant impact on the physical and biological environment, influencing land use and cover, ecosystems, biodiversity and climate change and also strongly influence the socio-economic system of the areas in which they occur. Mediterranean-type ecosystems are among the most diverse areas in the world, thanks to the climatic conditions that offer a diversification of habitats for various species. At the same time, due to climate change, with the increase in intensity of the periods of drought and heat, the vegetation of these ecosystems is subjected to strong water stress, with the consequent increase in the risk of fire incidents.

And it is precisely the risk of forest fire that is the main theme of this study which is an essential element for the planning and prevention of fires in order to avoid future natural losses which obviously have a direct impact on neighbouring territories but which indirectly also result in changes, in the most remote territories from them, which on a large scale manifest themselves in a situation of instability for the entire world ecosystem.

The aim of this study is therefore to define the risk of forest fires, precisely in the province of Turin, by identifying the various factors that characterize the probability and behaviour of fires, attributing them to a weight factor throughout the Analytical Hierarchy Process.

The study starts from analysing the current climatic situation that the earth is facing during this last century, which sees the succession and increase of extreme and unpredictable climatic events, which cause human and economic losses and its influence on incidents and the effects that these cause on the climate. Subsequently, the phenomenon of incidents and its trends over the last 20 years is analysed specifically, its effects on ecosystems and the landscape, also defining all the possible causes that may arise from incidents in a natural environment. Arguments that then lay the foundations for all planning and prevention actions from the European to local level. All these elements have allowed us to understand which are the determining factors, static and dynamic, which can influence the incidents such as morphological elements (Elevation, aspect, slope), climatic ones (temperature, wind, precipitation),the vegetational (Land use and vegetation index) and the socio-economic ones, (road and settlement proximity) which through a weighted linear combination have determined the creation of the risk map. In the analysis in question, among the elements that have greater relevance there is vegetation, by the fact that different species of vegetation burn differently from each other, furthermore this flame characteristic may also depend on the conditions of the vegetation. Multispectral satellite images collected by landsat 7 ETM + were used , to determine three different vegetation indices such as NDVI (normalized difference vegetation index), VCI (Vegetaion condition index) and TCD (Tree cover density). These vegetative condition, however, are extremely dependent on the vegetative period of the plants and its hydrometric conditions, making the indices extremely variable depending on the period of acquisition of the images. Having said that the final result of this thesis leads to three different risk maps defined by the three different vegetation indices, which have given positive results according to the data of the incidents already available.

In conclusion, spatial remote sensing data, now widely available, highly increases the possibility of fire risk area analysis using GIS combined with Multi-criteria Decision Analysis (GIS-MCDA), which provide a template in advance for better planning of notification mitigation and regulation recovery as well as awareness activities for impending fires.

2 CLIMATE CHANGE

Changing climate does not mean changing conditions of the weather but, more precisely, some structural changes in the climate of the planet(Lanza, 2002). Climate is composed by different elements that are temperature, humidity, pressure, and wind. This one is determined by various factors, some endogenous like atmosphere, glacier, snow, vegetation; and other exogenous like the sun and the rotation of the globe. The earth absorbs energy and releases the same quantity of energy, maintaining a status of equilibrium. This exchange of energy is controlled by the greenhouse effect. This phenomenon is altered by the deforestation and the use of fossil fuel that leads to a rise of temperature.

Climate change is causing five critical global environmental changes(Permanente & The kresge fundation, 2016):

-Warming temperature of the earth's surface and the oceans, since 1957, the earth has warmed at a rate of 0.13° C per decade, nearly two times faster as it did during the previous century;

-Changes in hydrologic cycle, The total annual precipitation has changed significantly geographically over the past century, with some regions experiencing severe and protracted drought and others seeing an increase in annual precipitation. Storm frequency and intensity rise as the atmosphere gets warmer and can hold more water vapor.

-Declining glaciers and snowpack.

Sea level rise; as also a result of glaciers melting and snowpack accumulation.

-Ocean acidification: About 25% of the CO_2 that is released into the atmosphere is absorbed by oceans, which causes seawater to become more acidic.

This global change appear in such events that we are experiencing especially in the last period like , more frequent and severe extreme heat events, severe droughts and more intense precipitations , higher mean temperatures , longer wildfire season and frequent and severe floods due the intense precipitation and snowmelt . Of course this will have an impact on local climate bringing environmental , social and economic change and of course on human health.

The main causes of this effect are the Carbon dioxide but there are also some other green house gases that are emitted by the human activity like: methane e nitrous oxide(Angelini & Pizzuto, 2007). The actual rising of temperature is strictly connected to the rising of CO2 and other pollutant emitted into atmosphere, started since the industrial revolution an then enhanced after the second world war. Measurements of air in ice cores show that for the past 800,000 years up until the 20th century, the atmospheric CO2 concentration stayed within the range 170 to 300 parts per million (ppm), making the recent rapid rise to more than 400 ppm.(The Royal Society, 2020)As a result of anthropogenic activities, other greenhouse gases (particularly methane and nitrous oxide) are also rising.
Compounding the phenomenon of temperature rise are greenhouse gases that until now who were trapped in permafrost, which is rapidly warming(Turetsky et al., 2020). Di facto all this greenhouse gasses stops the heat that otherwise would escape from the earth into space, this effect is connected to their own molecular properties and to the unique way of light absorption. The heat trapped in the atmosphere will rise the temperature of the earth to a higher value to those there would be. The heat will be distributed in unequal way. The earth's climate and weather conditions are the product of temperature differences between the polar zones and the equator, there will be changes in the strength and direction of the winds, precipitation, ocean currents.

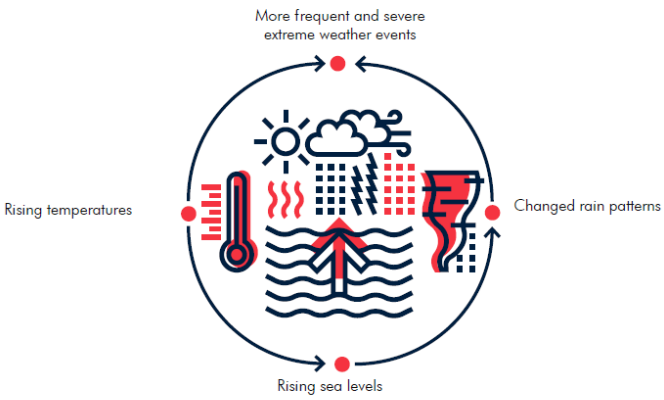


Figure 1 Effect of rising temperature

The situation is more complicated in the overall climate system, where warming has additional effects (feedbacks) that can either increase or decrease the initial warming (see upper figure 1). The most significant feedbacks involve different types of water.

More water vapor is typically present in warmer environments. Water vapor is therefore considered an amplifier of climate change rather than a driver of it(Held & Soden, 2000). Higher temperatures in the polar regions melt sea ice and reducing seasonal snow cover, exposing a darker ocean and land surface that is more heat-absorbing and contributes to further warming(EPA, 2022). Another significant but uncertain feedback relates to changes in the cloud cover. According to changes in the horizontal extent, altitude, and characteristics of clouds, warming and water vapor increases may cause cloud cover to either increase or decrease, which can either amplify or dampen temperature change(Ceppi & Nowack, 2021).

Climate change accentuate the severity of extreme weather events, increasing the volatility and unpredictability and amplifying the vulnerabilities of affected community with Floods, hurricanes, droughts, heat waves, and wildfires that in the last period are already causing chaos on people all around the world, and we can expect them to get worse. Climate change is already underway. But how far and how fast global temperatures will continue to rise, and other changes will continue to unfold, is still up to us(et al., 2020). We can't stop climate change, but we can slow it down and thereby reduce the frequency, probability and severity of future calamities, and further minimize large scale irreversible damage to vulnerable ecosystems. These necessities must include massive changes in every part of our lifestyle. People and ecosystem are facing climate change now. Many changes are unavoidable and irreversible such as the loss of biodiversity. We need to adapt ourselves to this change and put the attention to reducing the risk from short to longer term climate and weather related hazards. And crucially, to do this well to prevent and manage the disasters that are coming, we need real and effective investment and action in adaptation.(Freebairn et al., 2020).

2.1 CLIMATE AND DISASTER

Before talking about what are the effect of climate on the earth and what are the future perspectives, we have to underline some terms that can help us to understand what is happening. One concept is Disaster that is a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts(UNDRR, 2017).

Due to the large range of typologies, classifications, and definitions used by various organizations, tracking human-induced risks can be difficult. Then the extreme climate events that is are a time and place in which weather, climate, or environmental condition, such as temperature, precipitation, drought, or flooding, are ranked above a threshold value near the upper or lower ends of the range of historical measurements(David Herring, 2020). Giving some data in the last ten years, there have been 2850 disasters triggered by biological, geophysical, climate and weather-related hazards. These were primarily brought on by extreme weather and climate events, like floods, storms, and heatwaves, accounting for 83% of all cases, and of the almost 1.8 billion people affected, 97% were affected by extreme weather and climate event. (UNDRR, 2017). Understanding who has been impacted, how they have been affected, and why is crucial to understanding disasters. Natural disasters do not always result from hazards, and while hazards' frequency and intensity are unquestionably important, they are not the only factors that determine risk. Disaster risk depends on people's vulnerability to climate-related hazards, their exposure to hazards, and their ability to handle shocks.

While hazards may be natural and inevitable, disasters are not. Disasters occur when a community is "not appropriately resourced or organized to withstand the impact, and whose population is vulnerable because of poverty, exclusion or socially disadvantaged in some way"(Mizutori, 2020).

Therefore, disasters can and should be avoided. By lowering risks (which are brought on by a hazard, exposure and vulnerability) and empowering resilience, we can try to stop hazards from causing disasters.

2.2 TRENDS AND IMPACT

While the estimated amount of human-induced warming had risen to about 1°C above pre-industrial levels, the IPCC noted in 2017 that many regions and seasons had already seen warming above the global average, with land regions experiencing warming above the average and most ocean regions warming at a slower rate(Masson-Delmotte et al., 2018).

The graph below (Figure 2) shows the average temperature anomalies, from what we can see the values follow an increasing trend, and that global warming will probably rise 1.5°C between 2030 and 2052 if it continues to increase at the current rate.

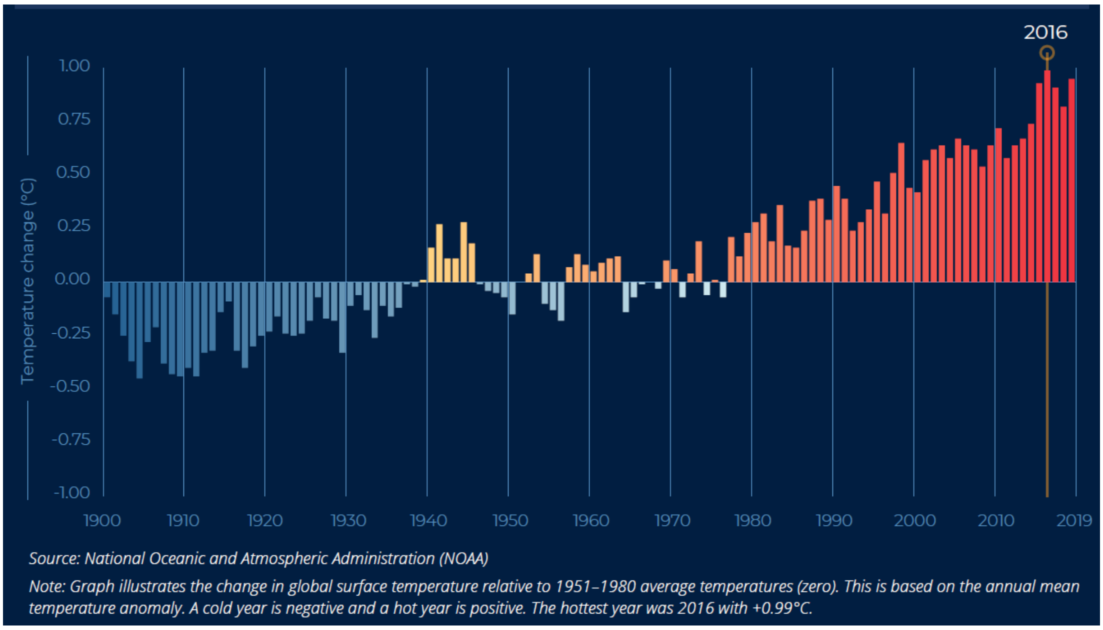


Figure 2 Global temperature change in C° , 1901-2019

The global average temperature has not changed this quickly in at least the last 10,000 years (Global Monitoring Laboratory, no date), and these changes are taking place on a global scale, so even though a 2°C or 1.5°C increase may seem like a small change, it is significant. Given current emissions and even if current measures taken under the Paris Agreement on climate change are achieved, the world is still online to experience a 3 to 5°C global temperature rise by 2100(Climate Action Tracker, 2019).

In 2019 there were 308 disasters triggered by natural hazards, affecting 97.6 million people. The most frequent were floods (127), followed by storms (59), disease outbreaks (36), earthquakes (32) and hydrological-related landslides (25). Extreme temperature events (10), wildfires (8) and droughts (8) were less frequent, while volcanic activity was quite rare with only three significant events. In 2019, the vast majority (77%) of these disasters were triggered by climate- or weather-related hazards (storms, floods, droughts, wildfires, extreme temperature or landslides).(Freebairn et al., 2020)

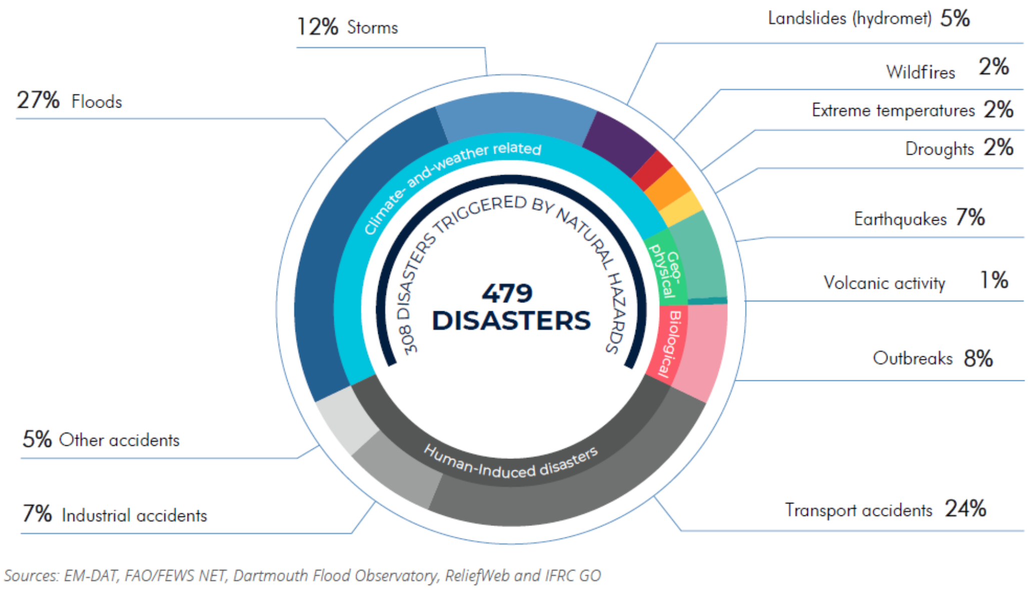


Figure 3 Type of disaster in 2019

Note that while EM-DAT is country based (so one storm affecting two countries would be counted twice), IFRC uses an events-based analysis, so a hazard that has led to a disaster in one or more countries counts as one disaster.

Wildfires and extreme temperature events are frequently not regarded as disasters but rather as "environmental events" without recognition of the human consequences. In addition, data monitoring is significantly less effective for extreme temperatures, disease outbreaks, and wildfires than for floods and storms. This explains the lower value in the cake (Figure 3)(Freebairn et al., 2020).

Glaciers, polar sea ice, and snow cover have already decreased due to global warming, and permafrost thawing has increased. Due to rises in atmospheric temperature, it is predicted that this process will continue. The oceans' continued acidification and rising ocean temperatures are also "practically certain." This will have an impact on communities that depend on the ocean's livelihoods, income, and food security by destroying coral reefs, decreasing the global biomass of animals across marine ecosystems, and decreasing the productivity of fisheries(Pörtner et al., 2019).

On land, the anticipated warming is predicted to cause a shift in some climate zones toward the poles as well as an increase in heat-related events, droughts, wildfires, and pest outbreaks. Additionally, this will result in a functional decline of the water shortage in dryland areas, a decrease in crop and livestock production in some regions, and unstable food supplies. Due to a combination of stronger storms and sea level rise, it will also result in more severe land degradation(Masson-Delmotte et al., 2020).It is anticipated that the frequency, severity, and variability of hazards like storms, floods, heatwaves, droughts, and wildfires will all rise. While some areas will experience greater risks, others will encounter brand-new risks that have never been seen or anticipated before(Masson-Delmotte et al., 2020; Pörtner et al., 2019).

2.3 WILDFIRES: INCREASED HEAT AND DESTRUCTION

The direct physical effects of wildfires include human fatalities, property damage from destroyed buildings and goods, as well as the loss of livestock and other animals. Due to fine particle air pollution, which affects the eyes and lungs and exacerbates pre-existing conditions while also causing new ones, fires can have a significant negative impact on public health. Due to the destruction of ecosystems based on forests and the pollution of others, such as rivers, lakes, and even coral reefs, they have long-lasting effects on biodiversity. Additionally, they cause a "climate feedback loop" by removing trees that would otherwise be consuming carbon dioxide, in addition to burning trees that are either contributing to greenhouse gas emissions(UNEP, 2020). In the last decades there was an increase in the of wildfire occurred around the world. The problem is probably going to get worse as time goes on. Scientists predict that the risk of fires of the same intensity would increase by at least four times in a world that is 2°C hotter than it is now, and even this estimate is likely to be low. The Americas, Europe, especially the Mediterranean region, Africa, especially countries in southern Africa, and Asia, especially Central Asia, are all expected to be more susceptible to and affected by wildfires(Masson-Delmotte et al., 2020). Of course this wildfire have a direct impact on loss of vegetation and animals, but with an increase of wildfire around the world there could be an indirect effect that perturb the economy and the ecosystem stability of the whole earth.

3 CHARACTERIZATION OF THE FIRE PHENOMENA

Forest fires are a complex phenomenon, involving the sphere of nature and man. Fire is an environmental factor of primary importance, which has always been present in most majority of terrestrial environments, which has influenced vegetation since the appearance of the first terrestrial plants and has contributed to the evolution of both species and communities(McLauchlan et al., 2020). Over the past fifty years, the abandonment of many lands and the reduced pressure of land uses forestry and grazing have resulted in a change in disturbance regimes that have initiated in many areas a general expansion of wooded areas and shrublands. Because of the increasing shrubland in abandoned fields, these new ecological conditions (of greater extension of areas of spontaneous vegetation and of forest areas no longer routinely managed from a silvicultural point of view) associated with an increasing presence of roads and residences, have resulted in an increasing number of extensive and destructive fires(Mantero et al., 2020). Fires appear more and more explicitly the symptom of socio-economic problems linked to a complex set of circumstances: the depopulation of large areas, the abandonment of agriculture, the distribution of new settlements in the rural environment, the rise of interests often conflicting with the conservation of natural resources, the means of activating forms of employment confirming that in Italy forest fires are not a natural calamity, nor a fatality, but rather an anthropogenic phenomenon, with an exclusive, direct dependence on social behaviours, voluntary or involuntary. The problem is assuming significant dimensions worldwide also in terms of its consequences on global changes, and therefore it needs to be addressed it with greater knowledge of the cause.

3.1 fire as ecological factor in the forest ecosystem

For thousands of years, fire has been a key ecological driver, forming the forest mosaic and keeping it stable. Because of the historical relationship between fire and forests, forests in places prone to recurrent fires are predominantly made of fire-adapted plants. Some species rely almost entirely on fire for competitive renewal. Each species has distinct features that ensure its survival under a fire regime. Fire has an impact on the establishment and survival of these plants at various stages, from germination through maturity(Enley, 1974). At the same time remove other sensitive species, releasing nutrients from biomass and increasing nutrient cycling, influencing soil features through modifying soil microbial activity and water relations, and producing diverse mosaics, all of which can influence fire behaviour and ecological processes. The effects of fire on an ecosystem are determined by the fire regime, plant type, climate, physical surroundings, and the evaluation scale in time and space. Indeed, as a destructive force, forest fires may destroy vast amounts of biomass and have severe consequences such as post-fire soil erosion and water runoff, as well as air pollution(Khan et al., 2018).

3.1.1 Release of pollutants into the atmosphere and climate change

Among the main ecosystem consequences induced by fires is the transfer to the atmosphere of a significant portion of about 200 compounds (methane, hydrocarbons, carbon monoxide and dioxide, oxides of nitrogen and particulate matter), which result from the processes of incomplete combustion of cellulose and lignin, to which are added resins and oils contained to varying degrees in vegetation and soil. The gases produced in the largest quantities are CO_2 and CO, which have respectively minimum and maximum emission factors of 907-1740 g-kg^{-1} and 10-270 g-kg^{-1} while particulate matter has an emission factor between 7 and 174 g-kg^{-1}.(Blasi et al., 2004)

The mass of pollutants depends on the behaviour of the fire and the fraction of biomass that is actually consumed. In large fires where on the fast front the live flame leaves behind a slow burn, which gives rise to eight times more gas than the alive combustion(Blasi et al., 2004). The mass of pollutants thus depends on the fire behaviour and the fraction of biomass that is actually consumed while varying with forest type, with the stage of forest development, with the age of the stands, with the prevalence of fuels light or mature ones. for these reasons, the release of pollutants into the atmosphere is related to the characteristic forest cover and the weather conditions at the time of the fire(Keywood et al., 2013). Some of the gases emitted during fires, in particular CO2 and CO, also known as greenhouse gases, have a direct effect on the warming of the atmosphere. Particulate matter can also change the local climate by scattering solar radiation or forming clouds, fires and their effects on vegetation, such as local and regional changes in surface characteristics, alter the climate of an area. Large fires alter the albedo by removing vegetation, resulting in reduced evapotranspiration, affecting the energy balance and thus the climate, affecting diurnal and seasonal temperature fluctuations(Veraverbeke et al., 2012).

3.1.2 Effect on the structure of landscape

In recent years, in most of the Mediterranean European countries, fires have, however, become more extensive and more frequent with significant negative effects both from ecological as well as economic point of view.

The Mediterranean region saw profound socioeconomic alterations in the second half of the twentieth century, with huge rural abandon from poor inland agro-pastoral zones and movement of people toward urban-industrial centres(Moreira et al., 2011). The phenomenon of land abandonment, in which land is abandoned and left to nature((FAO, 2020), causes landscape changes that impact disturbance regimes. This process resulted in significant land use changes in Italy, with the growth of shrublands and woods in farmed and grazed regions(Cimini et al., 2013). Changes in land use and vegetation cover have altered the structure of the landscape, creating more favourable conditions for fire ignition than in the past: in fact, the effects of fires frequently translate into an increase in the presence of shrublands, which in a few years will evolve into dense or very dense vegetation with a high degree of flammability.

Fire is one of the most important ecological variables capable of shaping the Mediterranean environment and influencing the structure of the plant landscape, which consists of a mosaic of stages in the regeneration and degradation processes(Blasi et al., 2004). Fire impacts in forested ecosystems range from minor changes in canopy structure to full death of existing plants. Large fires have a significant impact on the formation and maintenance of landscape heterogeneity in ecosystem (Turner et al., 1994). The size, form, and arrangement of remnant and stand-replacing patches within individual fires can influence post-fire ecosystem recovery, including the maintenance or reconfiguration of vegetation communities(Turner et al., 1998). In forested landscapes, these patterns are modified by topography: gullies and drainage lines are less likely to be severely burnt than slopes due to less flammable vegetation, protection from wind and higher moisture levels(Chia et al., 2015).Changes in habitat type and landscape variability impact other ecological processes and patterns, including future fire regimes, plant and animal colonization, community composition, and species abundance(Pickett & White, 1985). On the contrary, when fire predominantly affects shrubs rather than forests, it causes a decrease in fragmentation and a homogenisation of the landscape(Blasi et al., 2004).Landscape changes caused by fire are frequently immediate, but they can persist for decades to millennia(Steel et al., 2018)creating long term and broad ecological impact.

3.1.3 Effect on soil

Fire can give rise to a wide range of effects on soils in different types of environment. This is due to the inherent variability of the soil resource in the phases preceding the fire, the characteristics that the fire takes on in its development , the season in which it occurs and the environmental conditions preceding and following the fire, in relation to, for example, the frequency, quantity and duration of rainfall(Blasi et al., 2004). Because of their intricate interdependence, changes in soils after fires generate various effects in the hydrologic, floral, and faunal components of ecosystems(Neary, 2004). One of the major problem caused in the Mediterranean basin by wildfire is soil loosed by erosion. The Mediterranean climate plays an important role in the post-fire erosion process. Its tendency to concentrate the yearly rainfall in a short period of time, often in a few high intensity storms, is a negative trait that exacerbates the erosive pulses. Fire affects the erosion process in several ways. One effect is the destruction of the protective influence of the vegetative cover and the forest litter. This modifies the interception of water by vegetation with a consequently increase of stormflow . The lost of vegetation results in other important modifications. Soil evaporation is increased but obviously plant evapotranspiration is drastically reduced. Hence, the amount of water volume stored in the soil profile tends to be greater and more of the rainfall is available for runoff . About runoff if its generated , soil particle movement can be accelerated, the overland flow generally in a forest is around the 1% the year after the fire goes from the 10 % ranging up the 45% (Vega & Díaz-Fierros Viqueira, 1987). In the province of Turin, the effects on the soil showed a year after the fires in October 2017 in the Susa Valley, in fact in 2018 following a long period of heavy rainfall, causing a debris flow. A debris flow is a moving mass of loose mud, sand, soil, rock, water and air that travels down a slope under the influence of gravity . Debris flows differ from slides because they are made up of "loose" particles that move independently within the flow. The relationship between fire and debris flow is widely documented in the scientific literature. Debris-flow phenomena occur within a few years after the fire (generally within two years). The rapid regrowth of grass in the months following the fire should not mislead on the vulnerability of the catchment area. The recovery time of an area devastated by fire can vary from 2 to 6 years depending on whether the burnt area is grassland rather than forest. Fire can increase the amount of sediment available to debris-flow by up to three times the normal rate of erosion in undisturbed forest.

The greatest likelihood of post-fire debris flow is found where the soil has a high clay content and where the slope is steeper(Pittarello, 2019).

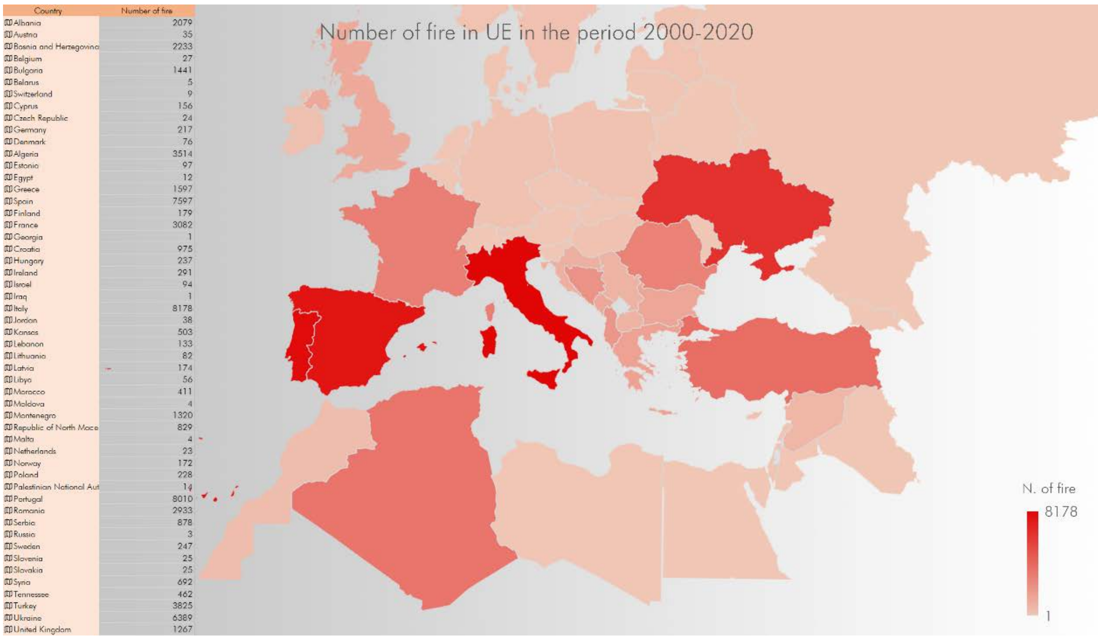
It should be noted that it is not correct to define a direct proportionality between the severity of a fire and its effects on the ground: even a small fire can create conditions that are particularly favourable to the development of debris flows. In this regard, the risk of erosion and scouring of slopes should be taken into account not only where there has been a violent fire but also in situations where the practice of controlled fires is used as a land management policy, precisely because even in the latter situation, phenomena that weaken the soil may occur, causing economic but often life loses.

3.2 FIRE REGIME AND TREND

Fire is an important ecological factor in many habitats around the world (Glitzenstein et al., 1995)and in these environments the fire regime can greatly influence the composition and the dynamics of the vegetation. The fire regime is generally used to summarise the characteristics of fires that typically occur in an area over a fairly long period of time and the effects that fire causes on the environments involved.

3.2.1 Forest fire in Europe

Forest fire, are an important part of Mediterranean ecosystems in Europe and around the world. However, the way humans deal with wildfires has rapidly changed over the years, particularly in Mediterranean Europe. Several conditions distinguish European Mediterranean ecosystems. These include rural exodus to cities, which results in the abandonment of low-timber-production forests and the simultaneous accumulation of fuels in these forests. Furthermore, as living standards in Europe have improved, rural areas have been populated by secondary homes, expanding the wildland urban interface. As a result, human populations and assets are more vulnerable to forest fires than ever before. Fire trends in Europe indicate that the Mediterranean regions have a significant concentration of fire events and, more importantly, fire effects. The burnt area in Europe as a whole is concentrated in this region, about 80% of it. Despite the fact that there haven't been as many fires in the past ten years, recent weather events has resulted in unheard-of economic losses and a record number of fatalities(Camia et al., 2014). Looking at the map (Figure 4) is clear that wildfire Is a clear problem of south European country , in fact looking at the data Italy(13,4%), Portugal(13,3), Spain (12,4%) and France (5%) include almost the 45 % oh the total number of the fire from 2000 to 2020 (Figure 4).



Country	Number of fire
Albania	2079
Austria	35
Bosnia and Herzegovina	2233
Belgium	27
Bulgaria	1441
Belarus	5
Switzerland	9
Cyprus	156
Czech Republic	24
Germany	217
Denmark	76
Algeria	3514
Estonia	97
Egypt	12
Greece	1597
Spain	7597
Finland	179
France	3082
Georgia	1
Croatia	975
Hungary	237
Ireland	291
Israel	94
Iraq	1
Italy	8178
Jordan	38
Kansas	503
Lebanon	133
Lithuania	82
Latvia	174
Libya	56
Morocco	411
Moldova	4
Montenegro	1320
Republic of North Mace	829
Malta	4
Netherlands	23
Norway	172
Poland	228
Palestinian National Aut	14
Portugal	8010
Romania	2933
Serbia	878
Russia	3
Sweden	247
Slovenia	25
Slovakia	25
Syria	692
Tennessee	462
Turkey	3825
Ukraine	6389
United Kingdom	1267

Figure 4 Number od fire in EU Period 2000-2020(Camia et al., 2014)

3.2.2 Forest fire in Italy

In Italy, the phenomenon of forest fires is widespread throughout the territory, however it takes different configurations from one area to another (Figure 5). Different parameters can be taken into consideration among which the most indicative are the number of fires, the area covered, and the average area per fire. The values collected and examined refer to the last twenty years, as all the data that will be examined in the study, in order to understand the correlation between fire events and other factors such as the climatic ones. Starting from the north, the Alpine territory is characterised by a conspicuous number of incidents that decrease from the west towards the east. It must be kept in mind that these events are often very intense and propagate in the canopy of conifers and are often governed by downwinds(Christian MAYER et al., 2020), so even if the phenomenon is limited, it is necessary to find possible preventive solutions, since the alpine region has the greatest amount of natural forest land. The same characteristics can be found in the territories of Veneto, Friuli and Trentino, but to a lesser extent. As one moves southwards, the number of fires increases, reaching its highest values in the regions of Sicily, Sardinia, Calabria and Campania, with smaller numbers in Puglia and Lazio.

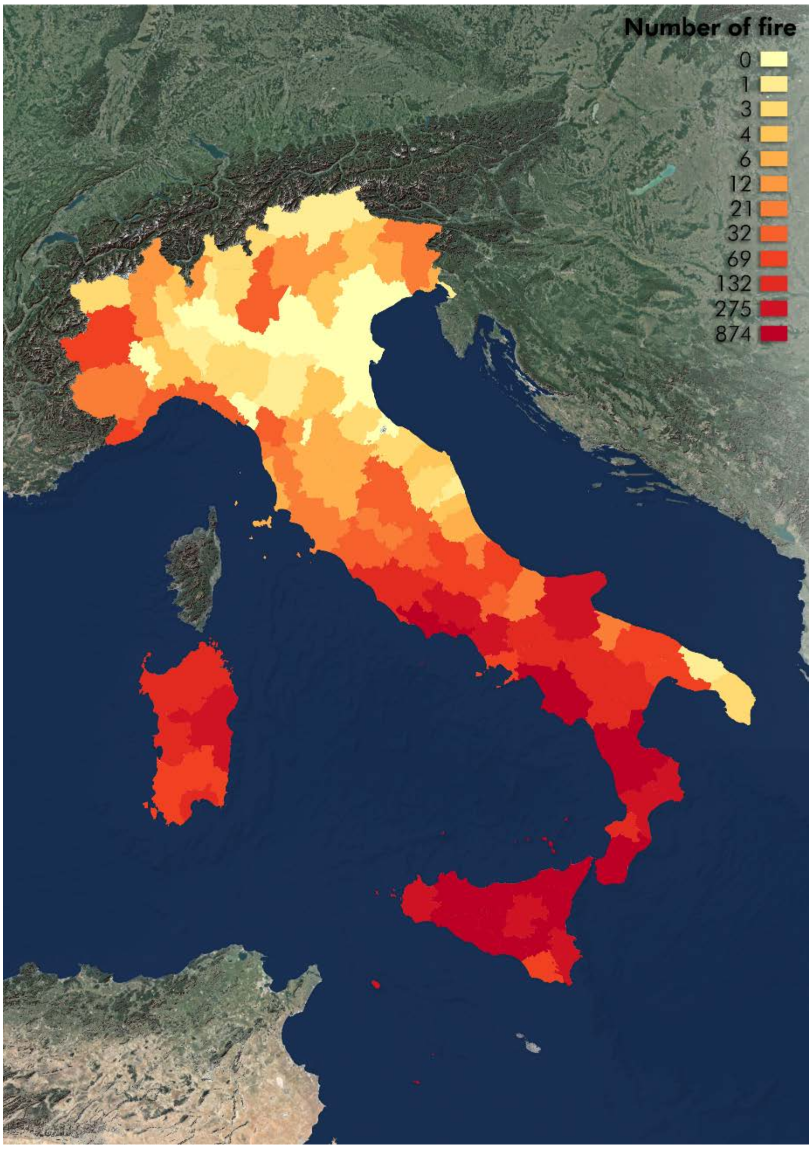


Figure 5 Number of wildfire per Province in the period 2000-2020
Elaborated from the author form European Fire Database.(Camia et al., 2014)

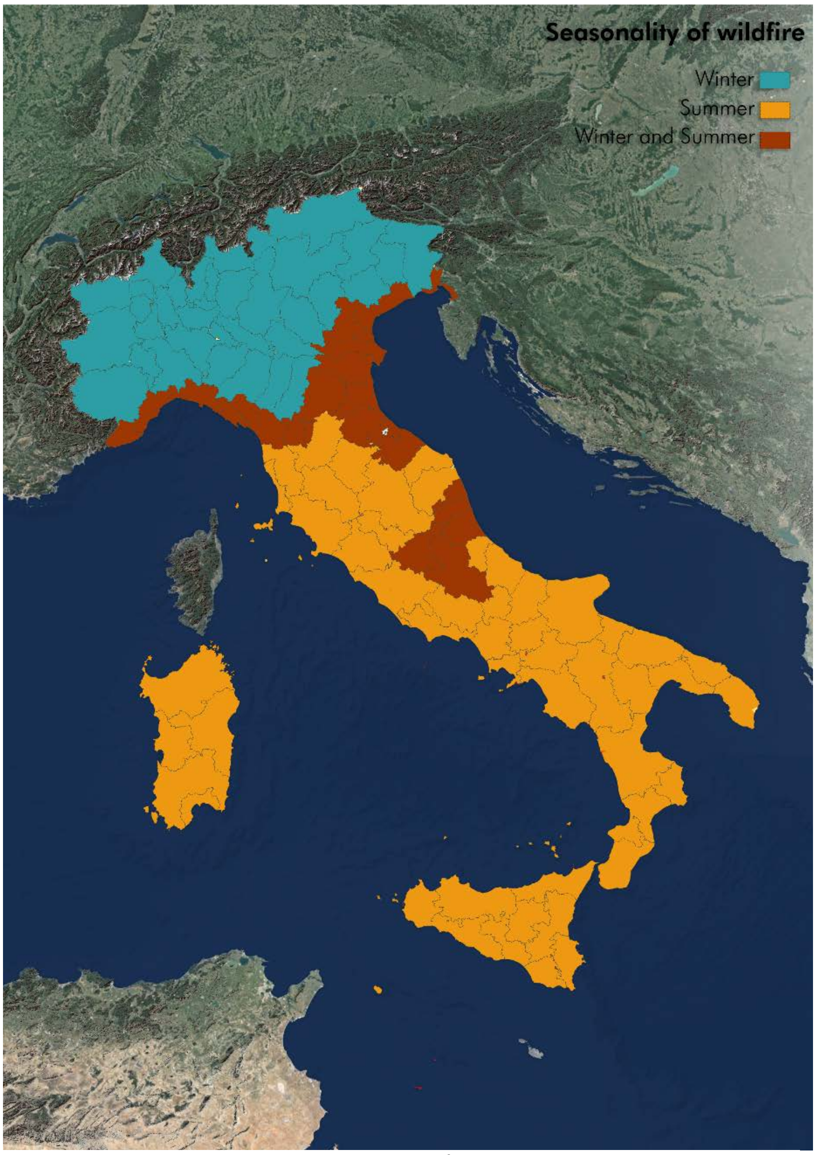


Figure 6 Redesigned by the author form (Blasi et al., 2004)

In Italy there are different situations in regards to the seasonality of fires: in particular, one difference between situations with a maximum frequency in winter, realities with maximum frequency in summer and others in which the frequency is distributed throughout all seasons. The provinces classified according to the seasons of maximum frequency are indicated in the Figure 6.

Aggregating the data over a long period in the Figure 7, the distribution of the number of fires seems to strongly follow rainfall trends, see §6.5.1. In particular, in the years in which the greatest number of fires occurred and the greatest area was burnt, i.e. 2007, 2009, 2012 and 2017, were the years in which were registered the major values of anomalies in terms of temperature and precipitation.

These dry conditions of the vegetation can probably also be deduced from the data showing the average distance travelled by each fire (Figure 8). In 2009 was registered the highest value of meters crossed by fire, year in which one of the highest values in terms of rainfall-free days was recorded, (see §6.5.1Figure 38 Consecutive Day without precipitation).

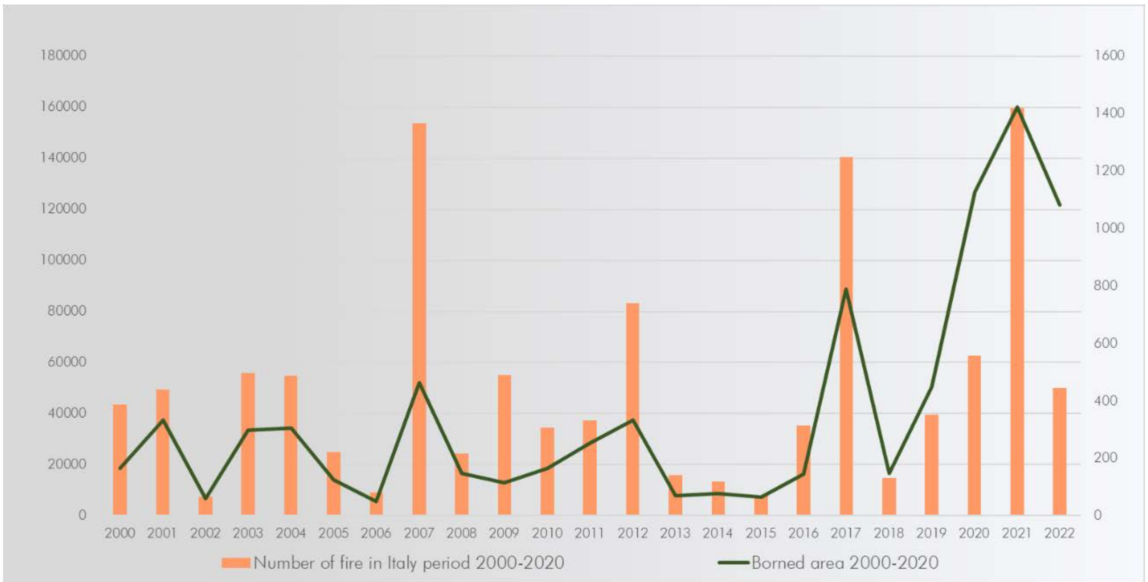


Figure 7 Burned surface and number of fire in the period 2000-2020 processed by the author from European fire database(Camia et al., 2014)

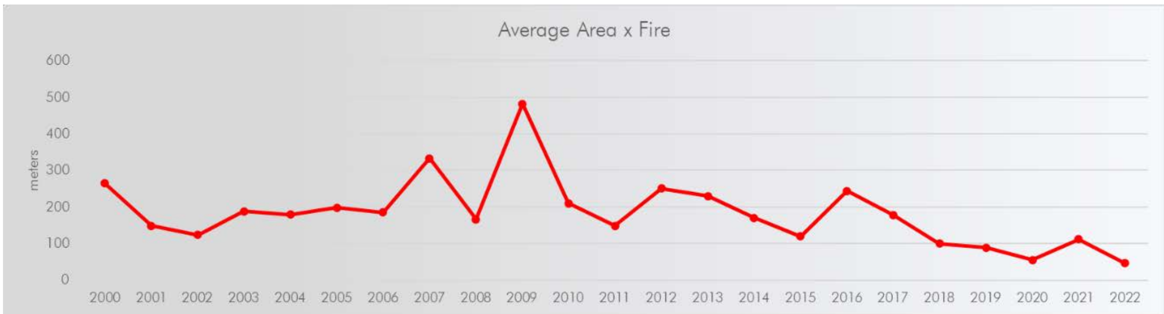


Figure 8 Everage distance percoured by the fire in meters elaborated by the author from European Fire database(Camia et al., 2014)

The data in the above paragraph are from the European Fire Database that contains the forest fire information compiled by EU Member States and other European countries. The Regulation EEC No 804/94 established a community system of information on forest fires for which a systematic collection of a minimum set of data on each fire occurring, the so called “Common Core”, had to be carried out by the Member States participating in the system. Since 2004 the forest fire data provided each year by individual EU Member States and other European countries are checked, stored and managed by JRC within EFFIS(Camia et al., 2014).

3.2.3 Wildfire in alpine region

Wildfire is one of the natural disturbance factors in European alpine area. Droughts that start in the Mediterranean during the winter months have produced preconditions capable of causing long and strong heat waves throughout Europe in the last decades years. Such conditions are likely to be amplified in the future, since higher mean temperatures facilitate the exceedance of thresholds considered to be extreme (Gobiet et al., 2014). Following a severe and persistent drought period, ten wildfire occurred in the alpine area of Piedmont region (Italy) during the autumn 2017(Morresi et al., 2022)but this prolonged drought period had impact not just on piedmont region farther in several part of central and south Europe. The extent of burnt areas ranged from 55 to 3974 ha, resulting in a total area of 9740 ha, of which forests covered 7202 ha (Morresi et al., 2022). Giving some ecological characteristic the burned area was principally characterized by mountain and foot hill broadleaf and coniferous forest. The broadleaf species were mostly sweet chestnut, European beech and downy oak. The predominant coniferous species were the European larch and the Scot pine. We must know that tree species burnt each in a different way. There must be a difference made between elements that influence the ignition potential of forest fires and those that influence the spread and severity of a fire.

The Ignition potential given by different elements. One is the soil in particular the moisture in the forest surface, like needles, leaves or grass and by a source of ignition. The moisture content is determined by climatic condition like precipitation, temperature, relative humidity and wind. In the Alps, special weather circumstances leading to dry conditions such as foehn winds or long-lasting thermal inversion are of importance, especially in the winter term (Christian MAYER et al., 2020). About the source of ignition in the alps the lightning strike are one source but often the human influence takes place. The infrastructural variable make easier the access to the forest areas trough infrastructure may lead to an increased fire ignition risk(Arndt et al., 2013). But intensity and the growing potential of a forest fire are determined by various other factors. For instance, typology of vegetation highly influences fire behaviour. Coniferous forest in the western part of the alps burn more frequently and intensively than broadleaf forests because the higher load and continuity of surface fuel. (Christian MAYER et al., 2020). The trade-off between tree cover and dead and live biomass load determines the spread and severity of a fire. The biomass fuel have different distribution between the season; rainy spring enrich biomass growth, meanwhile dry climate, especially in autumn, enhances shrub biomass and stimulated litter accumulation (Fréjaville et al., 2016). Forest structure determine in fact if the fire will be limited on the crown and passing to the ground or vice versa. In addition to vegetation also topography influences the fire. Since hot air moves upslope and preheats the fuel particles, fires tend to spread more quickly uphill. In the southern surface slope, since is more hit by the sun , vegetation is dryer; also wind make vegetation parched , the combination of this factor can lead to a spreading potential and a rapid dangerous change In propagation speed and direction of flame.

Several drought and temperature records have recently been recorded in the Alpine region . As a result, the Alpine region experiences more days with a high fire risk. On the other hand, drought may result in higher rates of tree mortality, raising the risk of a fire. Extreme precipitation events will likely become more frequent at the same time. Future extremes in humidity and dryness are likely to increase, posing new difficulties for fire departments and other emergency response teams in terms of equipment and operational strategies. Winter fires are more likely to spread in areas with a reduced snowpack (both in terms of surface and duration), which will likely become a bigger issue in the future.(Christian MAYER et al., 2020)

3.2.4 Forest fire in piedmont region

In this section we will try to understand the trends in the number of fires and the area covered by fire over the long period from 1997 to 2020. At the same time, we will try to understand the seasonal trends in fires, which can help us identify the possible causes of the events. The database used is the one provided by the Piedmont geoportal, which collects the data collected by the The database used is the one provided by the Piedmont geoportal, which collects the data collected by the" Sistema anti incendi boschivi " of a regional organization that unify volunteer, fire fighter Carabinieri Forestali(Regione Piemonte, 2022). The data include all the spatial and temporal information of the fire, and also the kind of surface burned such as forested and non-forested area. This data was used to create all the chart present in the current paragraph. The next chart represents the number of the fire for each year in the period taken in consideration (Figure 9, Figure 10).

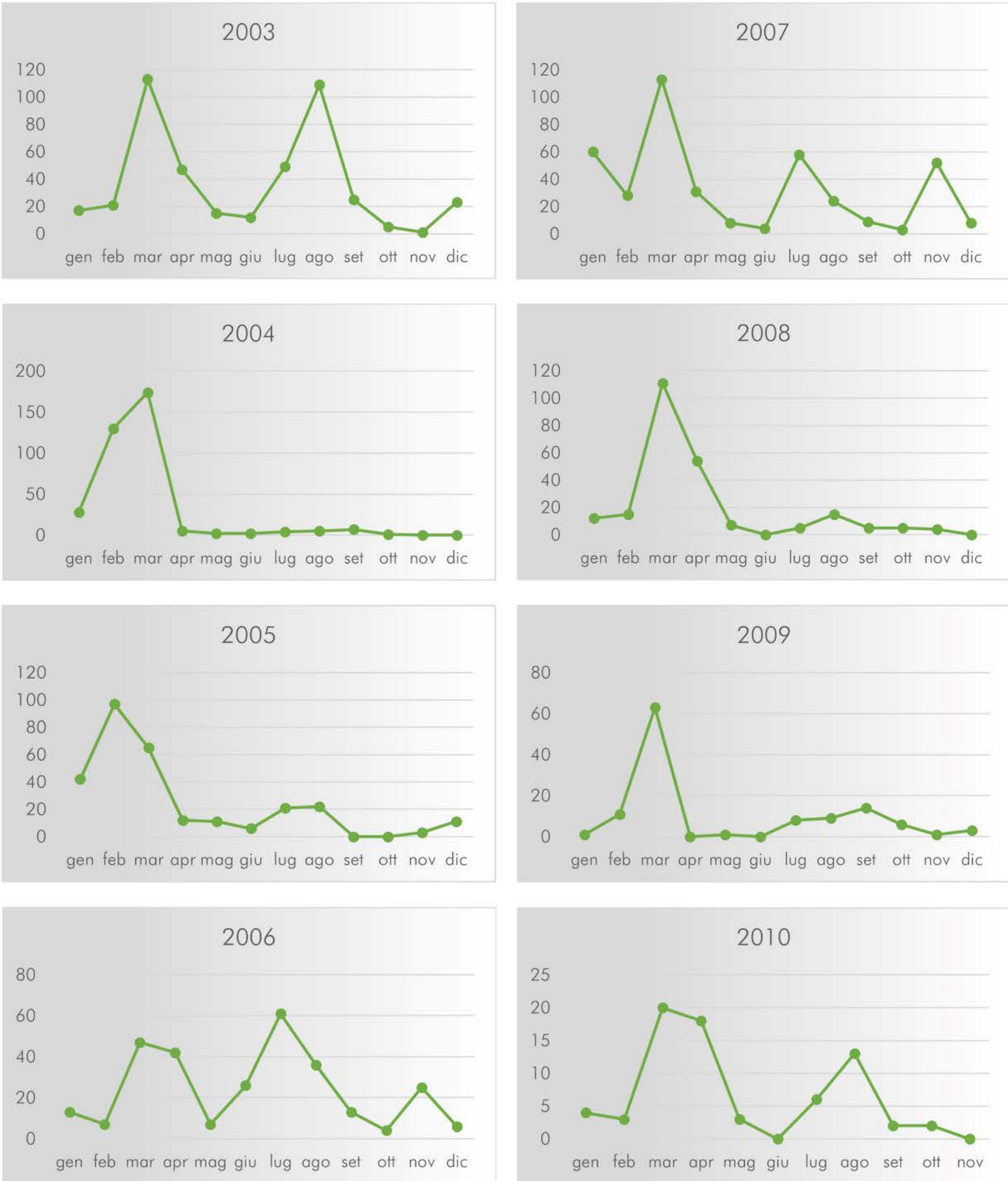


Figure 9 Number of fire , elaborate by the author from Fire Database Piemonte(Regione Piemonte, 2022)

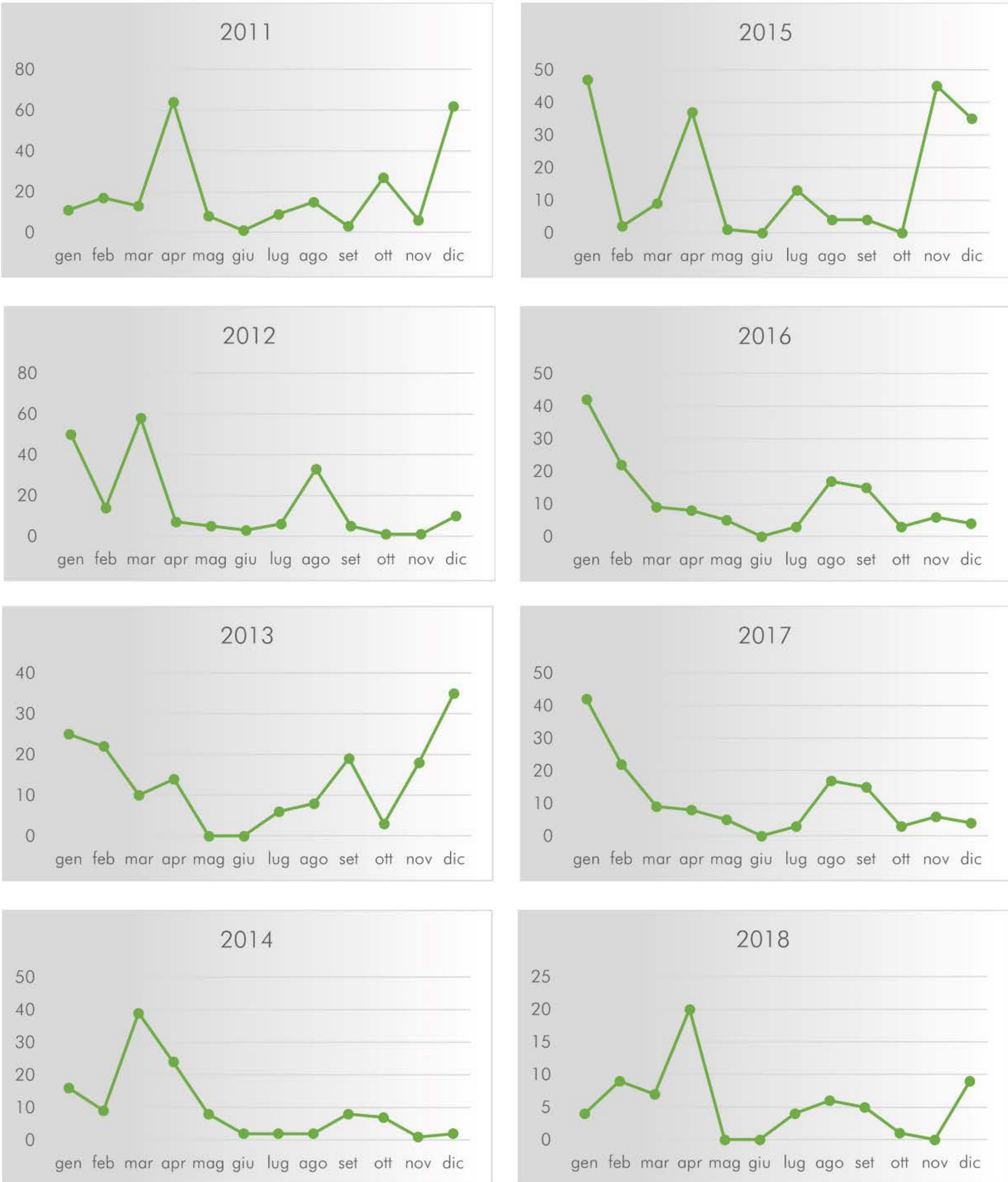


Figure 10 Number of fire , elaborate by the author from Fire Database Piemonte(Regione Piemonte, 2022)

From the upper charts is possible to understand the distribution of the fire event along the different year, it's possible to see there wasn't a big change on it. The majority of fire event happen in the winter period but in the last ten years is possible to a constant number of fire event also last period of the summer.

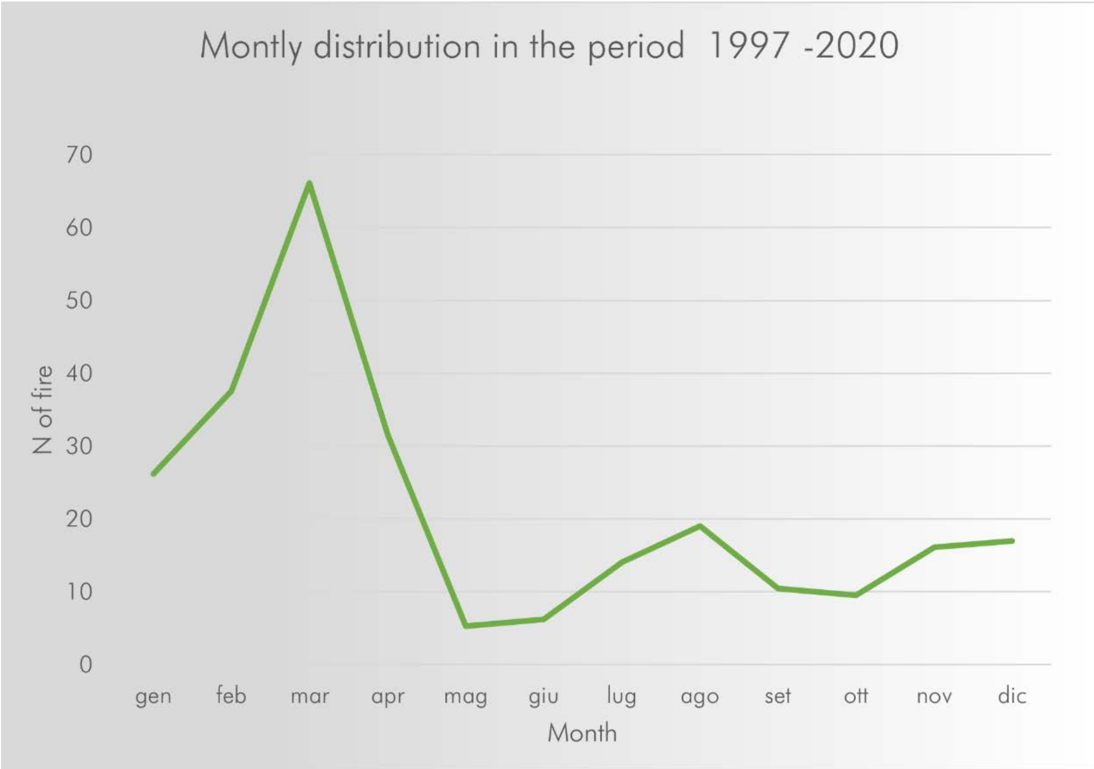


Figure 11 Mean monthly number of fire in the period 1997-2020 elaborate by the author from Fire Database Piemonte(Regione Piemonte, 2022)

The mathematical distribution among the whole period is given by Figure 11 below that represent the mean value of the number of fire event among the period 1997-2020 and is confirmed the high number of fire in the month of march with the highest peak and a conspicuous number of event in the month of august

These figures show the typical pattern of the Alpine arc regions, where the fire season has a winter-spring maximum. This distribution is closely correlated to the general weather trend, as well as to the phenological conditions of forest vegetation. There is a gradual increase in fire frequency starting in December, with a peak in March, and a sharp drop in May, coinciding with the advent of spring rains and the recovery of vegetation. Note also the summer maximum in August, which should not be underestimated.

About the monthly distribution of the burned surface Figure 12 was done the sum of all the years, the result confirms the same tendency for the period January-May but in the months of August and October is possible to see a negative corelation between number of fire and surface burned. Looking at the number of event the event occurred in the month of October are half than the ones happened in August;

differently in the burned area the value in the month of October is 10539 ha meanwhile in august is 3510 ha , three time bigger, this could suggest a fire event faster and stronger.

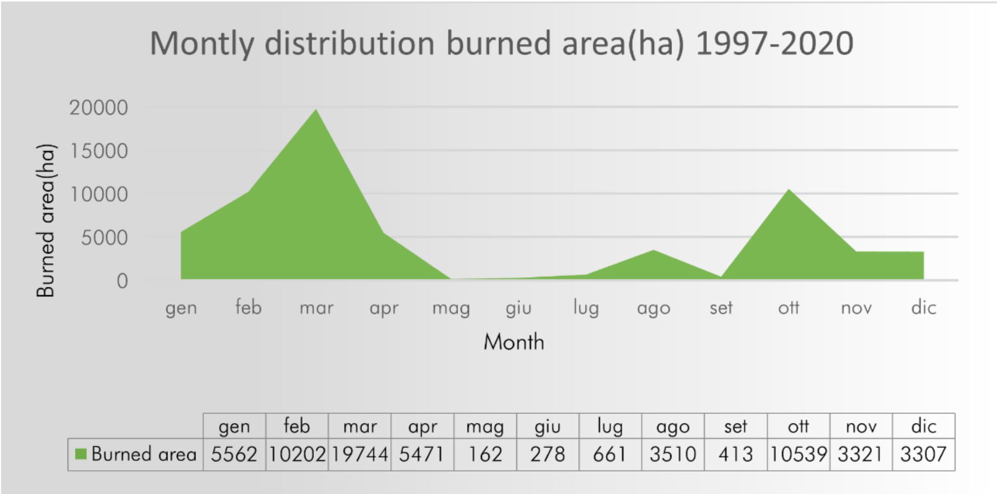


Figure 12 Cumulative monthly burned surface in ha in the period 1997-2020 elaborate by the author from Fire Database Piemonte(Regione Piemonte, 2022)

The number of fires in the period from 1997-2020 appear to follow a negative tendency with a strong decrease of fire ignition. The reason for this trend could be because people have become more responsible and aware of respecting nature and the risk of fires, but at the same time over the years technology and increasing anthropization have made it faster to identify a fire (Figure 13).

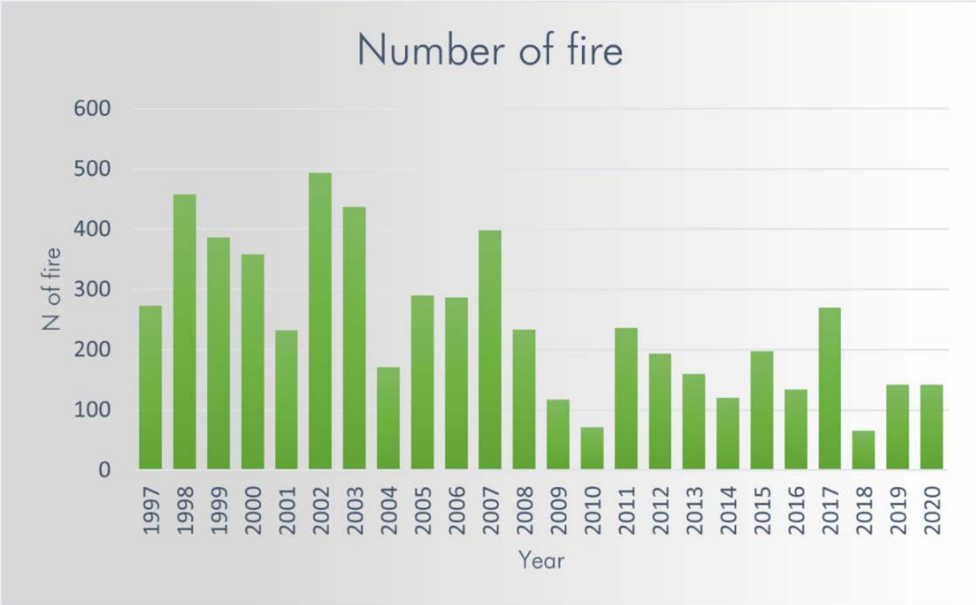


Figure 13 Number of fire in the period 1997-2020 elaborate by the author from Fire Database Piemonte(Regione Piemonte, 2022)

Looking at the total burned area the Figure 14 show a positive trend in the last 10 years with a peak in the 2017 , proof of the extraordinary fires in the Susa Valley that year. A comparison of total annual land area in wooded and unwooded areas (Figure 14) one can see how the proportion between these 2 land cover classes changes between the first period in which a certain equal distribution between the 2 types is evident and the second period in which a predominance of wooded areas crossed by fire over the non-forested ones (Figure 15).

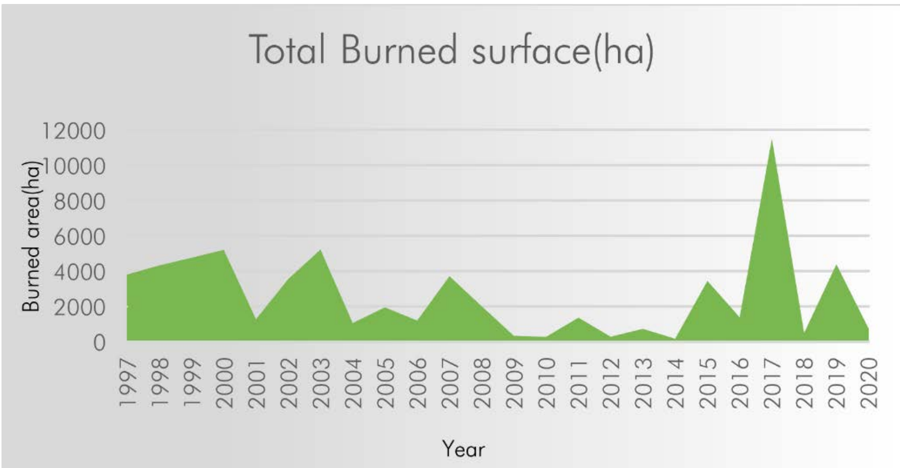


Figure 14 Total burned surface (ha) in the period 1997-2020 elaborate by the author from Fire Database Piemonte(Regione Piemonte, 2022)

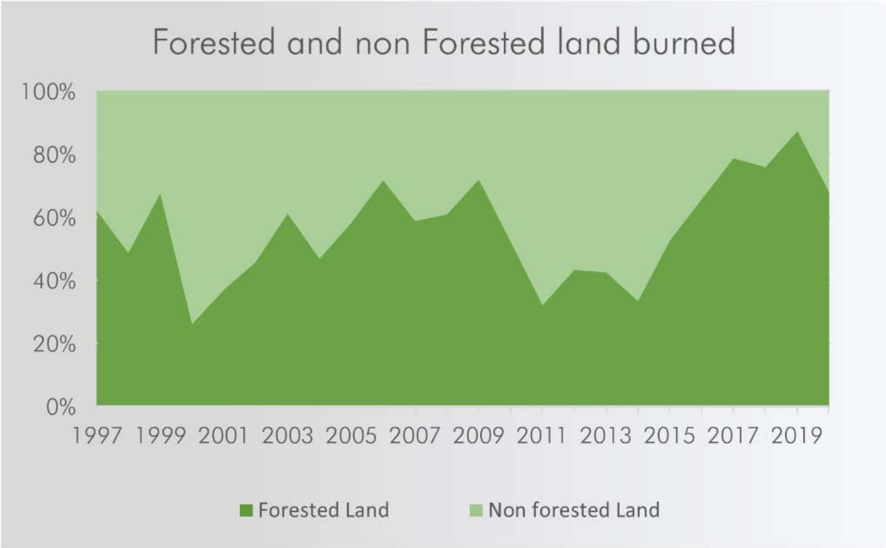


Figure 15 Forested and non forested burned surface (ha) in the period 1997-2020 elaborate by the author from Fire Database Piemonte(Regione Piemonte, 2022)

3.3 CAUSES

When talking about fires, one must confront deep-rooted common places, the first of which is that it is a phenomenon linked to modern patterns of life, hence to increased mobility tourism and leisure, which bring growing masses of visitors to the forest. It is this is an incomplete interpretation, which leads to a partial analysis of the phenomenon, seen essentially in terms of negligent behaviour negligent behaviour(Blasi et al., 2004). A first firm point seems necessary: at least in our country, forest fires are neither a natural calamity nor a fatality, but rather an anthropogenic phenomenon with an exclusive, direct dependence on voluntary or involuntary social behaviour. Fires are still opposed by a waiting defensive mechanism, designed to intervene with contrasting initiatives on the event taking place, which is limited to emergency intervention. One lack, in fact, is absence of organic intervention plans based on knowledge of the motivations, aimed to acting on the causes rather than mitigating the consequences of fires.

3.3.1 Causes and motivation

An accurate diagnosis of the causes and motivations of the phenomenon appears inevitable to direct prevention, also in terms of identification of the objectives of campaigns awareness campaigns and to implement targeted interventions in times of emergency. For an analysis of the most important motivations a review of the ways of classification of causes. According (F.A.O., 1999) for example identifies internal or external causes of the forest environment.

Such external causes recognize: needs related to agricultural and animal husbandry practices; needs related to hunting practices, needs related to land use; conflicts of interest and pyromania; implementation of agricultural practices without prevention; recreational activities and generally the increasing pressure.

Internal causes include: the increasing marginality of the resource forestry; a widespread lack of interest in its protection; the occurrence of fires in connection with employment needs.

The "Corpo forestale dello stato" gives a complex articulation of causes, which can be divided into four broad categories:

- **unknown causes;**
- **natural causes:** related to the triggering action of volcanic eruptions, lightning, spontaneous combustion;
- **negligent or unintentional causes:** related to imprudence, negligence, carelessness or ignorance of humans, which unintentionally cause fires; among these include:
  - recreational activities, attributable to lighting of picnic fires within forests or near ;
  - agricultural and forestry activities such as such as stubble burning, the clearing of cultivated fields, the burning of pruning and clearing residues;
  - burning of rubbish;
  - throwing of cigarettes and matches;
- **malicious and intentional causes:** include:
  1. fires from which the authors hope to make profit:

- destruction of forest mass for the creation of arable land and pasture at the expense of the forest;

- burning of agricultural residues, such as stubble and bushes, for the cleaning of the soil;

- burning of the forest to transform the rural land into building land;

- forest burning to bring about the creation of jobs in connection to reconstitution and extinguishing;

- use of fire for cultivation operations in the forest to save labour;

- fire to achieve supply of wood;

2. fires from which the authors do not expect to make a concrete profit:

- resentment against expropriation actions or other initiatives by public powers;

- grudges between private individuals;

- protests against restrictions on hunting activity;

- protests against the creation of protected areas protected areas and the imposition of constraints environmental restrictions;

- acts of vandalism;

Giving some data according the "PIANO REGIONALE PER LA PROGRAMMAZIONE DELLE ATTIVITÀ DI PREVISIONE, PREVENZIONE E LOTTA ATTIVA CONTRO GLI INCENDI BOSCHIVI" *in the period from 2000 to 2019 the malicious causes continue to be majority (56%), but negligent and dubious causes are also particularly important. important; the graph shows how an accurate information and education campaign of the education of the population could, however, play a role in minimisation of culpable events.* The causes are showed in the figure below(Figure 16)

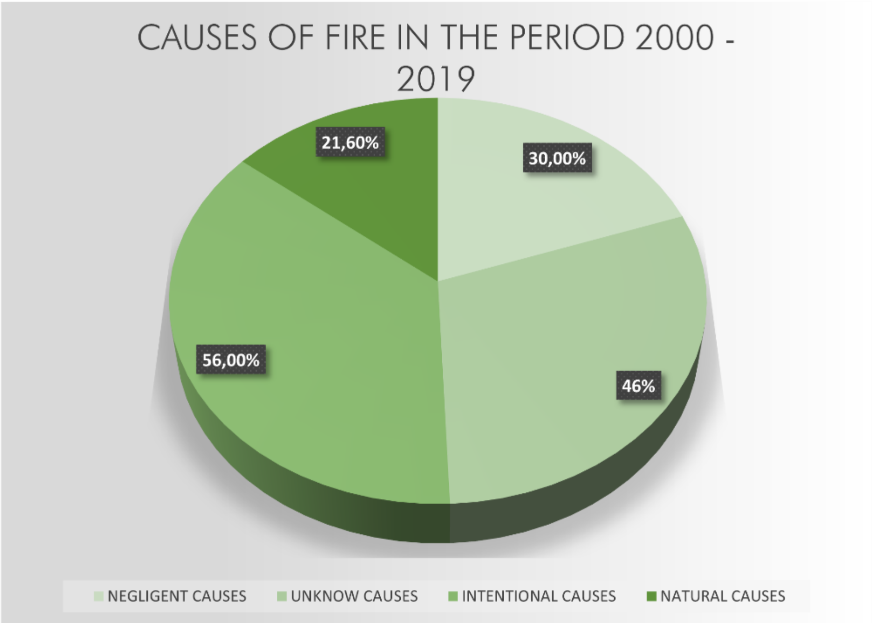


Figure 16 Causes of fire in Piedmont Region in the period 2000-2019(Bertani et al., 2016)

3.3.2 Natural causes

Natural causes are the least frequent, not surprisingly covering only 3% of the cause pie. A fire can start mainly for two reasons: lightning and spontaneous combustion.

3.3.2.1 Lightning

Lightning-caused Forest fires are not considered a serious issue in Europe, particularly in the Mediterranean region, where lightning is only a minor cause of forest fires. Lightning-caused fires occur in the Alps from May to October, with a peak in July and August (78% of the events!). These fires differ from anthropogenic fires in terms of geographic distribution and duration. Lightning strikes are most common at higher elevations, in coniferous forests, and on steeper slopes. Furthermore, climate and land use change are expected to increase lightning fire activity in this area(Conedera et al., 2006). From a strategic point of view, lightning-caused fires typically occur in more remote locations, delaying detection and arrival of fire fighters for suppression activities(Pérez-Invernón et al., 2021). Lightning prolonged latent phase between ignition and fire detection, the so-called holdover time(Schultz et al., 2019). In general, the holdover duration is relatively brief in the alps, with 96-98% of events detected within 3 days. This likelihood of detecting a starting fire in the Alps may be due to higher population density and favourable detecting conditions on steep slopes(Conedera et al., 2006).

Weather (drought or lack of precipitation, frequency and type of thunderstorms and associated lightning discharges, ventilation), fuel (type, moisture, density, and depth), and topography conditions all influence the frequency and distribution of lightning-caused forest fires(Wotton et al., 2010). Given the potential of climate change leading to an increase in the frequency of hot and dry summers, lightning-caused fires may play a significant ecological role and have a greater economic impact in the Alps in the future. To conclude, identifying single igniting lightning is not an easy task, but it is a necessary step in furthering our understanding of lightning-caused fires, particularly in predicting natural fire ignition probability and assessing daily fire danger(Moris et al., 2020).

3.3.2.2 Auto combustion

it is a very rare occurrence and, in any case, absolutely independent by the high summer temperatures, which cannot trigger any combustion phenomenon but only combustion but only promote its propagation, being a predisposing and not a determining factor It therefore appears to be a possible but very remote cause of forest fires, at least forest fires, at least at our latitudes. (Blasi et al., 2004). The phenomenon of self-combustion is generated, in fact, when the combustion process is not activated by an external energy source such as sparks, flame or contact with incandescent body, but by an oxidation reaction oxidation or by a fermentation process, at a point in the fuel mass, with production of heat that is not dispersed due to due to poor conduction of the material or insufficient ventilation, causes a localised rise in temperature until the self-ignition threshold(Zanut, 2022). Facilitate the process of spontaneous combustion elements such as oxides metal on fibrous materials soaked in oil drying agents, or the presence of pyrite or moisture in coal. These elements, apart from coal, are not natural elements and are often in fact derived from industrial processing. For this reason, spontaneous combustion can probably occur in conjunction with illegal dumping of waste in nature.

In conclusion, spontaneous combustion is an entirely unlikely process in the forest, but its importance is often emphasised, linking it to high summer temperatures contributes to the belief that forest fires are an forest fires an inescapable natural calamity against which it is worthless to fight, in clear contrast with the recognised need to properly inform and raise awareness among the public opinion.

3.3.3 Negligent causes

In Piedmont, negligent causes are responsible for approximately 21% of accidents, with agricultural and forestry activities among the main causes.

3.3.3.1 Stubble- burning

Agricultural activities are one of the major causes of fires, accounting for more than 30 per cent of all negligent fires in Italy(Corpo forestale dello stato, 2001). This varies along the regions, increasing from the Alpine regions to the southern regions. The fires mainly started because of the practice of stubble burning, which is an ancient and at the same time a wrong practice. Stubble is defined as rooted stems that remain in the field after crops have been harvested(Merriam-Webster, 2022).This practice constitutes a rapid method of destroying arable residues, returning the inorganic fraction to the soil. Farmers do it because they believe that fire provides convenience in tillage results and reduces diseases and pests, allowing for higher crop yields and lower transportation costs(Yakupoğlu et al., 2022). Burning stubble is highly risky as the harvest, resulting from the maturity of cereals, coincides both with the summer, hot-arid, and with the end of the biological cycle of numerous wild Gramineae. This leads to the presence of dangerous combustible continuities of easy ignition between cultivated land, uncultivated land and woods, in a pattern that is difficult to control(Blasi et al., 2004)l. In piedmont region It's regulated according the regional law again the forest fire L.R.15/2018 art. art.10 where lighting fires and stubble- burning , within 100 metres of wooded, shrub and pasture land is prohibited and the activity of burning is only permitted from dawn to dusk and in the absence of wind or weather conditions that may favour the starting of fires.(Regione Piemonte, 2021). Remedies can be stricter regulations prohibiting burning, combined with more intensive control and a more effective penalty system, as well as more effective knowledge dissemination through agricultural specialists. Farther allow fire use through regulation, zoning, and prohibition periods, requiring burning licenses in addition to the adoption of a set of measures to prevent fire escapes(Lovreglio et al., 2010).

3.3.3.2 Recreational activities and indirect ignitions

Fires started by recreational activities such as pic nics and those related to the use of cigarettes constitute the ignition of fires and are linked respectively to people's lack of understanding of the actual danger, and inadequate maintenance of roadsides. This is a cause that is underestimated by the general public which is constantly informed by advertising and road signs on the topic(Blasi et al., 2004). The remedy for these causes, in addition to increased road maintenance and surveillance, is intensive information activities in schools in workplaces and in general to all citizens spatially close to forest ecosystems.

3.3.3.3 Electricity and railway infrastructure

Many wildfires around the world have been linked to electrical distribution lines and associated infrastructures(Collins et al., 2016). Electricity infrastructures can ignite wildfires through arcs, molten and combusting metal particles that are expelled when vegetation contacts wires, and from burning insulation fluids in equipment such as transformers and re-closers(Miller et al., 2017). These little, hot sources can start a fire if they come into contact with fuel like grass and leaf litter.(Urban et al., 2015). And if the condition of the vegetation and of the whether are prone to the ignition point, can rise to wildfire. Those events are strictly connected to the power lines status, so an old infrastructure can have an higher probability of failure. With the actual trend of climate change the higher demand of electricity during the hotter day can lead to overheated insulators in transformers and other hardware that might lead to failures(Miller et al., 2017).

The composition and condition of the vegetation on the embankments are critical in terms of the fire hazard along railway routes. The importance of vegetation as a fuel source varies greatly depending on the density of vegetation communities found on embankments. Grasses and herbs dominate the vegetation composition of many railway routes and adjacent areas, though trees can be found growing directly on embankments. The condition of the vegetation then is determined by the weather condition, where long dry periods cause fuels to dry out fast, which is leading to an increase in ignition probability(Arndt, 2006). The risk of fire is greater on downhill routes where the train is subject to prolonged braking, as the friction caused by the brakes can release sparks and burning logs.

3.3.4 Malicious causes

3.3.4.1 Renawal of grazing

The relationship between fire and grazing, motivated by the use of fire in areas with strong deficit of forage production, to eliminate the infestation of herbaceous and shrub species poorly grazed or unused. In addition to its land-clearing function it seems likely that the fire constitutes a form of warning or latent threat, functional to the objective of emphasising the agro-pastoral destination of the land linked to the hunger for land of the itinerant pastoralists(Blasi et al., 2004).

3.3.4.2 Restoration of agricultural land

It is possible that in recent years some cases of destruction of forests and tree formations have occurred, especially in central and southern Italy, to obviate the difficulty due to the entry into force of regional forestry laws that set objective limits to the cultivation recovery of marginal land colonised by newly formed forests(Blasi et al., 2004).

3.3.4.3 Industry of fire

A conspicuous proportion of voluntary fires appears to be linked to concrete interests, to presumed benefits that the author wishes to achieve, like create jobs (in the activities of spotting, extinguishing, in the subsequent activities of recovery). The fire-fighting approach, based on firefighting interventions only at the emergency, has led to a widespread policy of temporary recruitment. The use of precarious and unskilled workers, with a purpose that is often more welfare than productive, has sometimes led to the onset of a vicious cycle, where voluntary firing by seasonal workers can constitute the instrument to maintain or motivate employment opportunities; this phenomenon is particularly widespread in southern Italian regions(Gangemi, 2022).

3.3.4.4 Pyromania

In a separate category, the arsionist must be mentioned; individuals suffering from a rare form of personality disorder that causes excitement in setting the fires and enjoyment of the effects of the damage. The latter, reported and amplified by the mass media, are experienced by the arsonist as an open challenge to the authorities to avoid being identified: these are individuals with intentions of revenge against everything and everyone, which is expressed in the irresistible impulse to ignite the fire.

4 PLANNING AND PREVETION

The basic tool outlining the criteria and content of effective territorial fire planning, is represented by the national reference norm with greater legislative power, and the laws that regulate the sector at regional level. In recent years, there have been significant legislative developments in the area of forest fires, in order to adapt to the context of the period.

4.1 NORMATIVE FRAMEWORK

4.1.1 National regulation

The first forestry regulation to cover the problem of forest fires as a threat to Italy's forest heritage, even if only in terms of sanctions and prohibitions, dates back to the Royal Decree 3267/1923(VITTORIO EMANUELE et al., 1923). With regards to the Italian situation, it started in 1967 to address the problem, following the conference on fire protection of the forest heritage in Bergamo, where it sensibilised public administrations on the on the importance of fire statistics and the fires and the need to conduct research specific research for fire prevention planning in correct way(Blasi et al., 2004). In subsequent years, the problem of fires was dealt sporadically without precise legal provisions and therefore without precise tasks the part of the administrations. It took about 50 years for the first law regulating the complex aspect of forest fires, with the enactment of Law L. 1.3.1975 no. 47 'Integrative regulations for the protection of forests from fires'. This addresses the problem of forest fires, promotes initiatives to prevent and fight forest fires, provides funding for the elaboration of 'regional and inter-regional plans' and codifies competences. It establishes the unbuildability and maintenance for forested areas affected by fire. The reconstitution of burnt areas with public financing(CNEL, 2000). In addition, the regions are asked to set up the Forest Fire Service, without prejudice to the State's competence as regards to the organisation and management, the aerial fire-fighting service and the employment of the Fire Brigade. Subsequently, a decree of the President of the Republic 616/1977 the transfer of forestry matters to region. The first start of the regions in the forestry sector, in the 1970s, was characterised by a protectionist vision that produced regional legislation aimed at enhancing the protective and productive functions of forests, with particular attention to prevention of forest fires(CNEL, 2000). Subsequently, the drafting of the " regional plan for the defence of the forest heritage from fires" was initiated in many regions. From 1975 to 2000, the relevant legislative measures on the subject of wildfires were essentially aimed at emergency intervention, for example to cope with the risk of fires in protected and areas of special environmental interest or have tightened up administrative sanctions against transgressors of the norms on the protection of forests from fires(Blasi et al., 2004). The Figure 17, shows the details of the national laws that have regulated the matter, in order to understand the motivations in support of the formulation and approval of a new legislative instrument to reorganise the complex and disorganised regulatory framework, which has finally arrived with the approval of Law 353/2000 (framework law on forest fires).

R.D. 30 December 1923 n. 3267	'Reorganisation and reform of forest and mountain land legislation'.
Law 9 October 1967 n.950	'Penalties for violators of Forest Police regulations'.
Law 1 March 1975 n.47	'Supplementary regulations for the protection of forests from fires'.
D.P.R. 24 July 1977 n.616	'Implementation of the delegation referred to in Article 1 of Law No 382 of 22 July 1975'.
Law del 24 November 1981 n.689	'Modification of the penal system'.
Law 4 August 1984 n. 424	'Tightening of administrative sanctions against violators of forest fire protection regulations'.
Law 8 August 1985 n. 431	'Urgent provisions for the protection of areas of special environmental interest'.
Law 8 november 1986 n.752	Pluriannual law for the implementation of planned interventions in agriculture.
Law 28 February1990 n. 38	'Urgent rules on local finance and financial relations between the State and the Regions, as well as various regulations'.
Law 3 July 1991 n 195	'Provisions in favour of the populations of the provinces of Syracuse, Catania and Ragusa affected by the earthquake in December 1990 and other provisions in favour of the areas damaged by exceptional adverse weather conditions from June 1990 to January
Law 29 October 1993 n. 428	'Urgent provisions to tackle the risk of fires in protected areas'.
Law 10 November 1993 n. 456	'Urgent provisions for the purchase of fire-fighting aircraft by the Civil Defence'.
Law 8 August 1994 n. 497	Urgent provisions to prevent forest fires on the national territory'.
Law 8 August 1995 n. 339	'Urgent provisions to prevent forest fires on the national territory'.
Regulation(CEE) n. 2158/92 del Council of 23 July 1992	Concerning protection of the Community's forests against fire
Regulation (CEE) n. 1170/93 della Commission del 13 May 1993	Concerning protection of the Community's forests against fire
Regulation (CEE) n. 804/94 della Commission dell'11 April 1994	laying down certain detailed rules for implementing Council Regulation (EEC) No 2158/92 as regards forest fire information systems.
D.I. 19 May 1997 n. 130	Urgent provisions to prevent and tackle forest fires on the national territory as well as interventions in the field of civil protection, environment and agriculture.
Law 6 October 2000 n.275	(converting, with amendments, D.I. 4.8.2000 no. 220) 'Urgent provisions for the repression of forest fires'.
Law 21 November 2000 n. 353	Framework law on forest fires'.

Figure 17 Chronology of the main forest fire laws before L. 353/2000 (source:www.corpoforestale.it).

4.1.2 Law 353/2000

Until the 2000's forest fire was intended generically as combustion, with characteristic of vastness, diffusiveness and difficult to extinguish would spread through forest. Only with the law 353/2000 with the article 2 fire Forest is to be defined as a fire with susceptibility to spread over wooded, shrub or arboreal areas, including any man-made structures and infrastructures located within the aforementioned areas, or on land cultivated or uncultivated land and pastures adjoining areas. In the same law (art.11) was recognized also the penal offences according which; whoever causes a fire on forests, woodlands or on forest plantations intended for reforestation, either their own or others, shall be punished by imprisonment from four to ten years(Normativa, 2022).

The article 3 assigns responsibility for forecasting, preventing and actively fighting forest fires to the regions and gives some guidelines saying that the plan is subject to annual review.

In Article 4, are precisely defined forecasting and prevention activities, also including suitable cultivation interventions to improve the vegetation structure of natural and forest environments, for which appropriate contributed measures in favour of private owners. This is an opportunity of great interest, considering that more than 60% of forest property belongs to private owners who are unlikely to have little interest in carrying out preventive silviculture. It is also introduced in the same article the notion of an area at risk in spatial planning.

In Article 5, the law provides for training activities, within the framework of an organic revision of the curricula of schools of all levels and degree and technical-practical training courses of subjects intended to operate in the activities of forecasting, prevention and active firefighting.

Information to the population is also appropriately regulated by Article 6.

The law then defines the various stages of firefighting (reconnaissance, surveillance, sighting warning and extinguishing by ground and air vehicles) in the article 7, defining the operational chain based on the use of air assets coordinated by the Unified Air Operative Coordination (COAU) at national level, and the permanent unified operating rooms (SOUP) at regional level.

These first articles of the law make a clear understanding of the role in planning and at the same time recognize the importance to estimate the risk in firefighting, in order to plan and prevent fire ignition with the right policy as well as with direct and indirect action on forest environment.

4.1.3 Regional normative

The Piedmont Region, already in its first regional law on forest fires, Regional Law No.13 of May 6th 1974 "Interventions for the prevention and extinction of forest fires", defined tasks and responsibilities, affirming in Article 1 that the "*Region, within the scope of its policy for the defence of the soil and the natural environment, ensures the protection of the forest heritage, promotes, especially in compulsory education and in agreement with the competent school authorities, propaganda for the prevention of forest fires, encourages studies and research on the way of prevention and fight; grants contributions for the reconstitution of forest property destroyed or damaged by fire*".(Regione Piemonte, 2021)

Subsequently, Regional Law No.16 of June 9th, 1994 (Interventions for the protection of forests from fires) indicated with even greater precision the role that the Piedmont Region was to play in fighting forest fires

Law 21/2013 had intended to pursue objectives of efficiency, effectiveness and safety: recognising the Operating Procedures as an improved tool for the management of the operative system and providing for specific actions to protect the health and safety of those involved in fighting forest fires, specifically with special attention to the volunteer component

Then with Regional Council Resolution No.35-6665 of 23.03.2018, it was conceived according to the widespread presence of AIB volunteers, specialised figures in the area, to support the institutional component of the fire brigade.

A particularly important issue in the new regional legislation is that of bans and penalties, since it details situations that needed greater clarity, as well as introducing new elements, for example by intervening, also to protect air quality and the environment, with a ban on the Stubble- burning, set for the entire period from 1st November 31st of March, which is statistically the period with the highest risk of forest fires. This is in order to pursue a change of mentality on the behaviour of the subjects (mainly farmers) and companies that manage the territory, aiming at replacing cultivation practices that involve the use of fire to dispose of processing residues with different types of solutions(Regione Piemonte, 2021).

4.2 PLANNING TOOLS

4.2.1 Wildfire risk at Global and European level

Traditionally, wildfire risk has been assessed at national or local scales using individual data sources and methodologies. This has led to local or national indices that are not comparable either across Europe or worldwide, but still wildfires are affecting many regions in the world and their effects are evident on natural system and humans society. So, for that reason supranational and global assessments are an essential tool to reduce the negative impacts of wildfire by establishing international guidelines and agreements for best practice among the wildfire management organisations(European Commission, 2019). Modern methods for analysing fire risk components and evaluating fire effects have found a home in national, regional, and global organizations as technology has advanced over the last decade. Regional wildfire information system initiatives include the European Commission's European Forest Fire Information System (EFFIS) and the recent Group on Earth Observations (GEO) initiative to establish a Global Wildfire

Information System (GWIS).

At European level the references about wildfire risk is the EFFIS, and they define wildfire risk as the combination of fire danger and vulnerability. The scheme below (Figure 18) provides the data structure to use for the assessment of wildfire risk analysis.

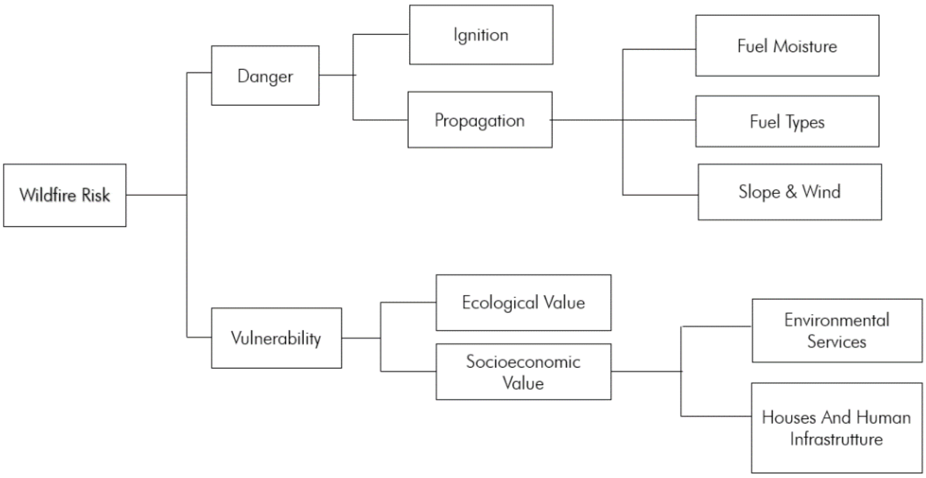


Figure 18 Data structure of fire risk Assesment at Pan- European level(San-Miguel-Ayanz et al., 2018)

For wildfire danger is intended the assessment of the conditions under which a fire can be ignited and would spread, and can be considered by an index that is the Fire Weather Index (FWI), that provides a direct assessment of fire danger due to weather conditions(San-Miguel-Ayanz et al., 2018).
To identify wildfires ignitions are necessary historical records on the number of fires, in fact the number of ignitions, next to other key factors such as fuels, weather, are used to characterize fire behaviour and thus fire danger(Finney, 2005).

Wildfire propagation is depending on 3 factors that are:
Fuel moisture, Fuel Type, Slope&Wind
Fuel moisture content is an important factor in wildfire spread because dry fuels burn easily and provide favourable conditions for wildfire propagation. Therefore, the moisture content of the fuel varies over time and space and is highly dependent on weather conditions(van Wagner, 1987).
The FWI was developed in Canada by Van Wagnes, but has been validated also in

Europe by (Viegas et al., 2000). The FWI includes different weather index, like temperature, wind speed, relative humidity and precipitation. The various components are used to generate the FWI-three system's sub-indices, which are aggregated into a single index, the Fire Weather Index see figure 19.

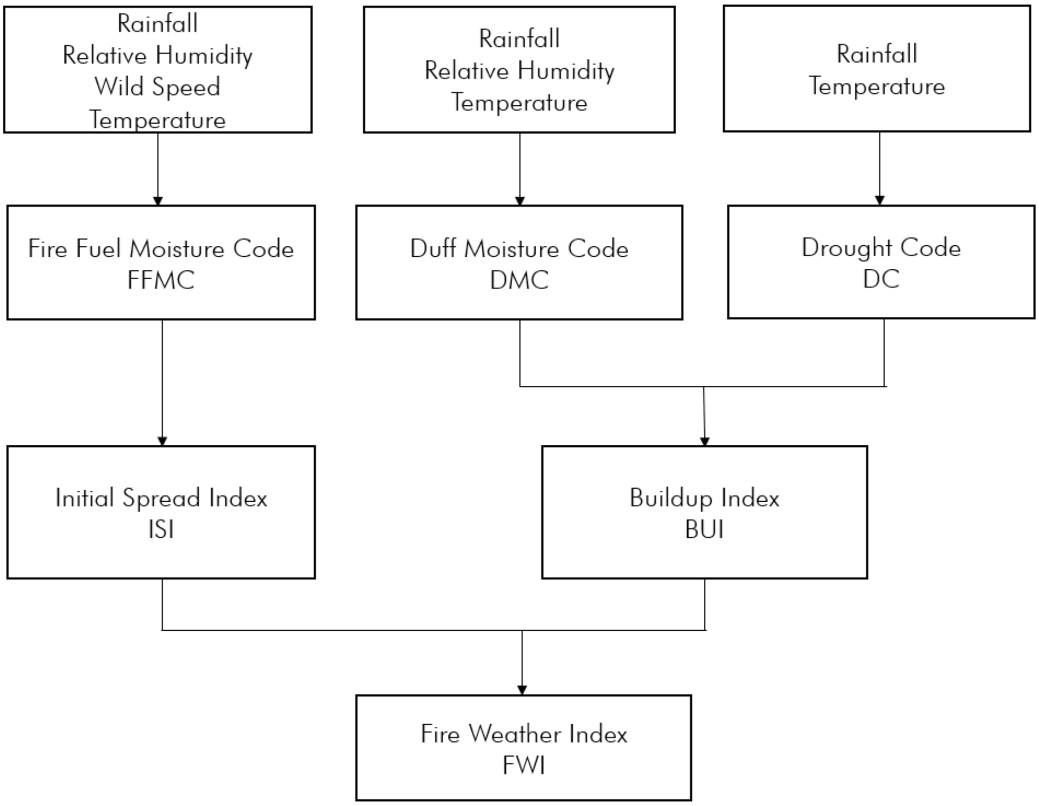


Figure 19 Forest Fire Weather Index (FWI) System(San-Miguel-Ayanz et al., 2018)

Within the FWI-system, there are three components of fuel moisture, related to the moisture content of three classes of forest fuel of different drying rates. These are: (1) the Fine Fuel Moisture Code (FFMC), related to the moisture content of litter and other fine fuels , (2) the Duff Moisture Code (DMC), which represents the moisture content of loosely compacted organic matter in the soil representing medium-size fuels, and (3) The Drought Code (DC) linked to the compact organic matter layer, representing the moisture content of thicker fuels that have a longer drying rate(San-Miguel-Ayanz et al., 2018).

In regards to the fact that we need to identify this type of fuel, which is a really complex and time consuming process for the European scale , it can only be done by indirect measurement such us the use of remote sensing , the data sets used are the Fuel Map of Europe that are simplified in 9 groups.

The slopes are derived from the ASTER Global DEM meanwhile for the wind is considered the Initial Spread Index (ISI) of the FWI- System by the fact that consider the combined effect of wind and the Fine Fuel Moisture Code (FFMC) and represents the expected rate of fire spread(San-Miguel-Ayanz et al., 2018).

Moving on to identify the vulnerability we need to identify the ecological and the socio-economic value.

Ecological values are difficult to quantify because they are often intangible, but their preservation is essential for all forms of life, including humans. It is difficult to calculate ecological value in quantitative terms, so a qualitative approach should be used. In the European context, the Natura 2000 network of sites, can be used to emphasize the special ecological values of a territory, Natura 2000 identifies Europe's most valuable and threatened species and habitats, whose damage from wildfires represents significant loss, potentially irreversible in the worst-case scenario.

The socioeconomic value is established using the Corine land cover, where for each class and country level was defined a restoration cost and according to the capacity of land cover was established also an average restoration time. The damage caused by wildfire was estimated by discounting the cost of restoring the land cover over a restoration period(Camia et al., 2017).

All these paragraphs set the basic criteria for the assessment of wildfire risk at European level and is the starting point for an implementation of the criteria used, which, considering the fact that technology is evolving faster and faster, lays the groundwork for ever more detailed assessments, leading to ever more targeted decisions and policies, but always with the sole objective of safeguarding our ecosystem and our existence.

4.2.2 Forest fire risk in Piedmont

Forest fire risk is understood according to the general meaning most widely applied today regarding natural risks, which can be summarised as follows

Risk = Probability x Vulnerability x Exposure(Cardona et al., 2012)

In forest fire protection, this approach requires some adaptations: in particular, the probability of a fire of a certain intensity is understood as fire danger. Vulnerability is understood as the resistance of the ecosystem to disturbance and its ability to react to the passage of fire, while exposure is understood as functional vulnerability. The following flowchart (Figure 20) summarises the methodology applied to define forest fire risk(Regione Piemonte, 2021).

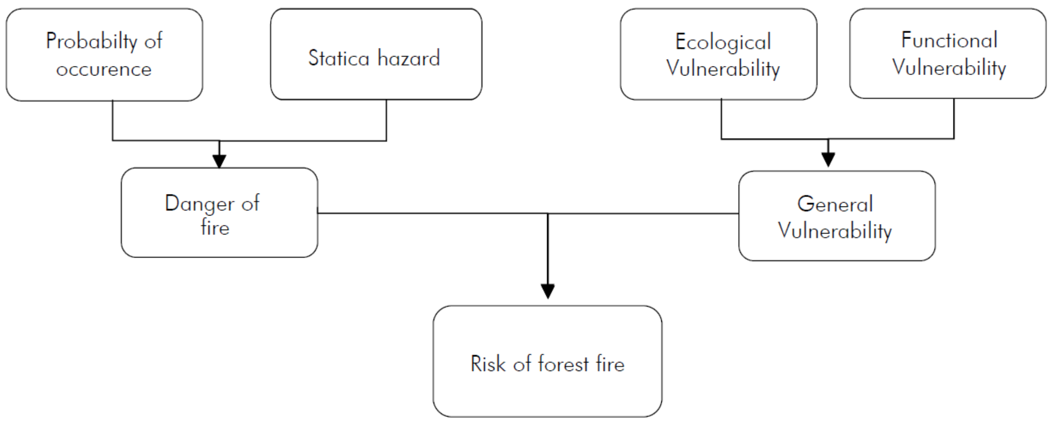


Figure 20 Flow chart of the methodology used to define forest fire risk for the Piedmont Region(Regione Piemonte, 2021)

The level of detail of the information provided over the entire territory of Piedmont refers to a grid with resolution of 25x25 m. In the next part section of this paragraph, we will explain the methodology used to build the various factors and reach the final output.

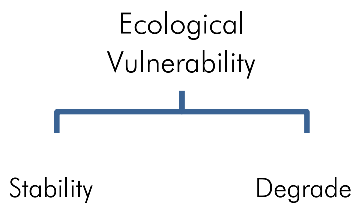
Fire danger is understood as the probability of a fire of a certain intensity occurring. In order to define the danger on a regional scale, it is used the probability of fire

occurrence and the estimation of the expected fire behaviour with reference to the linear intensity (expressed in kW/m) potentially reachable by the flame front.
The 'Flammap' software was used to simulate fire behaviour and to produce the fire probability and potential fire intensity map(Finney, 2006). To create the model, several inputs were considered such as: altitude, slope, aspect, fuel pattern, spatial distribution of the forest crown (using the Copernicus tree cover density(Tobias LANGANKE, 2018)) and several meteorological parameters (precipitation, temperature, relative humidity, wind). All these factors are spatialized obtaining a linear intensity map.

The fire probability analysis was instead performed by simulating 15,000 fires with a duration of 24 hours. The probability of fire is calculated proportionally to the number of times a cell has been crossed by the 15,000 simulations.

To define vulnerability to fire in Piedmont, were considered the resistance and resilience capacity of the ecosystem following the passage of fire (ecological vulnerability)(Lin et al., 2022) and the functional value attributed to the forest resource and the relative degree of conflict with the passage of fire (functional vulnerability)(Regione Piemonte, 2021).

The steps performed to define the two information levels are outlined below.



The ecological vulnerability can be attributed to stability and degradation (expected effects of fire) that influence the ecosystem's reaction to the transit of fire.

To define the stability were taken into account:
the characteristics of the main wood species such as passive resistance, regrowth and post-disturbance dissemination;
characteristics of other significant shelter species;

characteristics and stationary limitations (wet, dry).

Degrade, on the other hand, is conceived as the effect of fire on ecosystems, and a synthetic index representing its severity is the risk of soil erosion. According to Universal Soil Loss Equation (USLE) defined by (Wischmeier & Smith, 1978).

$$A = R \times K \times L \times S \times C$$

A: soil removed by water erosion;
R: Erosivity of precipitation;
K: soil erodibility, which is the soil loss per unit of R;
L: length of slope;
S: slope gradient;
C: land cover factor.

Finally, to define ecological vulnerability, a combination matrix was developed between the normalised stability and erosion values
Functional vulnerability supports and is complementary to ecological vulnerability because it focuses on the value assigned to threatened natural resources in terms of the functional role attributed to them. The proposed method consists of assessing the degree of conflict between the prevailing function assigned to the natural resource and the occurrence of fire attributing a value that provides an estimated measure of the degree of impact expected of the fire on the resource itself.

The final step is then to combine the danger and the vulnerability normalized value to reach the risk map of piedmont region(Figure 21).

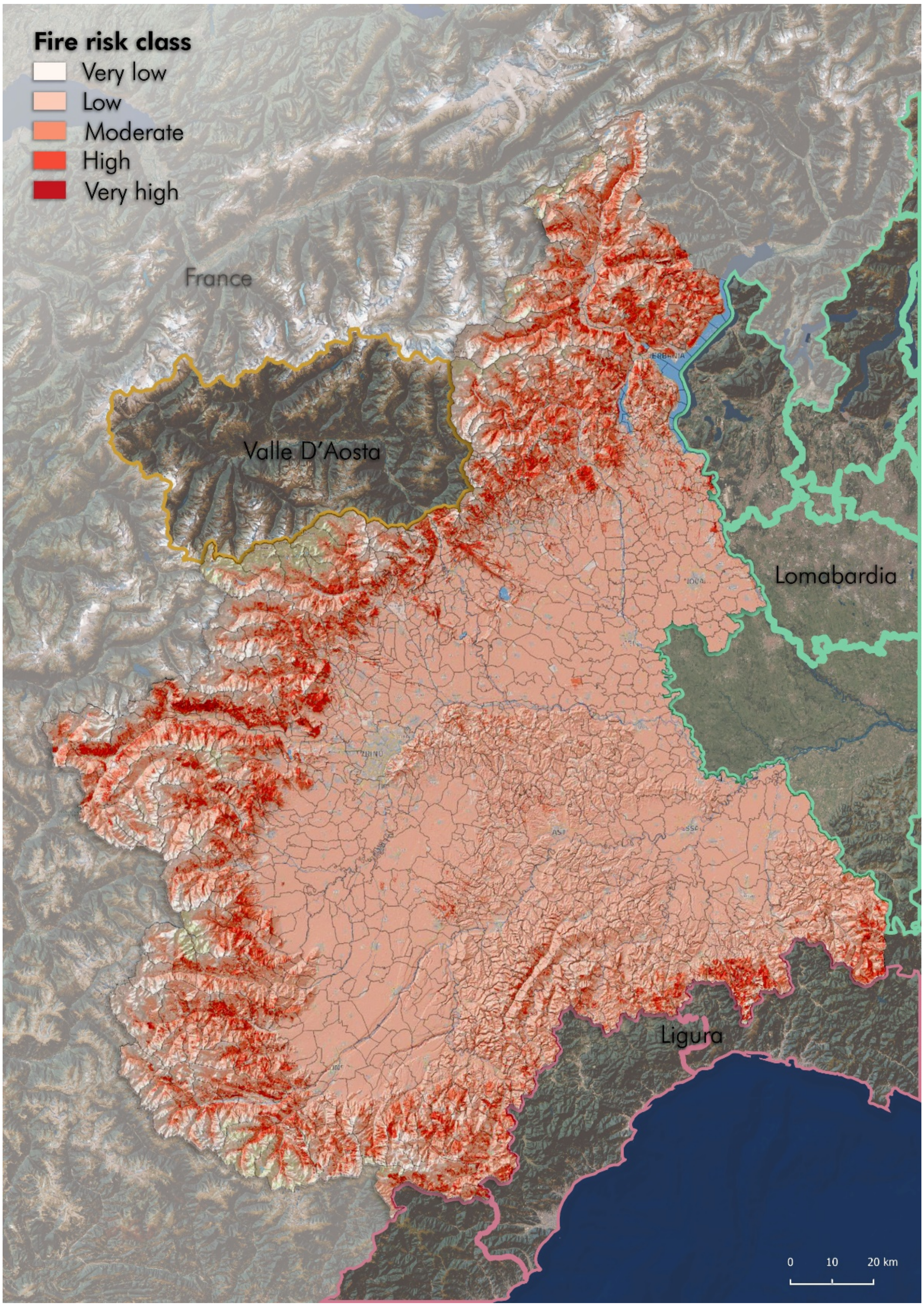


Figure 21Fire risk map Piedmont Region(Regione Piemonte, 2021)

4.2.3 A.I.B plans

The Law Law 353/2000 a entrusted the regions with the responsibility for forecasting, preventing and actively fighting forest fires based on the guidelines set out in the Ministerial Decree of 20th December 2001, the regions have drawn up provincial level plans. The plans are three-year plans but are revised annually. The guidelines for the preparation of the plans provide a general architecture that the individual regions adapt to their own territorial realities and specific operational structures.

It's possible to divide it in four parts (Protezione civile, 2022):

I. The **general part** that contains:

- description of the territory that provides indispensable elements for defining the priority objectives to be defended;
- reference cartography, the thematic maps must show the operational centres, the location of the teams and the map of the targets to be defended with an indication of priorities; the areas affected by fire; vegetation; land use; roads and water supply points;
- databases. to be updated annually, showing: forest fires in the last five years, monitoring, spotting and telecommunication networks; structural and forestry interventions already implemented; available vehicles and materials; information on personnel displaced on the territory and procedures for actively fighting forest fires;
- historical analysis of AIB data
- the organisational model, indicating the structures and forces used and any agreements of the region with public and private administrations.
- the main objectives to be defended: Human presence (residential, industrial, commercial, tourist facilities), protected natural areas, young reforestations and coniferous forests, and difficult accessibility from the ground are to be taken into account as elements in the definition of priority

objectives.

II. The **forecast** part identifies:
- the causes and predisposing factors of fire;
- the areas burnt by fire in the previous year, represented in a dedicated map;
- areas at risk of forest fire, represented in a thematic map with the prevailing vegetation types;
- risk periods and hazard indices.

III. The **prevention** part that includes
- and actions that could potentially trigger a fire;
- the size and location of access routes, firebreaks and water supply sources;
- the scheduling of forest management, maintenance and cleaning operations;
- training and educational activities
- informative activities, which are essential to raise public awareness of the problem of forest fires, but also to disseminate information on the periods of maximum danger

IV. The **fire fighting** part that identify
- description of the AIB operational structure and procedures for fire fighting activities
- the instructions for the reconnaissance-surveillance-warning network, fixed and mobile, terrestrial and airborne;
- information on the permanent unified operational units (SOUP).

To fully understand the A.I.B. plan, it is important to define the concept of zoning, which is that part of the territory affected by a common problem or characteristic. The first step for proper planning is to carry out current zoning, which consists of identifying within the regional territory, homogeneous areas that are characterised by specific manifestation of the forest fire phenomena; each of them, therefore, will require diversified and targeted interventions(Bertani et al., 2016). In the plan, these zones are defined by the combination of the severity and hazard values of fires occurring. The area covered by the plan is also determined by indicating which municipalities are to be included and which are not, based on their relationship with forest fire ignitions.

The final objective of the plan is defined by the permissible land area, which is the maximum value of rural area on which the passage of fire is allowed to occur annually. The permissible burnable area is proportional to the size of the territory to be planned because as it increases, so does the probability of finding areas where passage of fire can be allowed. Obviously, at the end of the validity of the plan, the objective is achieved by planning interventions in relation to the resistance and resilience of forest cover and the probable fire behaviour(Blasi et al., 2004).

In concrete terms, the protection needs of the area expressible in terms of local interventions, to be carried out on the specific territory of the area itself and with a graduation of interventions that only zoning can provide. These interventions can be divided into two main categories: infrastructural and coltural. In the former, they serve to mitigate difficulties or deficiencies related to the physical nature of the territory to be defended, they include construction, restoration and maintenance of: service roads, firebreaks; water supply points. The second act on the distribution is quality of fuels in the area, the actions include the reduction of high flammability biomass.

At the end of the plan, an evaluation is essential to size future interventions on the basis of those already realised and to avoid redundancies with already implemented projects.

4.3 PREVENTION

Despite its undeniable complexity and dimensions, the fire problem in Italy is still often handled from the point of view almost exclusively of the emergency in progress, concentrating every effort on the extinction phase, without explicit attention to the problems of prevention.

Prevention comprises, as is well known, a coordinated and planned set of actions and interventions aimed at eliminating or modifying the causes of fires through information, education protection of forests from the danger of fire ; limiting fires; limiting their damaging effects, providing the territory with the necessary defence infrastructures and creating the conditions to increase the effectiveness of firefighting interventions and through interventions aimed at modifying the predisposing factors, i.e. the load, type and distribution of vegetation potentially capable of spreading the fire.

4.3.1 Forecasting

As we have analysed in the previous paragraphs, fires are caused by certain factors that induce conditions favourable for fire (predisposing factors) and by other factors, mainly linked to human behaviour, which determine the ignition of combustion (determinant factors). Danger prediction methods are based on the relationship that has been found between predisposing variables and the start of fires. Precipitation, wind, low humidity, high temperature air and atmospheric instability are among the basic meteorological variables for forecasting, which expresses the predisposition to fire of a given area over a defined period of time(Blasi et al., 2004). In modern fire-fighting organisations, forecasting methods are integrated into decision support systems, as they represent essential parts of the systems used for co-ordination, as the actual prediction of hazard is linked to numerous fundamental activities including spotting, extinguishing the eventual management of the prescribed fire. Fire risk prediction is an activity which considers, in particular, focuses temporal variation of the hazard, and therefore focuses less on constant environmental factors over the medium to long term and more on variable factors, on the basis of which it makes it possible to modulate and dimension prevention activities over time. Risk forecasting allows, in other terms, to prepare preventive actions in good time and manifests its usefulness in many sectors of fighting and prevention.

4.3.1.1 Contribution of Google earth engine

To determine the severity and location of a wildfire, remote sensing and assessment tools are suitable for quick prevention and action. facilitating in the detection of fire in remote areas that are inaccessible to human eyes as well supporting systems that are ineffective in controlling wildfires due to managerial and social weaknesses. Ecosystems in forests are constantly evolving. These alterations may be handled by human evolution or by its natural evolution (Dimopoulou & Giannikos, 2001). This change in the ecosystem may have effects in fire severity from local to regional scale, at the same time there are methods and models used to assess forest fire risk in different areas at different scales and different efficiencies. The typical, nonlinear, complex, and human-influenced forest wildfire process is influenced by a wide range of ecological and human factors. Due to this fact, finding high accuracy prediction modes is challenging(Pettinari & Chuvieco, 2017). The model used in our study, as we will see in later paragraphs, is the AHP but in recent years has seen a significant increase in the analysis and prediction of the spatial distribution of natural hazards like wildfires using machine learning (ML) models. The benefits and drawbacks of various ML techniques vary and compared to more traditional methods like MCDA, integrating GIS models with ML models typically produce better performance and faster data processing(Piralilou et al., 2022).

Since for any evaluation must be decide which causes or influences have a significant impact on the hazard assessment and given that a wildfire is one of the most complex natural hazard in terms of severity, spread speed, coverage, and degrees of destruction, It is essential to identify the major conditional factors(Eskandari & Khoshnevis, 2020). In this study, we identified 10 conditional factors that significantly influence the wildfire ignition and spread. These conditional factors consist of four groups: topographical, meteorological/ hydrological, vegetation and anthropological factors (§ 7.3 Factor criteria). All this base map utilized are open data and for doing the analysis a GIS software is needed. Recently google has developed Google Earth Engine that is a multi-petabyte public data catalog of commonly used geospatial and remote sensing data. GEE contain dataset about remote sensing of the earth's surface captured by the different satellites. There are inside as well datasets regarding the land cover, climate and environment. Nearly 6000 satellite scenes are added to the collection every day from various sensors, usually within 24 hours of the scene's acquisition time, furthermore users can add existing dataset from the catalog or add their own dataset . In this way high performance calculation and cloud based process has become accessible for ordinary users(Cossu et al., 2010). Also satellite data that cover the whole earth surface has been available for free , from the main remote sensing organization like NASA , NOAA , ESA and soo on. This increase of availably of remote sensing data goes in line with the development of numerous specific tool for processing geospatial and remote sensing data(Loveland & Dwyer, 2012). Even with all the readily available information from various sources, these resources' alluring, full benefit still requires work and technical know-how to produce significant and valuable results or outcomes. One of the most frequent obstacles is the management of information technology, where the collection of data from numerous sources, storage of the enormous volumes of data derived from various sources, computation of the vast data volumes, database management, and data processing frameworks restrict researchers or smaller organizations from using the freely available data to produce meaningful results(Sudmanns et al., 2020). Google earth engine reduced such barriers , bring to the user a rapid process of large petabyte of remote sensing data without making their own investments in storage, computing power, and efforts to combine data from various sources. By the fact that GEE is a cloud based platform allow people to access and analyse geospatial and satellite data , including 40 years data , this make possible to perform comparison and time series analyses , furthermore this data are periodically updated. Additionally, the GEE makes it simple to disseminate results because it can use user-developed algorithms without the need for programming or web application expertise(Piralilou et al., 2022). Additionally, it offers a code editor, which is a web-based integrated development environment (IDE) for coding, prototyping, and visualizing the results, as well as APIs for connecting to and making requests to GEE servers (JavaScript and Python)(Google, 2022). It is clear that GEE and ML are tools with a vast supporting data, high processing speed, low human error coefficient and accuracy of results(Heidari et al., n.d.). This field of research is only in its infancy and still needs a lot of development, but there are already studies such as (Heidari et al., n.d.; Piralilou et al., 2022)which have used these tools in the wildfire risk map with excellent results. Thanks to these tools, it will be possible to draw up risk maps in short time resolution, or even in real time, and it is hoped that perhaps one day, man will be able to predict fires or identify them in the shortest possible time.

4.3.2 Sighting

The observation stands between prevention and extinction and is a very important component of the fire-fighting organisation, which cannot be designed and structured independently of all the others. In recent years, sightings have mainly been carried out with fixed installations, that consist in instruments capable of detecting and geo-referencing sources of fire. The technologies on which the monitoring equipment are various: cameras in the visible and infrared range, laser-based smoke detectors, systems employing microwave radiometry(Krüll et al., 2012). In any case, it is necessary to frame the sighting system within the planning framework and place it properly in the territory.

There are different system of sighting: by aircraft; this is and is especially suitable where there are vast forest areas with poor road connections roads and with low anthropic pressure, as it allows the control of large areas that cannot be reached easily or accessible from the ground. Usually small aircrafts with equipment such as thermal cameras are used, which transmit data to the coordination centre, and often carry small loads of water in order to extinguish the fire if detected. This method is not widely used in Italy due to the morphology of the land, which is characterised by numerous valley incisions. Furthermore it needs specific infrastructures for example for landing and it has high cost of use.

Just recently, UAV-based early wildfire detection and warning systems that incorporate various remote sensing technologies and deep learning-based computer vision techniques have emerged as promising technologies for wildfire monitoring(Jiao et al., 2019). Utilizing effective communication technologies, combining UAVs and deep learning architectures could be very helpful in detecting fires in their early stages and sending important information to the relevant authorities, approximately in real time, in order to reduce the risks and losses and can help firefighters to extinguish the fire at its early stages(Bouguettaya et al., 2022). In vision-based forest monitoring systems, remote sensing technologies based on UAVs are crucial. Therefore, combining them with modern deep learning-based computer vision algorithms and potent computational hardware may result in smart UAVs that are capable of autonomously navigating, detecting forest fires, and alerting the appropriate authorities. UAVs are the best platforms for identifying and monitoring wildfires because they can easily deliver high-resolution images in real-time from difficult and complex forest and wildland locations.

Other detection system are the terrestrial one, that usually consist in a network of sensor that are usually located in watchtower, that are structure located on high vantage point, for monitoring place with high risk of wildfire occurrence. There are used non only for the detection but also for the verification and localization of the fires occurred, that's why they need to be carefully located in the right place to ensure adequate visibility. Usually there are two types of cameras on these towers, the optical and the infrared sensors that can capture data ranging from low resolution to ultra-high resolution for different fire detection scenarios(Çetin et al., 2013) Colour information is provided by optical cameras, while thermal radiation from nearby objects can be measured by IR imaging sensors(Töreyin et al., 2007). Recently have been introduced early detection systems that combine both sensor image and with the implementation of machine learning and deep learning that can combine a big amount of data aiming to achieve a consistent level of accuracy maintaining a low false alarm rate(Barmpoutis et al., 2020).

A key aspect in achieving an effective detection is the location of the detection points: regardless of the technique used, they must be placed so as to cover the maximum sighting area. This area is normally less than the area of maximum risk, which must be subjected to detection priority. However, it must be considered that the detection coverage must be extended over a large part of the territory and therefore, especially with complex orography, to ensure the coverage that makes necessary a high number of detection points. However, it is not only the cost limit, but above all, the organisational limit of the administrative reality that must employ the proposed instrumentation, in fact in an advanced planning reality, it may be correctly proposed and supported a higher cost, to which the effective use of the system will correspond an effective use of the equipment(Blasi et al., 2004).

4.3.3 Infrastructure

Prevention activities are aimed at decreasing the occurrence of fires and mitigating their damaging effect, both by decreasing the intensity and therefore the potential destructive force of the fire and by guaranteeing the best conditions for active fighting. The structures and infrastructures of prevention refer, in particular, to planned interventions and implemented punctually on the territory, such as service roads, firebreaks, water supply systems, helicopter bases.

The presence of a good road network plays multiple roles in that it facilitates surveillance and firefighting operations, and at the same time, it facilitates, from an operational point of view the attack on the fire Frontline since the paths passing through the forest can represent, in particular situations, an interruption of the wooded surface, representing an obstacle to the spread of fire and permitting the isolation of areas, with consequent reduction of damage(Thompson et al., 2021).

Regarding firebreaks, there are three types: passive, active and green. The first require specific planning, as they consist in the elimination of a strip of vegetation between 100 and 200 m wide. These interventions have a very high landscape and ecological impact, as do the maintenance costs, since the total absence of vegetation must be maintained during the fire season.

Active firebreaks are intended to slow down the fire, modifying its behaviour and facilitating the work of the extinguishing teams.

Similar to active firebreaks are green firebreaks where the tree vegetation is not completely eliminated, and the shrub bio mass is reduced.

4.4 MONITORING AND RESTORATION

Monitoring may have several aims to support post fire management : to localize and estimate the extension of burned areas, to assess the damage on vegetation ; to control the ability of the ecosystem to naturally recover and at the same time the dynamic of vegetation growth after the fire, or to control the outcome of any restoration intervention (Corona et al., 2008). The complete or partial combustion of vegetation cover is the wildfire's most notable immediate after effect on the landscape. The intensity of the successional processes beginning and the return of vegetation, also known as recovery, is a crucial aspect of landscape dynamics(Pickell et al., 2016). This is strongly dependent on some factors like the performance of the affected species'; anatomical and physiological regeneration strategies, the extent to which other components of the soil-vegetation complex have changed, and how those interactions have changed because of environmental factors and post-fire temporal conditions(Pereira et al., 2018). Monitoring post-fire vegetation recovery is essential because it offers important data for assessing ecosystem resilience, figuring out landscape dynamics, and managing forests. Remote sensing techniques are a time- and money-efficient alternative to extensive and labor-intensive field campaigns for tracking post-fire ecosystem recovery(Fernández-Guisuraga et al., 2019). For the reason that satellite imagery is able to quantify the fire impact over extensive zone and different ecosystem ; understanding how ecosystems respond to fire which can enhance our comprehension of vegetation recovery patterns and contribute to the sustainable management of forests(Pérez-Cabello et al., 2021). Those changes on the vegetation are widely analysed through the use of Landsat data series thanks to their high spatial and temporal resolution. Moreover, the fact that restoration after a fire takes years and decades, long-term serial data are necessary pre-fire to have a proper risk assessment, post-fire to have a proper monitoring, and the Landsat constellation is one of those in orbit for much longer than that, which makes a huge amount of images, available for free. One of the characteristics of Landsat image is the multispectrality ; and is an essential feature to understand vegetation condition thought numerous vegetation indexes; these indexes are derived from the combination of different bands of the image (§ 6.3.2 Index derived from remote sensing, Figure 30); and by the fact that the sun light is reflected by a surface in different way and it is absorbed in different way by the sensor, so different band combinations give different indexes.

Combining remote sensing data from various wavebands can be used to monitor forest fires over a long period of time, and using various types of indexes as well, during different stages of forest restoration can effectively monitor the ecological restoration of forests(Fang et al., 2019).

The destruction of vegetation by fire is followed by natural processes of recovery and regrowth, which can lead, within a few seasons, to the reconstitution of the previous vegetation. This regeneration is, in most cases, self-succession, i.e. the plants present regrow more or less quickly and the more heliophilous species, advantaged by the temporary reduction in cover of shrub and tree canopies, find the favourable conditions for large explosions demographic explosions. disturbance. The effects of a fire on the ecosystem and consequently, its resilience (autonomous resilience), are extremely variable and depend on numerous factors amongst which the main ones are the main ones: the type of fire, the type of vegetation and the stationary conditions (climatic, pedological and vegetation)(Blasi et al., 2004). These factors are therefore independent of each other: they influence each other and their degree of interaction results in complex and variable responses, which condition in an equally variable manner the processes of vegetation recovery.

5 STATE OF THE ART

5.1 STUDY AREA

The Study area is the Province of Torino situated in the Piedmont region. Is a heterogeneous region it formed for a mountain landscape is prevailing with almost half the territory. The mountain landscape is characterized by the presence of the alps in the north and west and south-west part of the region and by the Apennines in the south-east of the territory. The alps that cross the region, going from the south to the north are the Maritimes Alps, Cozie Alp, Graie Alps and Pennine Alps. Just the Cozie and Graie alps are in the territory of the province of The is formed by 316 municipality have an extension of 6827 Km^2 with a population of 2.219.206(Tuttitalia, 2020). In its territory are distinguishable three altimetric bands, the most populated (1,693,703 inhabitants) of the lowland municipalities (extended for 1,820 square kilometres) that includes the municipality of Turin, the neighbouring hill area (460,242 inhabitants for 1,428 square kilometres) which serves as a buffer with the largest (3,580 sq. km) but least populated (143,972 inhabitants) mountain area culminating in the Alpine area and the French-Italian border(Vetritto et al., 2017)(Figure 22).

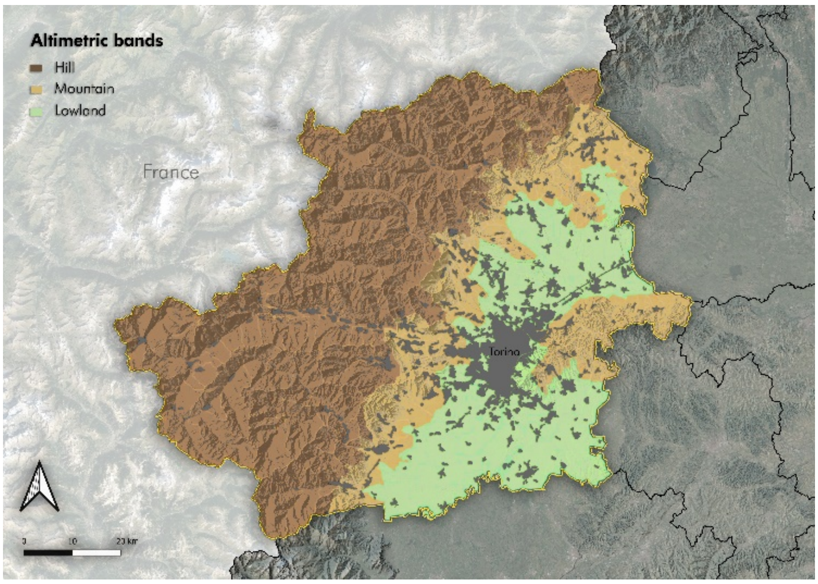


Figure 22 Altitude Bands Source: ISTAT 2014

5.2 TOPOGRAPHY

In the fire behaviour, topography is the Variable that is most stable. Fire spread is influenced by slope aspect and elevation and other topographic characteristics that determine how fast a fire moves in meters per hour. Topography affect energy and water balance that control vegetation growth, and therefore the accumulation of biomass that fuels fires when it is sufficiently dry(Dillon et al., 2011). Moreover, microclimatic elements (temperature, precipitation, direct solar radiation, wind exposure, etc.) that affect the moisture content of fuel are determined by elevation, aspect, latitude, longitude, topographic position, and nearby topographic context. This chapter will describe the three topographic elements: elevation, slope, and aspect, that were used for the construction of the forest fire risk map. The analysis of those element is also a first approach to understand the heterogeneity of this territory and its morphology.

5.2.1 Elevation

The elevation map is a classification of a Digital Terrain Model(DTM) based on its value, where this is the height above the sea level. The DTM is a three dimensional representation of the earth's surface. The terrain model contains information about height without considering vegetation, building and other object.(INNOTER, 2022) The province of Torino has an heterogeneous landscape that is characterized by a flatten, that is the most westerly part of Pianura Pandana(Figure 23). The lowest altitude in the province is at 140 meter above sea level. In the western part of the territory there is the mountain area where the highest point is at 4019 meter over the sea level. The complex morphology is clearly recognizable looking at the numerous valleys that go from the alps to Torino. Looking at the maps is possible to recognize the big valley that has the name of Val di Susa from the Susa river that passes through it. Elevation affecting wildfire affects the fires both for the diverse types of vegetation, both for the temperature difference, both for the difference in precipitation. The susceptibility to fire propagation decreases with increasing altitude, as areas at higher altitudes are affected from winter snowfall(Guglietta, n.d.).At higher elevation there is also a tendency of more lighting strike and subsequent ignition of fire. At the same time Due to higher temperatures and less precipitation, fuels tend to dry up earlier in the year in lower elevations (where the majority of private land is situated). Private land that are often managed by human and irrigated for the production of agricultural products.

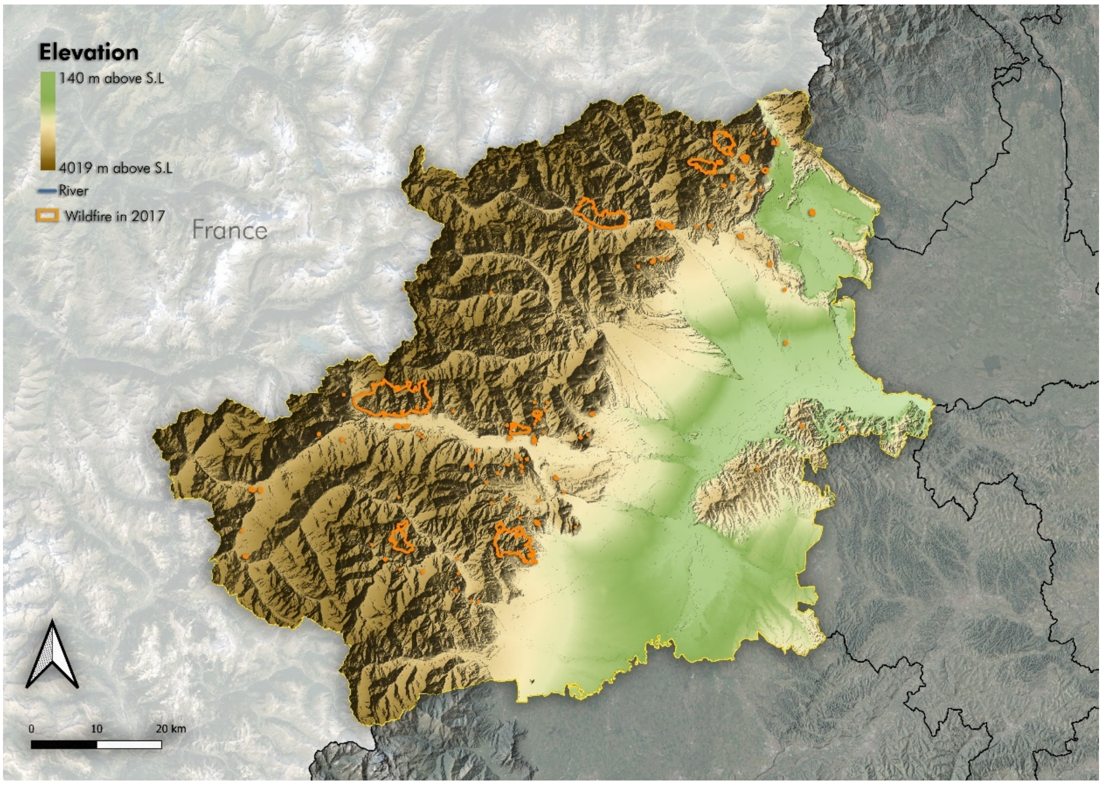


Figure 23 Elevation elaborated by the author on GIS resolution 25x25

5.2.2 Slope

The gradient map represents the acclivity of the soil measured in percentage. Terrain slope can be a primary force acting on a flame and on its spread rate(Weise et al., 1994). Some studies demonstrated a curvilinear relationship between rate of spread and slope , and the influence of slope began to be relatively slight at low windspeeds but grew correspondingly more important with higher windspeeds(Murphy et al., 1966). This topographic factor is crucial especially in the initial stage of a fire. Slope position are also an indicator of vegetation type , upper slope tending to contain more sclerophyllous vegetation and lower slopes dominated by more mesic vegetation(Estes et al., 2017). Sclerophyll is a form of vegetation that can withstand extended periods of heat and dryness. Meanwhile a form of environment called a mesic habitat has a balanced supply of moisture. In the province of Torino the predominant vegetation is the coniferous in the alpine area and according the literature , In a coniferous woods there aren't an increase of spread rate with slope from 0 to 10 ; this rate increase slightly for slope between 10 and 25 degree , an exponential acceleration of the are From 25 to 31(Butler et al., 2007). The province of Torino is characterized by a flatland area on the Est with an elevation less the 10 degree, this slope continues along the various valleys that divide a complex territory characterized by a slope of 20 35 degrees that increase going to higher altitude (Figure 24).

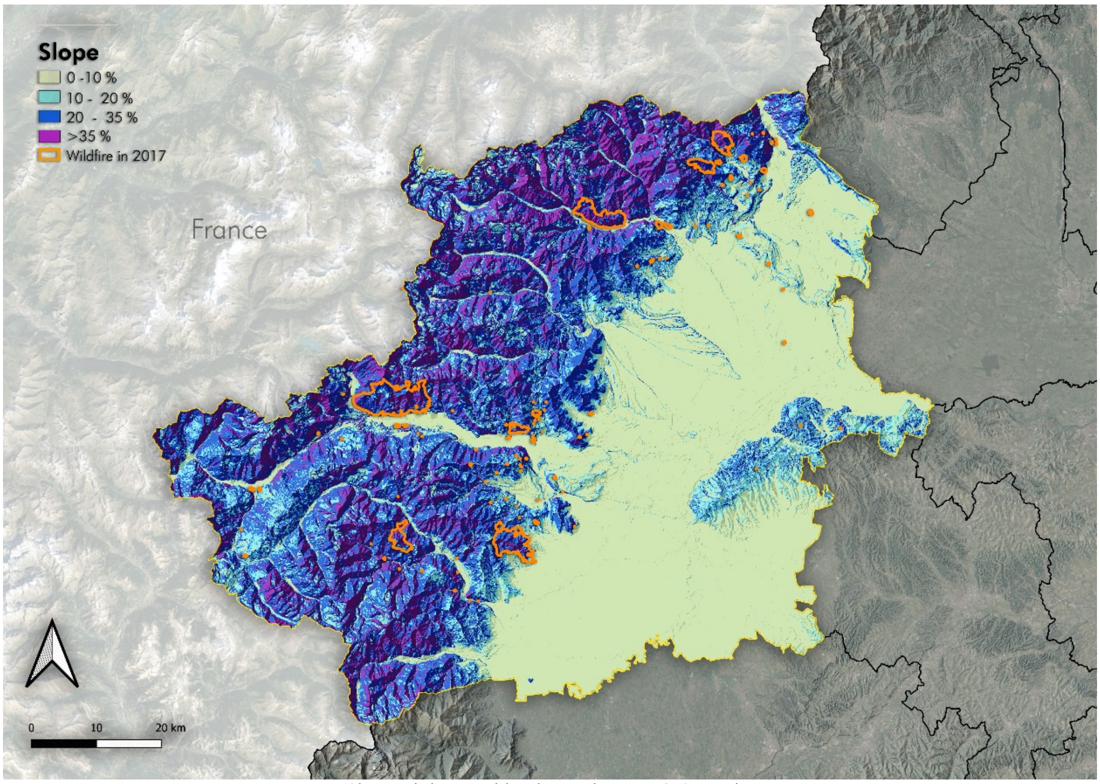


Figure 24 Slope elaborated by the author on GIS resolution 25x25

5.2.3 Aspect

The aspect map is related to slope map by the fact that, aspect value indicate the direction of the physical slopes face, therefore when the terrain is flat there is no slope, so means that there is no aspect (Figure 25). Where slope exist, aspect is measured clockwise starting north at 0°. It returns backs as 360° north again(GISGeography, 2022).

The aspect is classified according the following category:

- Flat (-1)
- North (0°to 22.5°)
- Northeast (22.5° to 67.5°)
- East (67.5° to 112.5°)
- Southeast (112.5° to 157.5°)
- South (157.5° to 202.5°)
- Southwest (202.5° to 247.5°)
- West (247.5° to 292.5°)
- Northwest (292.5° to 337.5°)
- North (337.5° to 360°)

Aspect influence soil temperature in mountain territory thorough solar insulation and vegetation canopy structure. This effect is most evident between north-facing and south-facing hillside due the significant difference in energy balance and vegetation(Ebel, 2012). Especially in spring and autumn the diurnal variation and average soil temperature is bigger from the two aspect slope side. But as the canopy closed throughout the growth season, the change was barely noticeable(Kang et al., 2000). In northern Hemisphere southern aspect tend to burn with more intensity and at the same time with a severity higher than other aspects, as southern aspect receive more solar radiation and fuel moisture was lower(Lecina-Diaz et al., 2014).All this factor that are influenced by the aspect slope are important for the start and the speed of a fire the most important is the soil moisture , often the fire especially in a mountainous landscape, start from the dead litter on the ground and then move to the crown of the tree, bringing to dramatic event that are difficult to control.

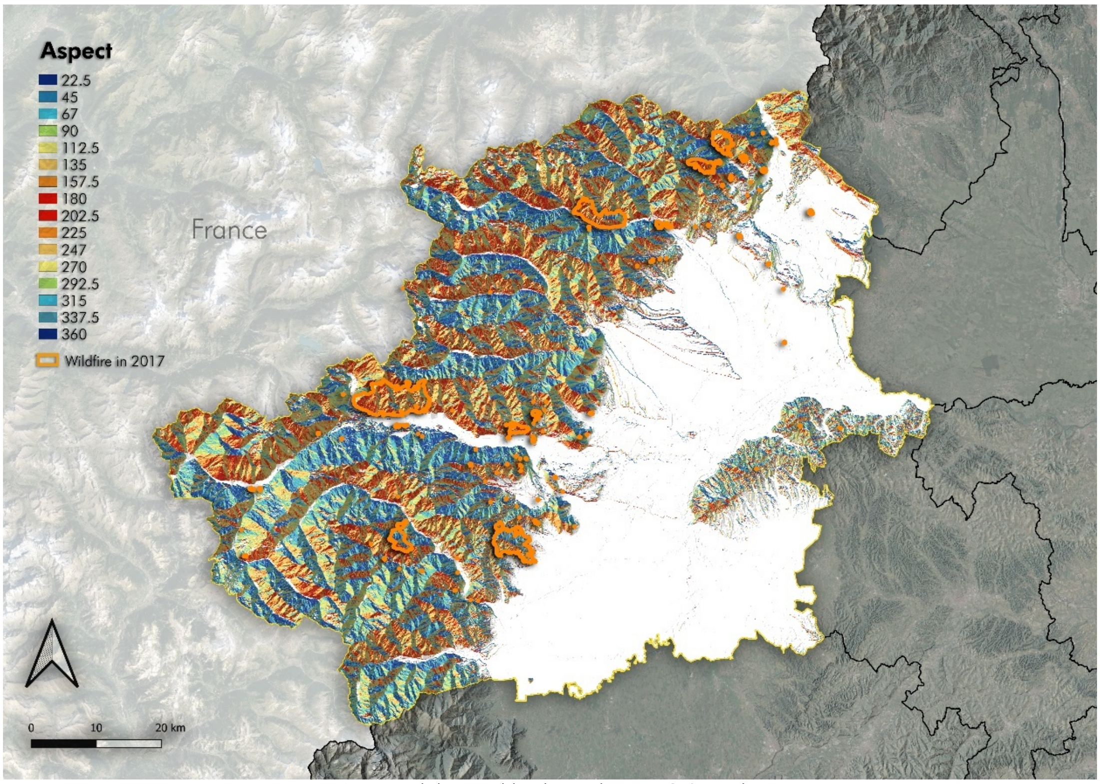


Figure 25 Aspect elaborated by the author on GIS resolution 25x25

5.3 VEGETATION

About the vegetation in the piedmont region there is a total forested land of 976.953 ha in the period of 2016, with an increment of 4.6% since the 2000.More detail about the surface are in the table below (Figure 26) that show the forested land for each province . Looking at the table the largest amount of forest area is l in the province of Torino and in the province of Cuneo, following then by the province of Verbaniaa-Cusio-ossola and Alessandria.

Forest area distributed by province				
Province	**Woods**	**Other forested areas**	**Arboriculture for timber**	**total**
Alessandria	114.711	1.397	7.449	123.557
Asti	44.713	-	5.693	50.406
Biella	46.011	839	548	47.398
Cuneo	258.369	2.573	7.439	268.381
Novara	35.528	-	2.405	37.933
Torino	242.278	3.123	9.473	254.874
Verbano-Cusio-Ossola	129.782	790	163	130.735
Vercelli	61.122	652	1.845	63.619
Totali	**932.514**	**9.374**	**35.015**	**976.903**

Figure 26 Forest area distributed by Province(Camerano et al., 2008)

How we highlight in the previous chapter the typology of vegetation strongly affects the risk of wildfire, so is it crucial to know which kind of tree species prevails in the piedmont region, to understand better the phenomena of the forest fire. In the Piedmont region ¾ of the forested surface is formed by 5 forestall category of the 21 present in the whole territory. Chestnut groves (22%), Beech forests (15%), Robinieti (12%), Larch and Cembrete (10%) and Pioneer and invasion woods (8%)(Figure 27).

Surfaces of forest categories						
Forest categories*		**Forest Map 2016**				
		Woods	**Other forested areas**	**Total**	**%**
Castagneti	CA	206.582	415	206.997	22,0
Faggete	FA	141.288	311	141.599	15,0
Robinieti	RB	117.379	104	117.483	12,5
Lariceti e Cembrete	LC	89.164	3.369	92.533	9,8
Boscaglie pioniere e d'invsione	BS	72.660	2.335	74.995	8,0
Acero-tiglio-frassineti	AF	46.017	453	46.470	4,9
Querceti di roverella	QR	45.883	94	45.977	4,9
Querceti di rovere	QV	40.548	351	40.899	4,3
Querco-carpineti	QC	36.486	-	36.486	3,9
Arbusteti subalpini	OV	32.282	766	33.048	3,5
Rimboschimenti	RI	20.099	290	20.389	2,2
Abetine	AB	15.175	-	15.175	1,6
Pinete di pino silvestre	PS	14.875	78	14.953	1,6
Saliceti e pioppeti ripari	SP	14.199	32	14.231	1,5
Orno-ostrieti	OS	14.087	41	14.128	1,5
Peccete	PE	9.264	28	9.292	1,0
Alneti planiziali, collinari e montani	AN	4.684	-	4.684	0,5
Cerrete	CE	4.367	3	4.370	0,5
Arbusteti planiziali, collinari e montani	AS	4.121	603	4.724	0,5
Pinete di pino montano	PN	2.669	102	2.771	0,3
Pinete di pino marittimo	PM	683	-	683	0,1
Totale		**932.512**	**9.375**	**941.887**	**100,0**

Figure 27 Surface forest Typology(Camerano et al., 2008)

The Upper table(Figure 27) shows the surface of forest category and the different colors how the row explains in which altitude we can find the different species. In green are the Planizal Forest Categories, in blue the Mountain Forest Categories, and in yellow those found in all altitudinal ranges. Among all the species present in the territory nine of that are into the 23 Site of Community Importance, present in the piedmont region (Beech, Larch and Cembrete forests, Chestnut groves, Quercus-carpine groves, Willow and riparian poplar groves, Alne groves lowland and montane, Peccete, Pine forests of pine hooked pine, Maritime pine forests)(Camerano et al., 2017)(Figure 28). Among all the forested area 941.888 almost the 55% of the surface is inside the SIC (485.066 ha) of those the 16 % are included into the protected area of Rete Natura 2000 and other protected areas.

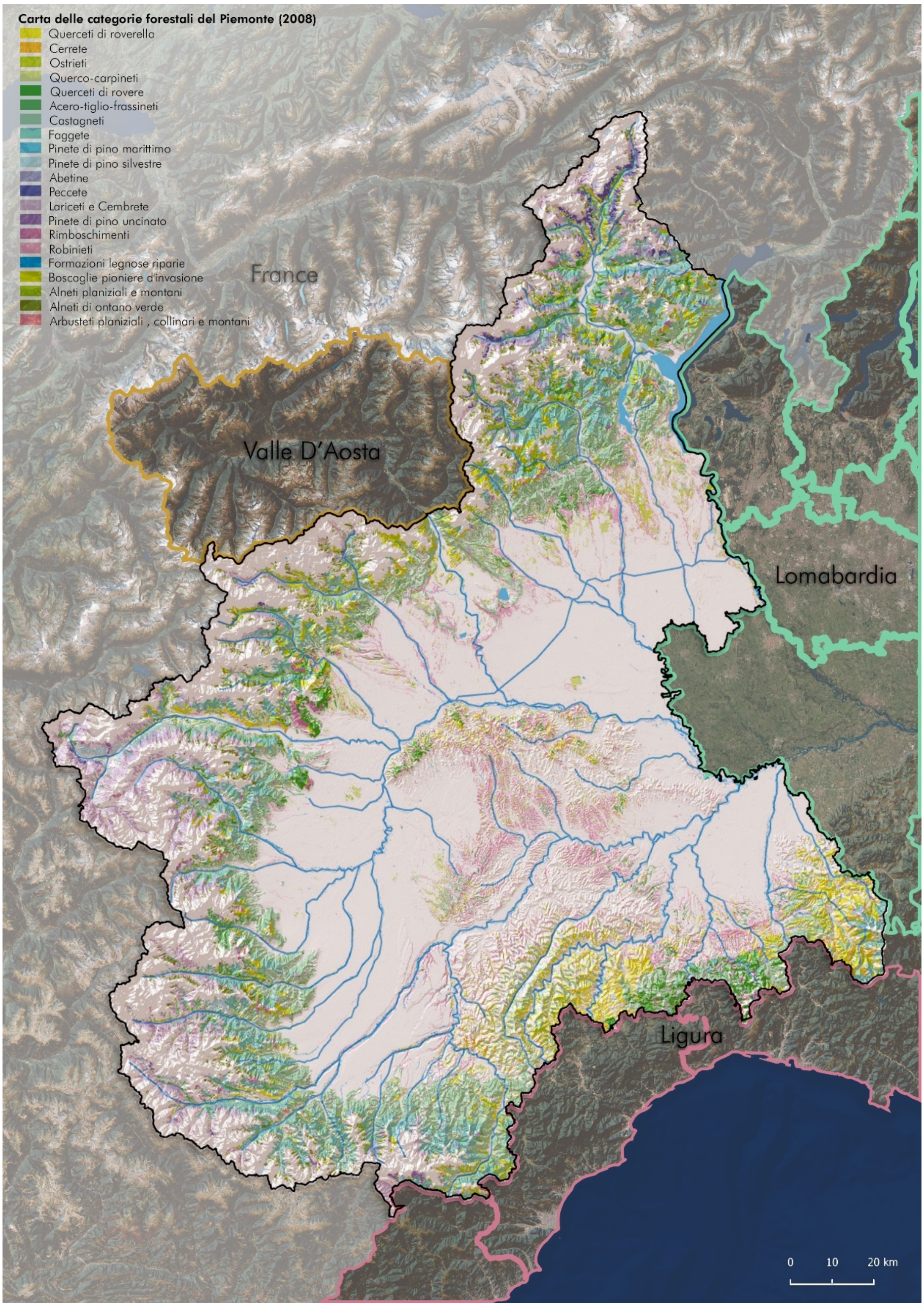


Figure 28 Forest type map(Camerano et al., 2008)

Is important to highlight that also if the forest is not into a protected area, the forest is important as equal, because it gives to the human a multitude of ecosystem services for instance cleaning the air by the pollutant or for regulating the micro climate condition, clean our water or provide us food. We could not live without these "ecosystem services", so is our duty to take care of all the woods and all the green areas as our own backyard. Because we are living in an ecosystem, and we as human beings, are involved in these complex networks of interdependent relationship with other species. We are part of the biodiversity and the extinction of a species may have unforeseen impacts, sometimes snowballing into the destruction of entire ecosystems(Chivian & Bernstein, 2010).

5.3.1 Land Use

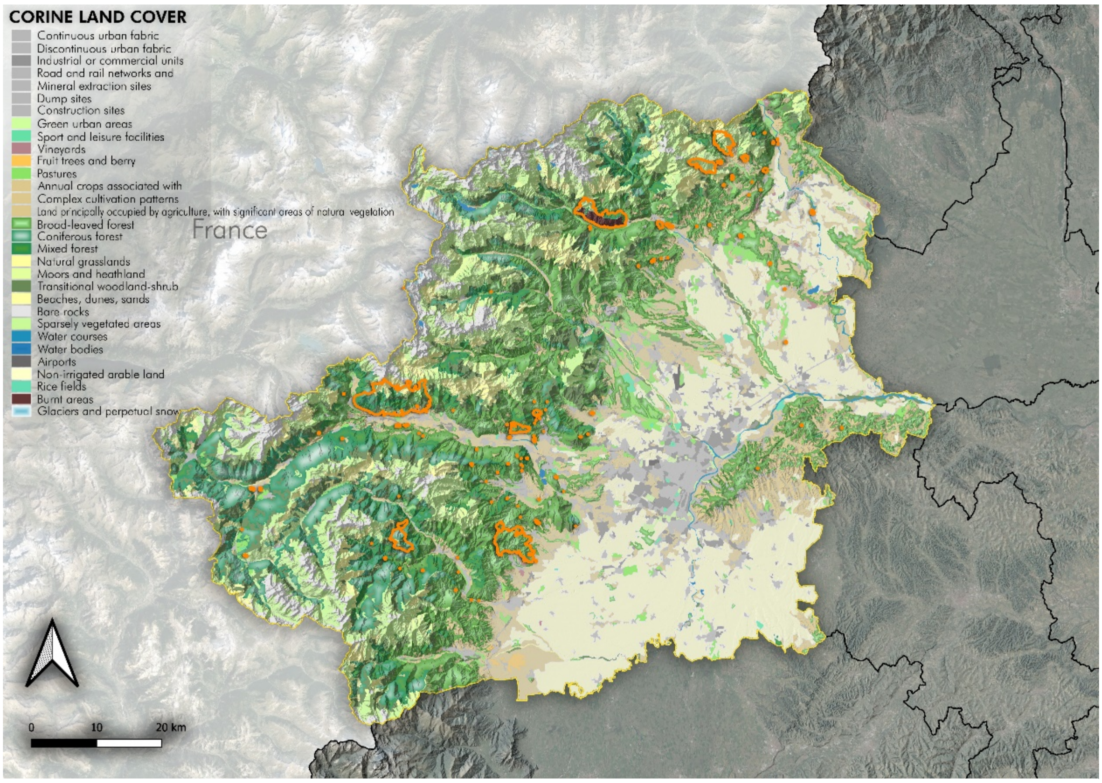


Figure 29 Type of vegetation

In the Mediterranean basin, human activity is the main source of fire ignition(Bajocco et al., 2010). But also land use is a factor that imply in a positive or negative fire behaviour in terms of fire number and size. At the same time different land cover mean different amount of fuel and its spatial distribution are the basic factor in explaining fire ignition and propagation(Burgan et al., 1998). Analysing the land use of the Province of Torino(Figure 29) there are a big agglomeration of residential and industrial area with few green areas. Going east is possible to recognize the hill of Torino characterized by broadleaf tree in the highest part, surrounded by agricultural land with a presence of important natural place. Is possible to recognize this land use type also in the collinear territory on the west. It's important to say that these kinds of lands are characterized often by grassy vegetation, that during a dry period became highly flammable due the low presence of the water in the plant. This condition can move rapidly the fire in other land use type, as the woods. In the at the foot of the mountain can see the prevalence of deciduous tree in all the province with the presence also of mixed forest. Meanwhile in the south west in the Maritime alps there is a strong presence of coniferous tree. Moving to higher altitude the vegetation is less dense and the territory is characterized by pastures and shrublands. This preface about land cover type is essential because land cover is one of the principal driver of intensity of the wildfire and rate of speed of the flame thought its effect on Biomass , vegetation structure and moisture content(Moreira et al., 2009).

5.3.2 Index derived from remote sensing

In the last époque GIS and remote sensing technology allowed the monitoring of change on the earth surface on even more spatial and temporal scale. Remote sensing data are the interpretation of the various spectral signal that after interact with the different type of surface go back to the sensor, the interpretation of those can help to understand many physical characteristics of that surface, among other things surface elevation , temperature, and aspect of the land use and vegetation(Melesse et al., 2007). In the natural environment can be used to define different species of the condition of the species. All the metrics the use the different spectral reflectance that deal with plant are called Vegetation index(VI). In this study the index are analysed are the NDVI(Normalized difference vegetation index) , VCI(vegetation condition index), and TCD(tree cover density), al that index are derived from an interpretation of remote sensing data and the next paragraph explain each one.

5.3.2.1 Landsat data preparation

To produce those indexes, it was necessary to elaborate two different quadrants of landsat 7 ETM +. Respectively in the image was the number of the quadrant were path 195 row 028 and 029, booth was necessary to cover the whole territory of the province of Torino. Was used this satellite for the reason that is the one that covers a large temporal arc. The first step was to download the image for the defined period, in this was taken in consideration the period since the October 2002 since

October 2017, so were downloaded the image with low cloud cover in October of each year. This long period was necessary to calculate the vegetation condition index.

After the download was necessary to correct the image of the Landsat through ENVI 5.0 software. Since the 31 May 2003, Landsat image are affected by a scan line error due the failure of the Scan-Line Corrector(SLC)(Figure 30). Was executed a gap filling process the used a triangulation method.

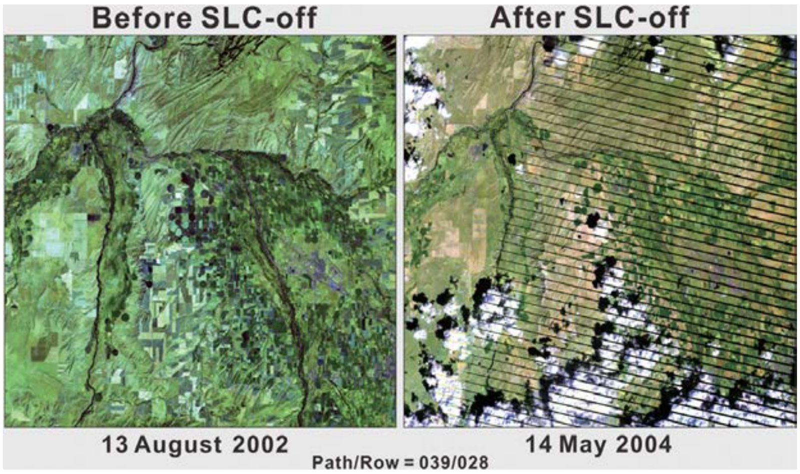


Figure 30 Scan line error example(Lee et al., 2016)

The next paragraph explains in detail the index used the study. These indexes are calculated using the different band of the Landsat 7 satellites, but each satellite have difference sequence of the spectral band, the next table (Figure 31) show the sequence of bands of Landsat 7 and Landsat 8; for the study was used the RED band the NIR and SWIR.

Landsat-7 ETM+ Bands (μm)			Landsat-8 OLI and *TIRS* Bands (μm)		
			30 m Coastal/Aerosol	0.435 - 0.451	Band 1
Band 1	30 m Blue	0.441 - 0.514	30 m Blue	0.452 - 0.512	Band 2
Band 2	30 m Green	0.519 - 0.601	30 m Green	0.533 - 0.590	Band 3
Band 3	30 m Red	0.631 - 0.692	30 m Red	0.636 - 0.673	Band 4
Band 4	30 m NIR	0.772 - 0.898	30 m NIR	0.851 - 0.879	Band 5
Band 5	30 m SWIR-1	1.547 - 1.749	30 m SWIR-1	1.566 - 1.651	Band 6
Band 6	60 m TIR	10.31 - 12.36	*100 m TIR-1*	*10.60 – 11.19*	Band 10
			100 m TIR-2	*11.50 – 12.51*	Band 11
Band 7	30 m SWIR-2	2.064 - 2.345	30 m SWIR-2	2.107 - 2.294	Band 7
Band 8	15 m Pan	0.515 - 0.896	15 m Pan	0.503 - 0.676	Band 8
			30 m Cirrus	1.363 - 1.384	Band 9

Figure 31 Band characteristics of Landsat 7 and Landsat 8 (Markham, 2013)

the Figure 32 is a false colour image were at various colours we assigned different bands respectively (Red, green, Blue = Near infrared, Red, Green). This band combination makes vegetation appear as shade of red; because vegetation reflects a lot of NIR light. Brighter red means healthier vegetation. Soil will range from white to green and brown, depending on moisture and organic content: water will range from blue to black. Urban area appears blue grey. Clouds and snow are white(NASA, 2022). This false colour map is a first approach to understand not just the distribution of the vegetation along the morphology of the territory, but also the health condition.

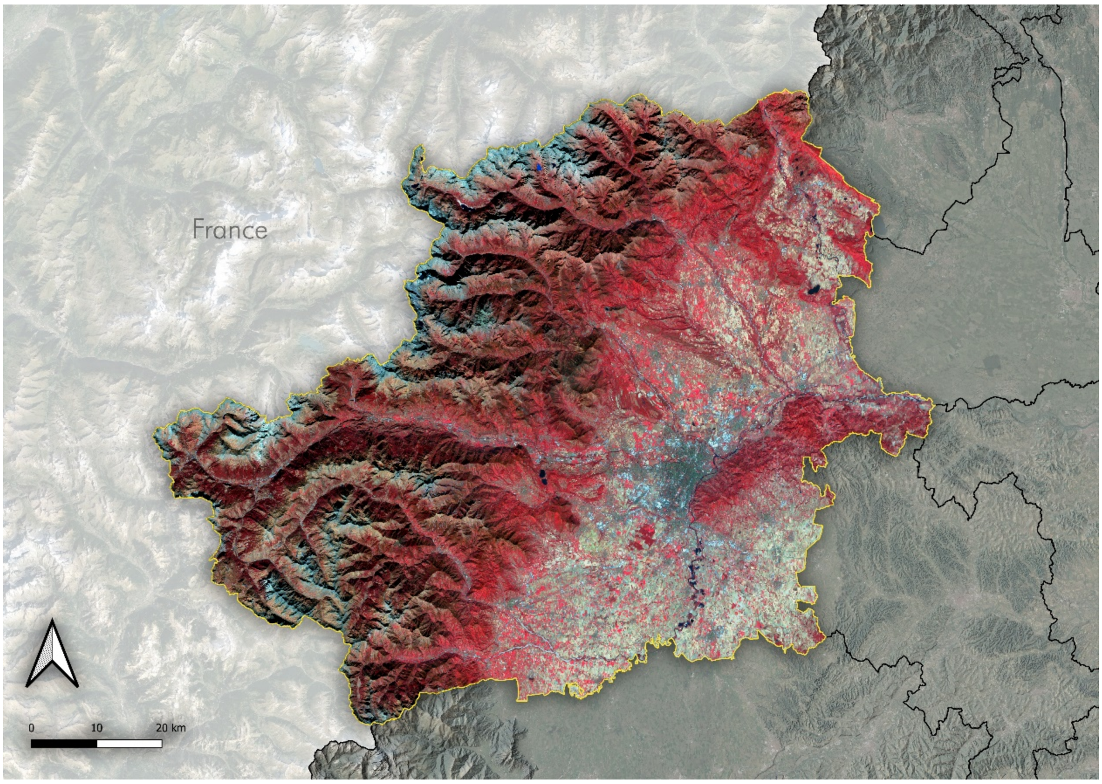


Figure 32 False color map created by the author on GIS from data of Landsat
(NASA, 2022)

5.3.2.2 NDVI (Normalized Difference Vegetation Index)

Most popular index used in the natural environment is the NDVI. NDVI is used to estimate the photosynthetically active biomass is then used the productivity of the vegetation, commonly defined as greenness(Tucker, 1979).This vegetation index is one of the many spectral ratio , an uses the percent reflectance of two bands of the electromagnetic spectrum de visible red(0.4–0.7 μm) and the near-infrared (NIR; 0.7–1.1 μm). Red radiance because is inversely proportional to the amount of chlorophyll present in the plant canopy and thus is sensitive to green and photosynthetically active vegetation. NIR because the radiance is sensitive to live vegetation and , to a lesser extent, the non-photosynthetically active vegetation(Tucker, 1979). Therefore the NIR have an high degree of intra and inter leaf scattering absorption in the plant canopy.

According to the formula, the density of vegetation (NDVI) at is equal to the difference in the intensities of reflected light in the red and infrared range divided by the sum of these intensities.

NDVI = (NIR- RED) / (NIR+RED)

In our case the two spectral bands were respectively band 4 and band 3 of Landsat 7. And was taken in consideration the NDVI value just some day before the big wildfire in Susa Valley in October 2017.

Because NDVI is a spectral evaluation of the photosynthesis taking place in a certain geographic region, the value typically rises during the grooving season and falls during the senescence period of the plant. Likewise, there could be intra and inter annual change because the environmental change like the rainfall and the temperature. These variation Cleary influence the vegetation vigour(Prasad et al., 2008). This index ranges from -1.0 to 1.0. Values near to zero are generally made up of rocks and barren soil, whereas negative values are primarily made up of clouds, water, and snow. Very small values (0.1 or less) of the NDVI function correspond to empty areas of rocks, sand or snow. Moderate values (from 0.2 to 0.3) represent shrubs and meadows, while large values (from 0.6 to 0.8)indicate temperate and tropical forest(EOS Data Analytics inc., 2022).The Figure 33 represent the NDVI of the province of Torino. By the fact that vegetative activity are partly dictated by water content; NDVI sometimes is combined with other index as surface temperature to monitor fuel moisture and fuel type(Chéret & Denux, 2007). Fuel is defined as the physical characteristic of the live and dead biomass that contribute to the spread, intensity and severity of wildfire(Keane et al., 2001). For the reason explained NDVI is widely applied for fire risk mapping but at the same time is used to identifies fire scar after the passage of a forest fire. It helps to evaluate the most vulnerable areas of a summer vegetation dryness information useful for the less accessible area.

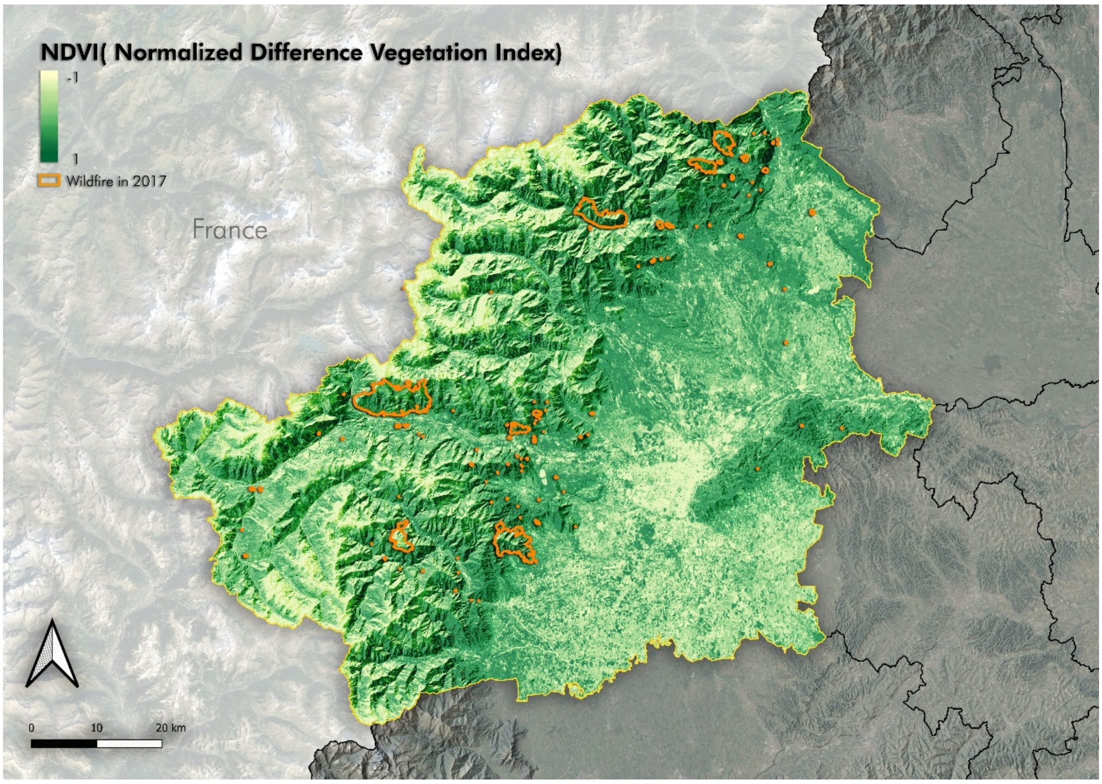


Figure 33 NDVI map created by the autor on GIS from data of landasat(NASA, 2022)

5.3.2.3 VCI Vegetation Condition index

The qualities of the combustible and the vegetation's moisture content play a key role in how a fire will behave and spread. To calculate the vegetation condition index (VCI) was necessary calculate before the Normalized Difference infrared index (NDII). The peculiarity of this index is: one the wavelength of near (NIR) and short (SWIR) are more sensitive to the absorption and variability of water content in the plant canopy. Second this index is more sensitive to humidity change compared to other index (Vallejo-Villalta et al., 2019). For that reason NDII value is subject to weather variations in precipitation and evaporation, tend to be lower during the dry season and higher during the rainy season. Hence NDII is promising proxy for root zone moisture content during dry spells when leaves are under moisture stress. Moreover, for its own spectral characteristic can represent the relationship between rainfall, soil moisture, and leaf water content, making it a crucial indicator for both hydrological modelling and drought assessment(Sriwongsitanon et al., 2016).

To obtain the NDII, the respective formula was used

$$NDII = (NIR - SWIR) / (NIR + SWIR),$$

where NIR is reflectance in near infrared (band 4 in Landsat 7 ETM+ and SWIR is reflectivity in medium infrared (band 5 in Landsat 7 ETM+). This index provides values between -1 and 1, where a value close to -1 indicates less water content (more dryness) and a value close to 1 indicates more water content (more moisture). Subsequently the Vegetation condition index (VCI) was calculated; this index was designed to extract the weather component from NDVI values(Kogan, 1995). In practice NDVI include two environmental signal: ecosystem , that display long- term changes in vegetation(determined by climate, vegetation typology, topography, etc.), and weather, defining intra and inter annual variation of each ecosystem in relation to the weather variation(F. Kogan et al., 2003). According (Vallejo-Villalta et al., 2019), to calculate VCI the NDVI was logically replaced by the NDII as it is the index to determine the moisture stress.

The formula applied is the following:

$$VCI_i = [(NDII_i – NDII_{min})/(NDII_{max} – NDII_{min})] x 100$$

Where VCIi is the vegetation condition index of the defined date; $NDII_i$ is the index for dryness on the date in question; $NDII_{min}$ is the index of minimum dryness from the 2002 – 2017 time period; $NDII_{max}$ is the index of maximum dryness from the 2002 – 2017 time series. The NDII value were calculated for each year in the same period (October)and for each pixel. Basically, the multi- year maximum and minimum NDII values were utilised as the benchmark for determining the upper (favourable weather) and lower (unfavourable weather) limits of the ecosystem in relation to the extreme weather condition. These boundaries characterize the carrying capacity of each pixel(F. Kogan et al., 2003). The VCI gives value between 0 to 100 and display the variability in vegetation condition, where value close to zero indicate severe dryness condition while close to 100 indicate an optimal humidity condition(Figure 34). In the last period forest fires are becoming fuel driven fires, for two reasons: first because there is more frequent end longer drought period due the climate change and second there are an increase of fuel load forest under a decreasing of forest management. For that reason it's important to know the fuel load and how dry is those vegetation to reduce fire risk, and take right decision in the complex environment of forest fire management, not only in the operational phase (tactical decision), but also in the emergency phase (strategic decision)(INFOCAM, 2020).

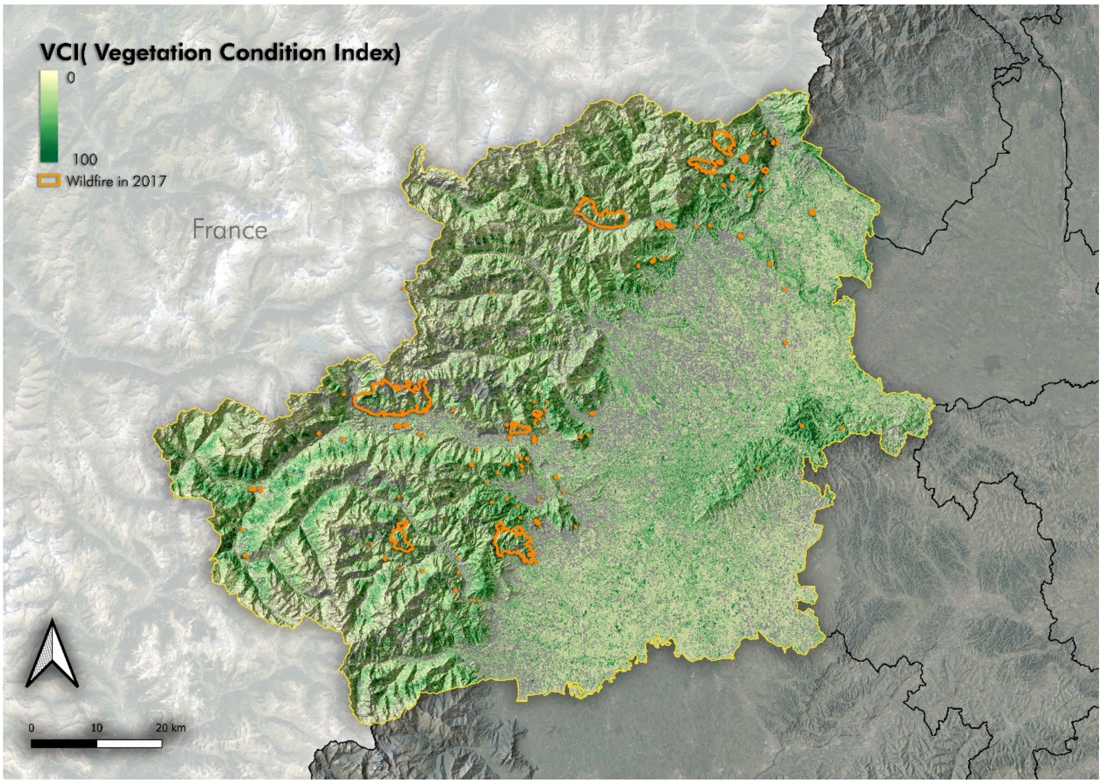


Figure 34 VCI map created by the autor on GIS from data of landasat(NASA, 2022)

5.3.2.4 TCD (tree cover density)

The tree cover density (TCD) is defined by the Copernicus High resolution Layer as the vertical projection of tree crowns to a horizontal earth's surface and give information on the proportional crown coverage per pixel(Tobias LANGANKE, 2018). This data is derived as reference data from the very high-resolution satellite (VHR) and from ortho photogrammetric image. The tree cover density is assessed by visual interpretation using a point grid approach and subsequently transferred to the high-resolution data by a linear function.

The Figure 35 below shows an ideal demarcation of tree cover on a multispectral high resolution image, then the second image shows the derived tree cover density in different colour , so different density value, within a 20m raster grid, that is the spatial resolution of the TCD data.

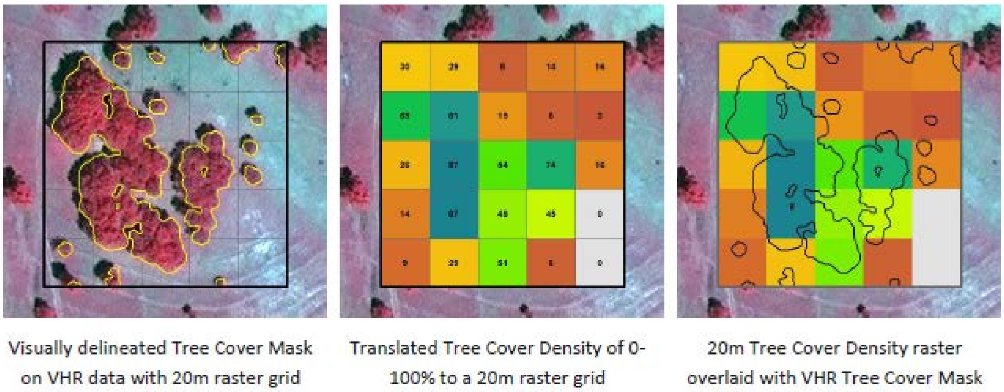


Figure 35 : Ideal-typical illustration of the Tree Cover Density product, delineated from a VHR satellite scene. Please note that the visual delineation on the left is only included for illustration purposes: it is not a product of the HRL Forest. © DigitalGlobe Inc. (2015)

TCD value in this case study was downloaded from Copernicus land monitoring service it has a spatial resolution of 20m, its value display the Tree cover density expressed in percentage from 0 to 100%(Figure 36). This data is referred to the year 2015, that was the first data available before the big fire in the 2017. Vegetation density is essential because determines the quantity and the shape of fuel load, in fact where tree are densely packed, the fire can spread from tree to tree, this phenomenon is called crowing(Forest Service, 2003). A fast crown fire typically burns all the fine fuel in the forest canopy into the mix with wind and topography. Crown fire caused by an excessive fuel accumulation are a serious risk from an ecological and human point of view. By the fact that this type of fire kills a big amount of tree, degrade soil, increase erosion and can destroy species habitat. The crown is just one part of the forest structure, in fact it has different layer of live and dead vegetation, known as surface and ladder fuel. The surface fuel are the grasses, shrubs and wood material lying on the ground and is important because in some specific condition surface fire reduce the probability that future wildfire will grow into crown fire. Ladder fuel are live and dead tree shrubs, lower branches, needle, vines, lichens .and all the biomass located over the surface fuels and at the bottom of the tree crown(Forest Service, 2003).

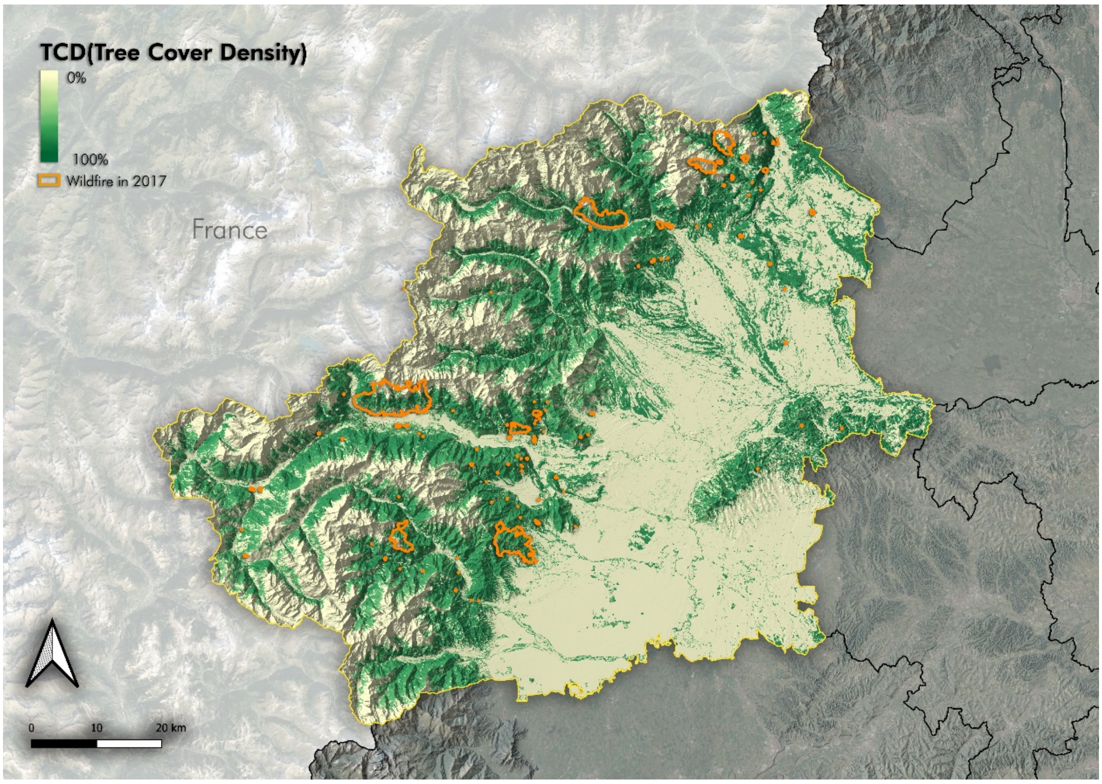


Figure 36 TCD map created by the autor on GIS from data Copenicus data

5.4 SOCIOECONOMIC (ROAD TRAIL HUMAN SETTLEMENT)

Climate change and is effect on nature, and the global change with an increase of demands of society and the general in the provision of ecosystem services are potentially going to apply a significant pressure on environment with a probable increase of forest fire in the future. Generally forest fire occur for two main reasons: the natural (mainly lighting) and anthropogenic causes, that are strictly connected to human activities. This probability of Human related fire is the result of direct and indirect presence of human activity in the landscape, like agricultural landscape fragmentation, agricultural abandonment and development processes (Martínez et al., 2009). Approximately 90% of forest fire in European are caused by people just a small part has natural causes.

The forest offer numerous ecosystems services and all of those are impacted by wildfire by the fact that long life-span of trees does not allow for rapid adaptation to environmental change(Lindner et al., 2010).Especially in the densely populated European mountain the danger of wildfire have an high significance for the maintenance of its ecosystem goods and services. Additionally in the alpine region is recognized an high economic value through sporting activity and outdoor recreation(Hall & Page, 2009). Furthermore, in the alpine area there are a dense infrastructure of routes, those help to promote tourism across the mountainous region, which is leading to an increase of development of touristic infrastructure and environmental infrastructure. This last are used in order to improve the public enjoyment of the natural heritage(Gambino et al., 2003). Those activity increase the number of tourist putting more pressure on forest and potentially increasing the danger of fire ignition (Arndt et al., 2013). As the transportation for the provision of living good and the access to services also affect fire ignition. According (Morrison, 2007) there is a strong relation between wildfire, where the 60% of fire occurs in a distance of 200m from road, almost the 20% in a distance between 200 -400m, and a 10% in a distance from 400m to 600m. At the same time this infrastructures have an effect on the forest in a positive way . Forest roads play a key role in the firefighting activities. In fact, all the ground based activities are strictly related to the presence of this road as access of fire edge(Laschi et al., 2019). Furthermore forest road are also associated with spatial pattern of ignition and fire perimeter , function as fuel brake and fire brake, supporting a safer and effective wildfire management(Thompson et al., 2021).Till know was analysed the correlation between the linear infrastructures with wildfire , nut in this study was taken in consideration also an aerial infrastructure, that is the human settlement. Those are interacting with the natural and seminatural landscape – excluding agricultural – creating the so called wildland urban interface (WUI). A lot of interaction between human and natural process are happening in the WUI and these interaction occurs into the settled area and in the surrounding natural landscape as well(Bar-Massada et al., 2014). Fire in the WUI is a considerable threat to human lives and houses(Spyratos et al., 2007). However, the settlement present in the WUI influence fire regime. Where these area constitute enough amount of wildland fuel loads, ignition Is prone , and the surround natural area are increasing the risk of wildfire. Compared to the natural fire, anthropogenic fire in the WUI are more frequent but tend to burn small area , by the fact that are early detected and supressed , and vegetation are more fragmented by the road(Bar-Massada et al., 2014).Looking at figure 37 the settlement infrastructure in the province is condensed I the flatten area, but along the whole territory there are numerous cities that going far from Torino and in higher elevation are becoming smaller. This small village often are surrounded by woodland and due the high presence of biomass, this area could be considered with a high ignition probability. Then about the linear infrastructure there are a dense road infrastructure along the plain, that for the majority cross agricultural land. Then the road basically follows the morphology of the landscape through the various valley that characterize the mountain area. About the trail the densest areas are the foothills area from north to south. Then is possible to recognise along the valley all the trail that start from the lower part and go to the peak of the mountain. The crowded area is the Susa valley due its morphological characteristic. Comparing the trail data with the wildfire database is possible to hypothesize that the origin of the ignitions is often human.

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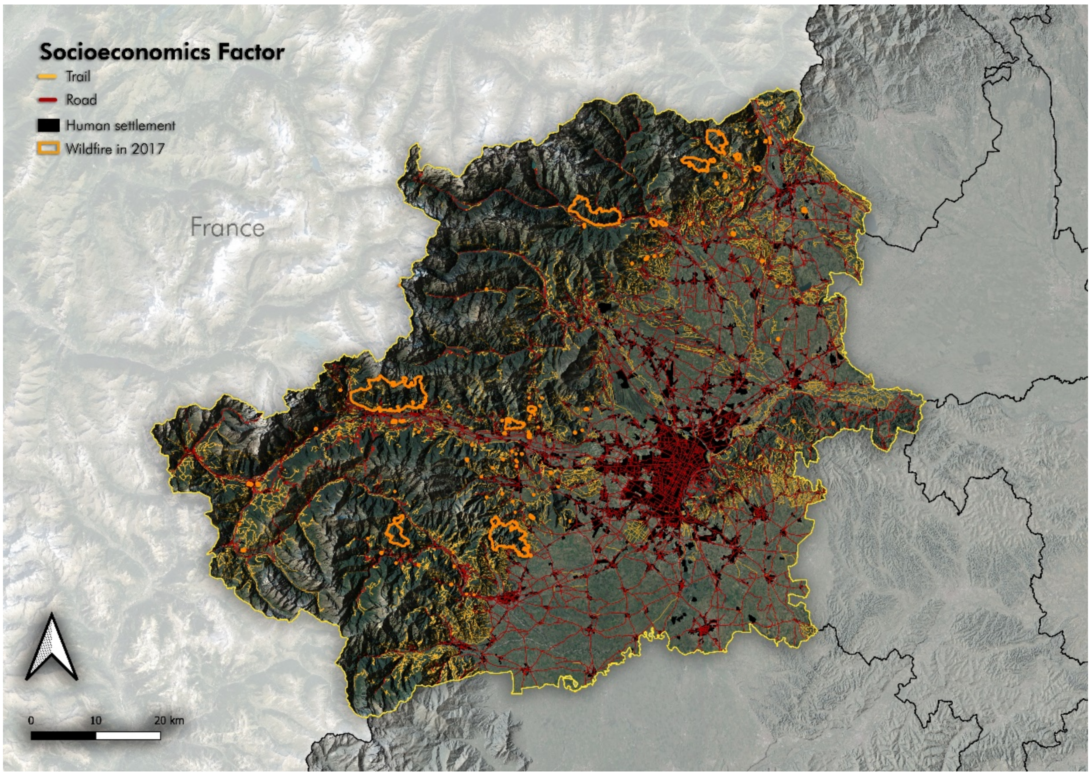

Figure 37 Soscio economic factor map created by the autor on GIS from data of(Regione Piemonte, 2022)

5.5 CLIMATE VARIABLES

Climate is the complex of weather condition that characterize a specific location along a year or in a long period time range. "Koppen" has distinguished five different climate zone based on what type of vegetation growth in a given climate classification region(Beck et al., 2018). Wildland fuel type characteristics such as fuel loading, fuel volume, continuity, moisture content, and size and shape are intimately associated with various climate zones(Benson et al., 2008). By the fact that there is different climate from each zone, respectively there will be different fire season, this start in lower latitude areas and then move poleward as the warm season progress. At the microscale, where fire, weather, fuels, and topography interact, synoptic scale forcing of weather results in the meteorological factors that are crucial to impacting fire behaviour(Benson et al., 2008). Furthermore daily change in relative humidity , temperature and wind may drastically change fire pattern(Veblen et al., 2002). Also the regional water balance is driven by those climate variable as precipitation and temperatures , which affect the change fire occurrence and severity through the alteration on fuel moisture(Mueller et al., 2020), meanwhile the wind influence more the rate of fire spread(Steinfeld et al., 2022). Looking at the future scenario with Intra and inter annual change on this climatic feature, we can expect a warmer spring and longer summer dry season and drier vegetation. Furthermore those conditions will reduce the winter precipitation will reinforce the tendency of the early spring snowmelt and a length of growing season, all this change will accentuate the condition favourable to the occurrence of wildfire with consequences on the start and on the length of fire season(Westerling et al., 2006).

5.5.1 Precipitation

Precipitation play a I important role on fire occurrence and fire behaviour by altering fuel moisture in dead and living vegetation. Moreover increasing of fuel moisture act to retard the rate of combustion , preheating of fuels, and ease of ignition(Benson et al., 2008). But this correlation between fire and precipitation can be positive or negative: positive corelation by the fact that spring precipitation enhances biomass productivity and allow fine fuel accumulation; Negative correlation because precipitation during the summer it increase fuel moisture that reduce fire spread(Koutsias et al., 2013). Before to understand the situation at the period in analysis is better to understand how weather has changed in the long period before the 2017. The Foundation Euro-Mediterranean Centre on Climate Change (CMCC) give to us an overview about the climate trend about precipitation, on seasonal and annual scale. The Figure 38 show the anomalies for the period 1989-2020, namely the difference between annual values and the average of the period, in reference to the annual precipitation values (expressed in percentages). The graph doesn’t show a significant trend.

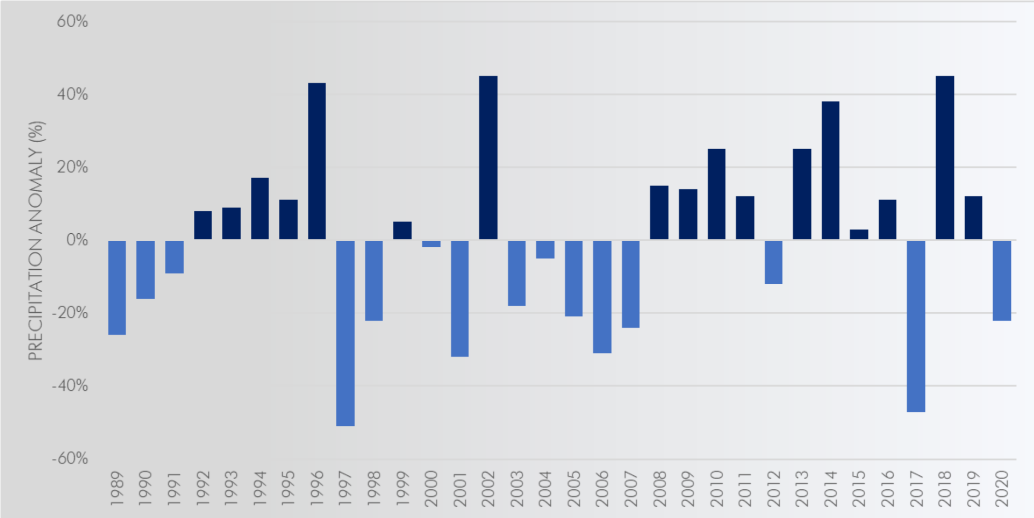

Figure 38 Precipiation anomalies in Turin (Mercogliano et al., 2021)

The next graph will show tree indicator: Consecutive **days without precipitation**: monthly average percentage of the maximum number of consecutive days without rain (i.e. with rain less than 1 mm).

Intense precipitation: number of days with very intense precipitation (equal to or greater than 20mm).

Maximum rainfall: the maximum amount of rainfall in a day.

From the graphs below (figure 39) that report the annual trend of the indicators over the period under study.

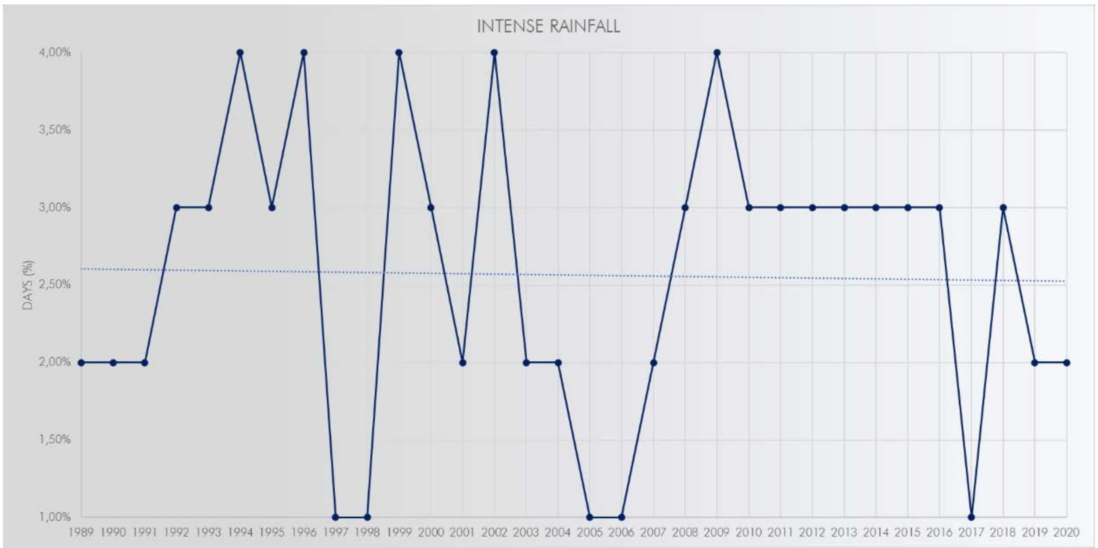

Figure 39 Intense rainfall in Turin in the period(Mercogliano et al., 2021)

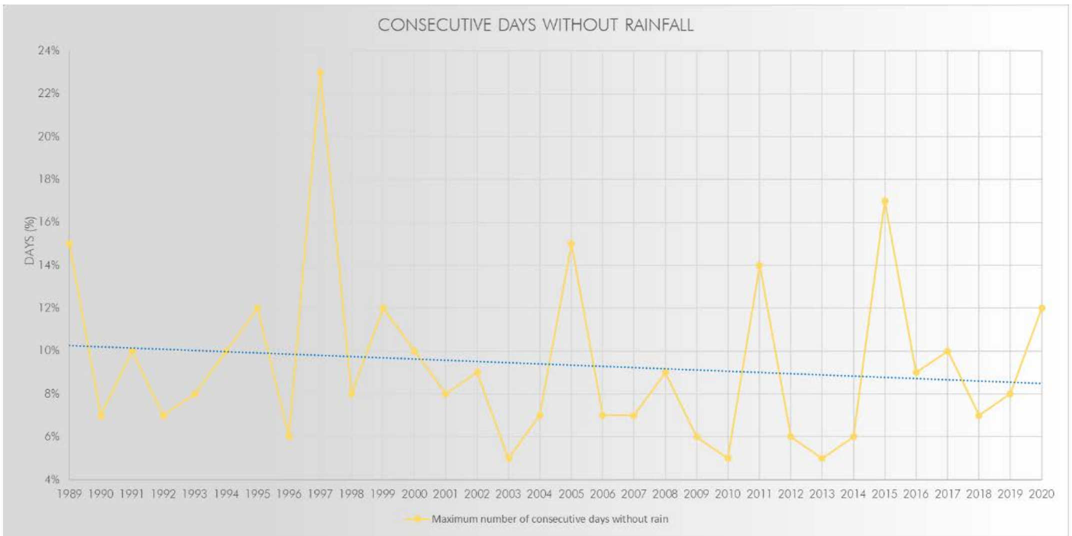

Figure 40 Consecutive day without rainfall in Turin in the period 1989-2020 (Mercogliano et al., 2021)

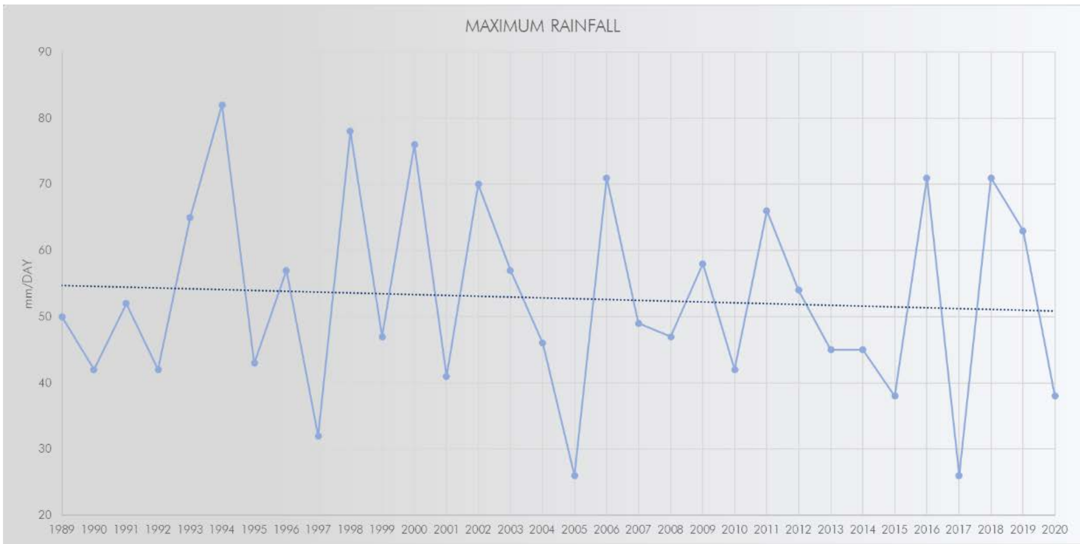

Figure 41 Maximum rainfall in Turin in the period 1989-2020 (Mercogliano et al., 2021)

The annual evolution relative to the intense precipitation (Figure 39) and the maximum number of day without precipitation (Figure 40) are both calculated in term of percentage of days per month, meanwhile the maximum precipitation (Figure 41) is expressed in daily maximum values.

The trend is not so significant for the first indicator, whereas the other two indicators are both characterized by a statistically significant decreasing trend over the period.

Then the following graphs will show the seasonal trend of the same indicator mentioned before.

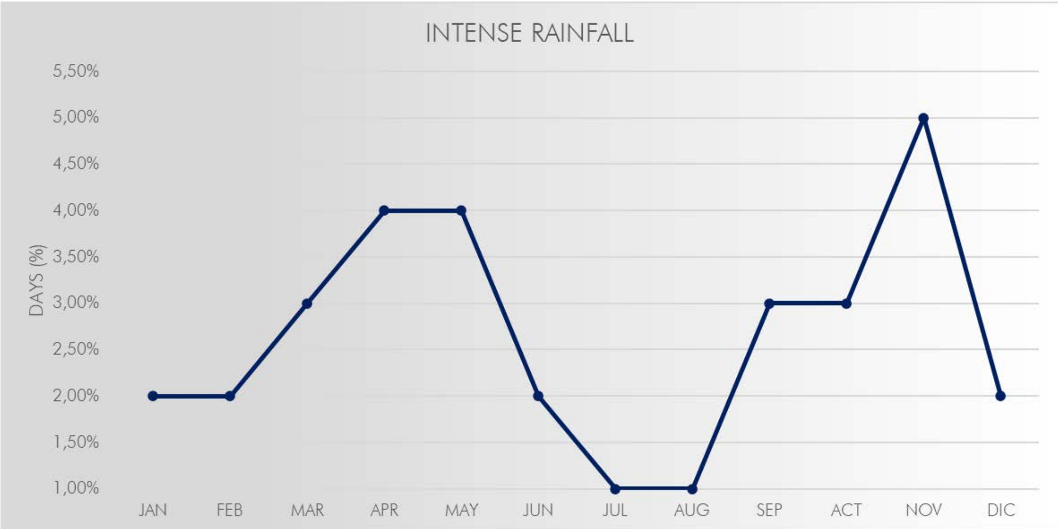

Figure 42 Monthly distribution of intese Rainfall in Turin in the period 1989-2020(Mercogliano et al., 2021)

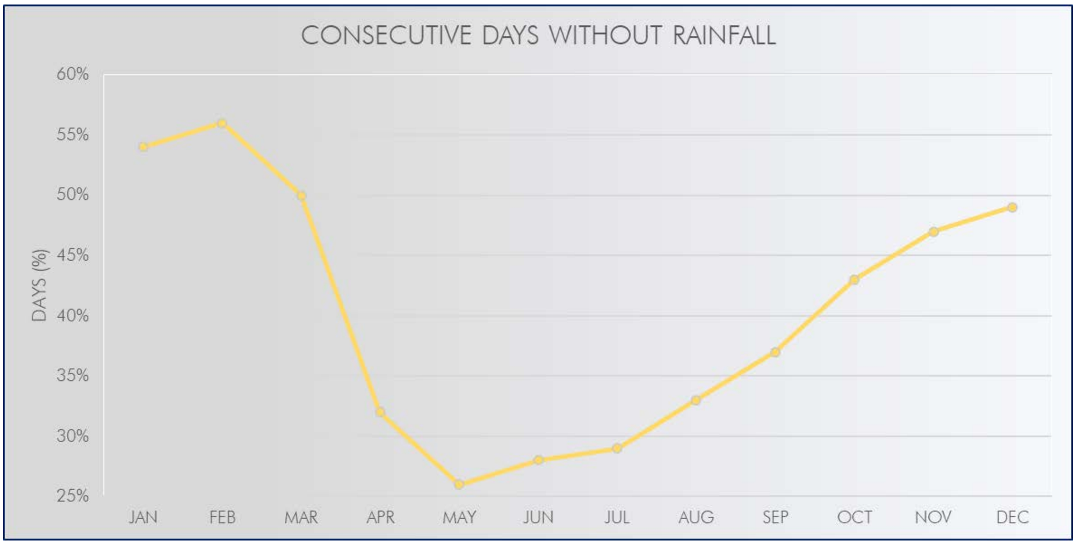

Figure 43 Monthly distribution of consecutive day whitout precipitation in Turin in the period 1989-2020(Mercogliano et al., 2021)

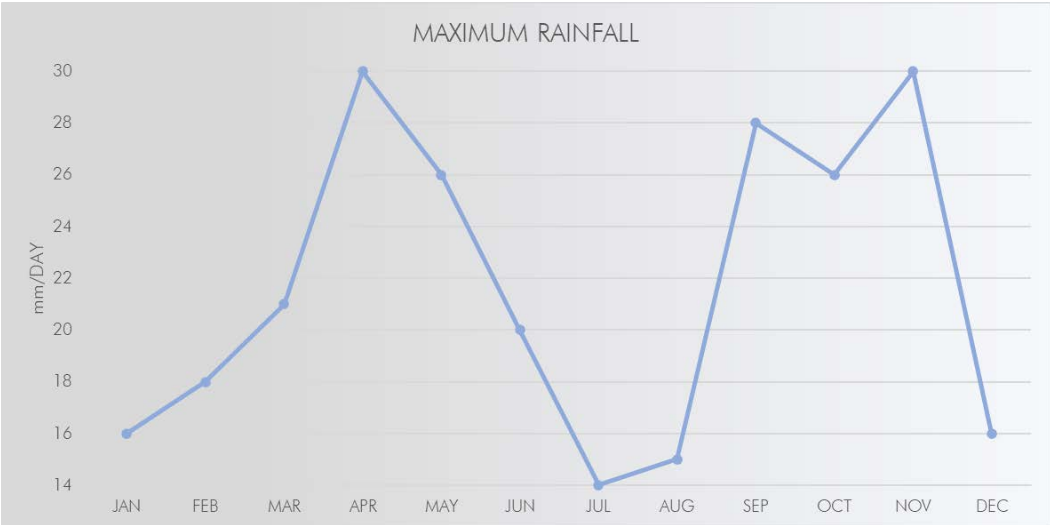

Figure 44 Monthly distribution of Maximum rainfall in Turin in the period 1989-2020(Mercogliano et al., 2021)

The most significant graph is the one relative to the day without precipitation (Figure 42), the maximum value is reached in the winter month and a minimum value in May. On the seasonal scale it is observed a maximum number of days without precipitation of about 28 days in the winter season and about 17 days during the summer. Intermediate values occur during the spring and autumn season. This long period without rain have a direct implication of vegetation and on water cycle, but pessimistic scenarios could bring indirect effect on human increasingly worse. Prolonging the wildfire season and increasing at the same time the probability of ignition of a fire.

For the study was taken in consideration the cumulative precipitation for each pixel in the period taken in consideration. The data was downloaded from the "Worldclim " dataset develop by the Climatic Research Unit of the University of East Anglia, the data are collected monthly and are available in four spatial resolutions, the one used for the study is the most detailed that has a spatial resolution of 2,5 min (of a longitude/latitude degree) that at the equator is about 4.5 km(Harris et al., 2014). The following figure 45 was developed on Arcgis PRO calculating the cumulative value expressed in millimetre of each pixel in the period October 2016-17 before the occurrence of the big fire in the province(Busico et al., 2019).Then the raster was resampled using a bilinear interpolation, and modifying the spatial resolution to 30 m. In the province of Torino, the maximum value in reached along the alps with a value of almost 1100 mm that decrease according the elevation, in fact in the plain it reached the lowest value.

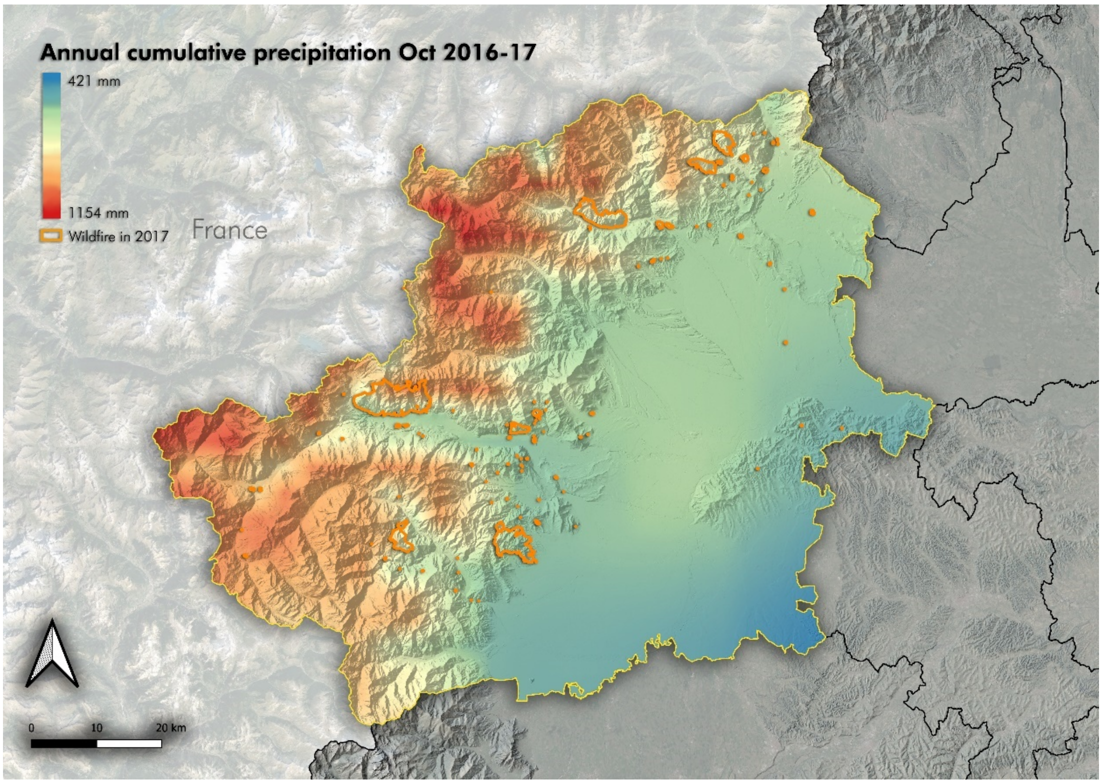

Figure 45 Cumulative annual precipitation in the period October 2016-2017 resampled on GIS from (Harris et al., 2014) spatial resolution 30x30

5.5.2 Temperature

A part of the solar radiation that is coming on the earth surface is not reflected is absorbed and converted to heat. Due the greenhouse gasses the this global temperature is rising with an increase as well as of frequency, intensity and duration of heat waves and droughts, factors that are often influencing forest fire occurrences(Kirsanov et al., 2020).Heat is a crucial aspect of the fire triangle and in fact this energy goes from the hotter object to the colder. This heat is decisive at the beginning of a fire where there is the preheating phase of combustion. As the result warmer temperature heat forest fuels make more probable the ignition from a natural or some anthropogenetic source(Benson et al., 2008). Temperature then follows its own daily cycle that can increase the fire activity during the hottest part of the day and reduce it during the coolest part of the day. This cycle is called temperature inversion that start during night time and generally bring to a decrease of fire activity. Also, the distribution of the temperature is a significant element

connected to fire behaviour, these distributions can be horizontal or vertical. The level of atmospheric stability describes vertical temperature disparity in the atmosphere. When the air became cool to the increasing of heigh from the surface of the earth, it can cause an unstable atmosphere, that can lead to thunderstorm or cloud development as air is allowed to move upward from the surface(Benson et al., 2008). This unstable ai can increase fire behaviour by allowing weaker wind to mix down to the surface crating horizontal roll vortices and higher fire spread rate(Haines, 1982).
Higher temperature then can Enache evaporation which reduces surface water and dried out soil and also vegetation. This influence of high temperature and drought make then vegetation physiologically weaker and dried. In Younger tree this negative impact is less observable. However, the effect is more significant in Middle Ages tree since the require more water. dry. In younger trees, this negative impact is less observable. But the effect is more significant in middle-aged trees since they require more water. Conifer species with shallow, plate-like roots, like the spruce, are among the forest tree species that are most vulnerable to damage(Živanović et al., 2020). Hence high temperature absence of precipitation and droughts lead a reduction of tree vitality , making circumstance ideal for the occurrence and spread of fire. Forests receive considerable direct and indirect damage, which is frequently unforeseen and has broad repercussions. For planning for the future is essential to know the past for understanding possible trend. The Figure 46 show the anomalies for the period 1989-2020, namely the difference between annual values and the average of the period, in reference to the annual temperature values (expressed in Celsius).

The graph show is a statistically significant growth trend since the year 2013 this process is more observable.

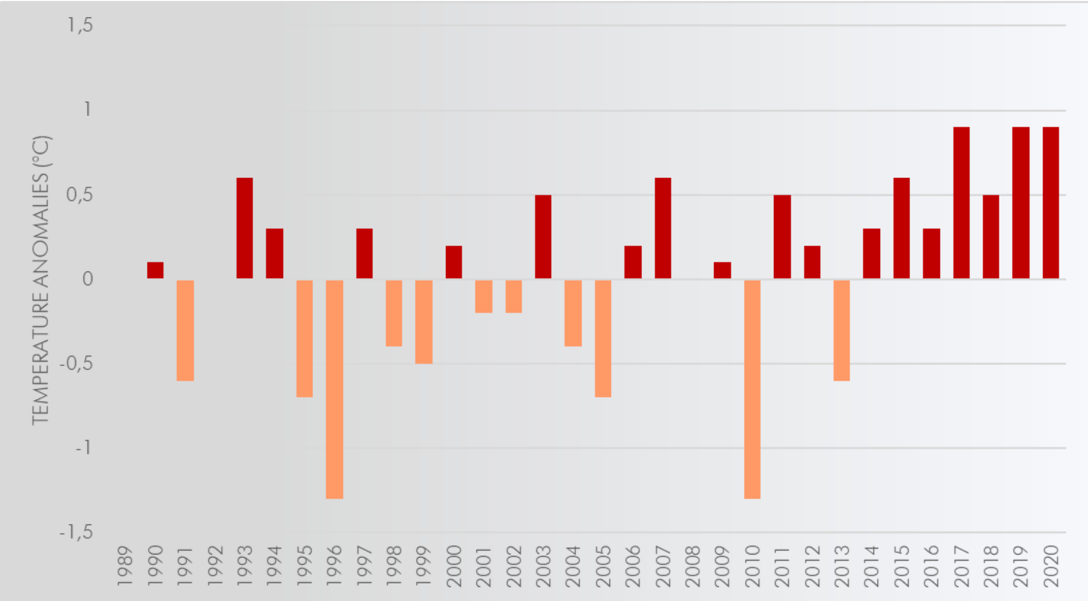

Figure 46 Temperature anomalies in Turin in the period 1989-2020(Mercogliano et al., 2021)

Then other indicators are useful like:

Hot nights. Indicates the number of days with a minimum temperature greater than 20 ° C.

Very hot days. Indicates the number of days in which the maximum daily temperature exceeds 25 °

Cold days. The number of days the temperature drops below 0 ° C.

The graph below (Figure 47) shows the annual cycle for the indicators in the period 1989-2020 reporting a significant trend in the warm night.

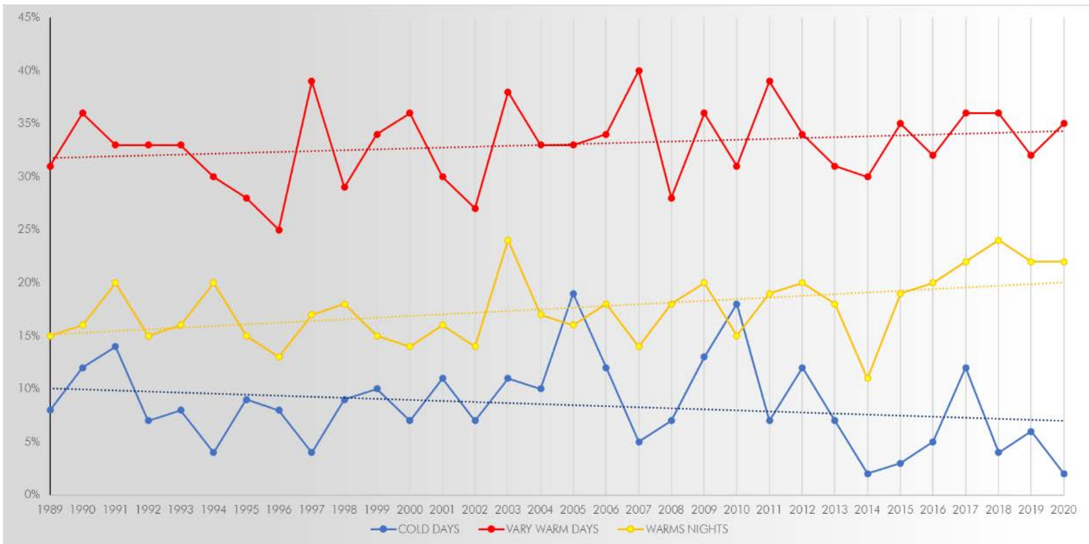

Figure 47 Hot night, very hot day and cold days in Turin in the period 1989-2020(Mercogliano et al., 2021)

For the study was taken in consideration the mean temperature, the data was downloaded from the "Worldclim " dataset develop by the Climatic Research Unit of the University of East Anglia , with a spatial resolution of 2,5 min (Harris et al., 2014). The data are collected monthly and represent the mean temperature expressed in Celsius so on Arcgis Pro through a raster calculation was executed the mean of the twelve raster (one year) taken in consideration. After that the output was resampled with a spatial resolution of 30m using a bilinear interpolation method. By the fact that temperature is strictly connected to elevation of the surface in the province along the highest territory we find the lower temperatures with a mean of – 4 C° degrees, then temperature rise going to the lowland, with a temperature of 14 C° degrees as it showed in the Figure 48.

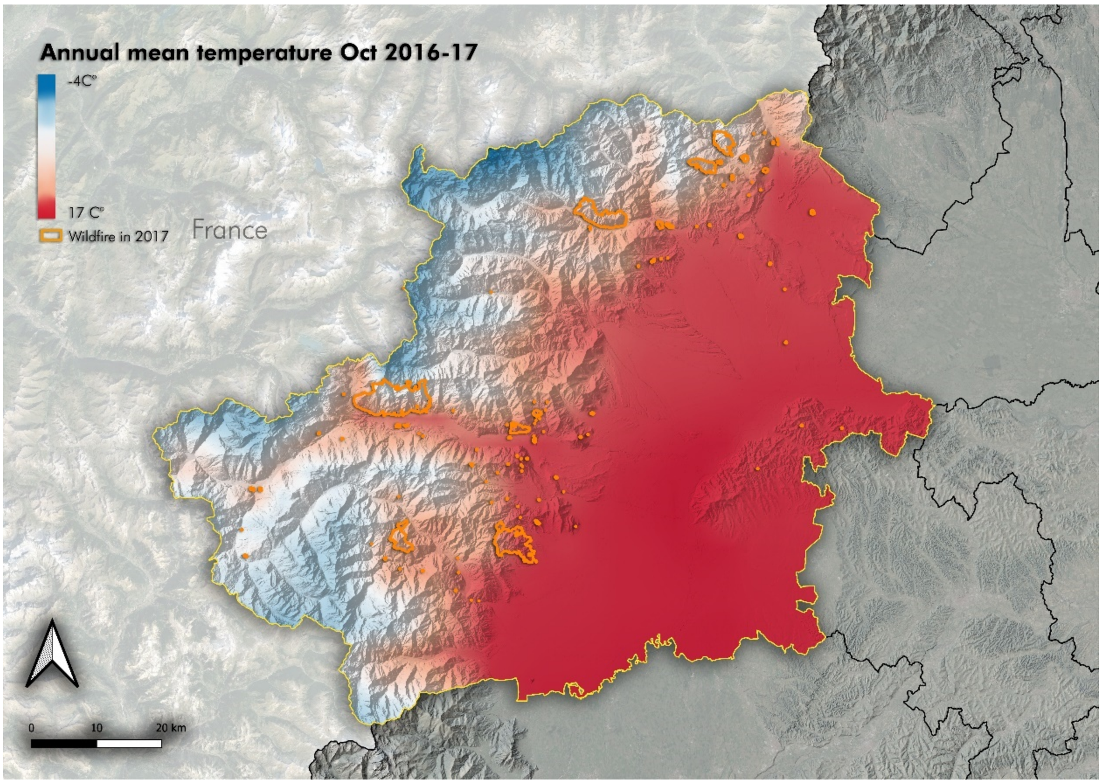

Figure 48 annual mean temperature in the period October 2016-2017 resampled on GIS from (Harris et al., 2014)

5.5.3 Wind

Aire flow across the earth surface has an effect on the fire environment both before and after ignition. Speed and direction of a fire are significantly influenced by the wind. Wind may impact forest fire behaviour by:

Moving humid air away from fuels enhancing their drying process or on contrary moving moist air over the fuel increasing moisture content.

Carrying burning embers through the convective air igniting fire along the perimeter

Bending the convection column, which encourages preheating of unburned fuels in front of the fire.

Suppling fire with a constant flow of oxygen(Nova Scotia, 2021).

But not all the air movement are influencing fire at the same way, lower from the surface are more impacting than higher airflow. For that reason is important to underline that different wind are moving in different altitude at the same time as different duration and there are acting at differ scaly from a synoptic scale passing through the mesoscale to the microscale.

General winds are caused by broad scale pressure gradient between high- and low-pressure system. And they may be influenced and modified in the lower atmosphere by topography and vegetation.

Local winds know as thermal, convective wind are the product of local temperature differences, there are affecting just a small part of territory and differ from the general wind in that they are only limited near the surface and they are regulated by the intensity of the daily solar cycle. In this category are recognized slope winds, that can move up slope and downslope and valley winds that are similar and linked to the previous ones by the fact that they precede some hours slope winds and are faster.

At least Surface wind measured near the earth surface at 10 meters upon the average vegetative surface and a distance equal to at least 10 times the height of any obstruction to minimize the distorting effects of local obstacles and terrain(NWCG, 2021). This last Is the one that with it's speed and direction are affecting the rate of propagation of a fire and the direction.

Thanks to the morphology almost all masses of low/ high meteorological pressure that are coming from the ocean and from the north Europe are blocked by the alps. This create a phenomena called also calm of wind that follow an increasing trend since the 2000 , orographically conformation lead to a poor flow and exchange of air mass with consequent stagnant atmosphere and it is a determinant factor for the concentration of pollutant in the flatten area(ARPA PIEMONTE & REGIONE PIEMONTE, 2020). The wind condition is represented in the Figure 49 below where are showed the mean speed of the wind in m/s, 10 m above the surface, in the year from October 2016 to October 2017. The Data was downloaded from the Terraclimate datasets that are collecting monthly climate and climatic water balance for global terrestrial surfaces from 1958-2019 and it's spatial resolution is 2.5 min(Abatzoglou et al., 2018).

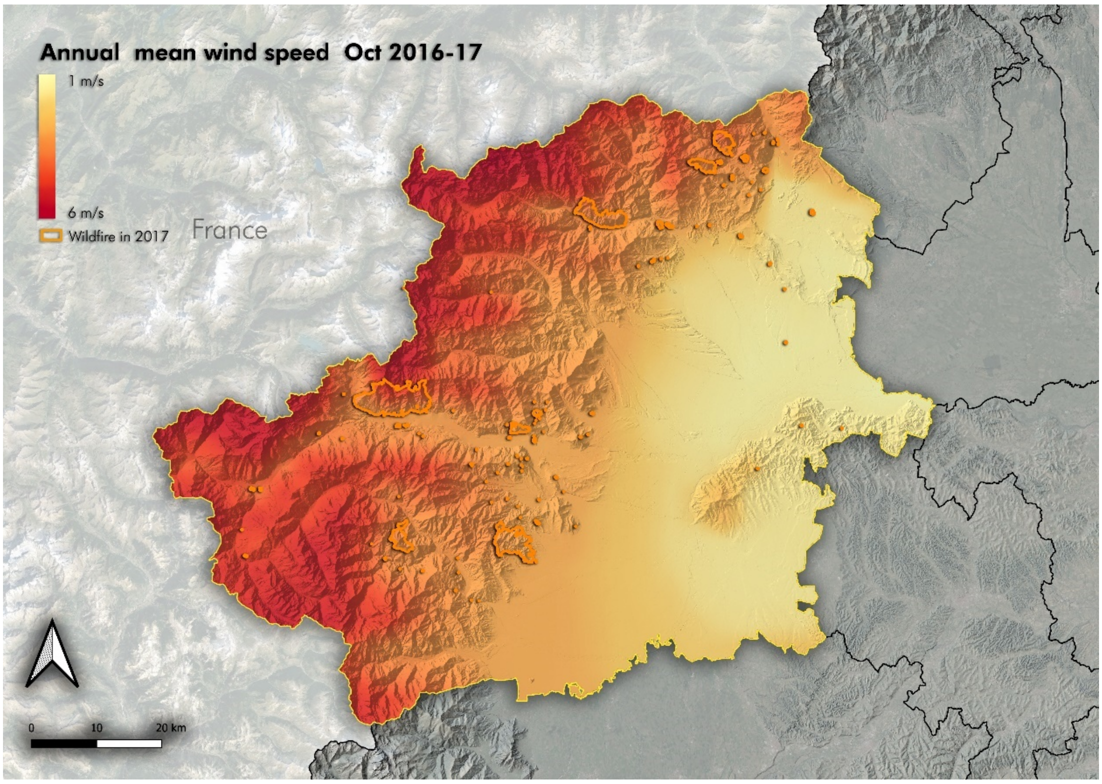

Figure 49 Annual mean wind speed 10 m above surface in the period October 2016-2017

6 METHODOLOGY

The study applies a model namely Geographic information system Multi-Criteria Decision Analysis (GIS- MCDA) integrated with Analytic Hierarchy Process (AHP)

6.1 GIS- MCDA

GIS software emerged in early 1980's offering the power of automating, managing and analysing a multiplicity of spatial Data. Many applications of GIS provide information necessary for the decision-making in diverse areas including natural resource management, environmental pollution and hazard control, regional planning and utilities management(Jankowski, 1995). When we are dealing with spatial planning, decision is taken considering several perspectives, because third part are taking part in the decision-making process. These processes affect several stake holders like organizations, governmental, environmental and private corporation. Decision is taken to reach medium and long goals and need to be based on concrete evidence, for that reason a lot of spatial data is needed. Hence this type of data depends on a large number of criteria is useful to use integrate GIS with MCDA that is a component of a SDSS (spatial decision support system)(Antão & Carrilho, 2015)

MCDA is a potential spatial decision support tool; the objective of the MCDA is to assist decision-makers in choosing the best alternative from a number of feasible alternatives under the presence of multiple-choice criteria and diverse priorities. The decisions are made by judging options against one or more relevant factor for the issue. They are the outcomes of an intellectual process of weighting process. Therefore, the MCDA used, had to be intuitive in the decision thinking, requiring weight assigning, and an intuitive structure of the decision. The MCDA method found to cover these points was the Analytic Hierarchy Process (AHP)(Antão & Carrilho, 2015)

6.2 ANALYTIC HIERARCHY PROCESS (AHP)

The MCDA approach used in this thesis is the Analytical Hierarchy Process (AHP). The AHP was developed by Tomas L. Saaty in 1980, and as a multi-criteria decision-making analysis arranges the factors in a hierarchic structure.

The process is about breaking a problem down and then aggregating the solutions of all the subproblems into a conclusion. It facilitates decision making by organizing perceptions, feelings, judgments, and memories into a framework that exhibits the forces that influence a decision(Saaty, 1994). ("KarpakB Bayazit an AHP application in vendor selection") The MCDA Deal with problem by designing weighing and ranking decision and alternatives. The essential logic behind determining each factor's significance is based on the knowledge and experience of the expert. To help this process the AHP method is used to generate a weighting value by pairwise comparison of each factor and combination of factor, and defining a liner hierarchy importance among the factor(Busico et al., 2019). The comparison is a numerical representation of the relationship between two element and follow a fundamental scale developed by Saaty ,that goes from 1 to 9 and give a value about the relationship between the element (Figure 50).

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong importance	Experience and judgment strongly favor one activity over another.
7	Very strong or demonstrated importance	An activity is favored very strongly over another, its dominance demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit.
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix.
1.1–1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9.

Figure 50 Fundamental scale (Saaty, 1994)

When weights have been derived, the factors are combined according to :

$$S = \sum_{i=1}^{n} W_i * X_i$$

Where S is the factor to be generated (output), W_i is a weight of factor *i* X_i is a factor *i* (input)(Walelegn & Mengist Zeleke, 2019).

The study was based on ten factor criteria (Proximity from settlement, proximity from road, proximity from trail, aspect, slope, elevation, temperature, wind, precipitation, vegetation type, an then were used three different factor derived from remote sensing that were used to have three different final output, respectively are the VCI

(Vegetation Condition Index), NDVI (Normalized Difference Vegetation Index) and the TCD (Tree Cover Density)

The Flowchart below (figure 51) show the source of the different factor used for the development of the fire risk map. These factors were then categorized in five level from one to five, so basically all factors were normalized. The earth of this layer was weighed and then combined to produce the final result: Finally, was validated using firefighting dataset.

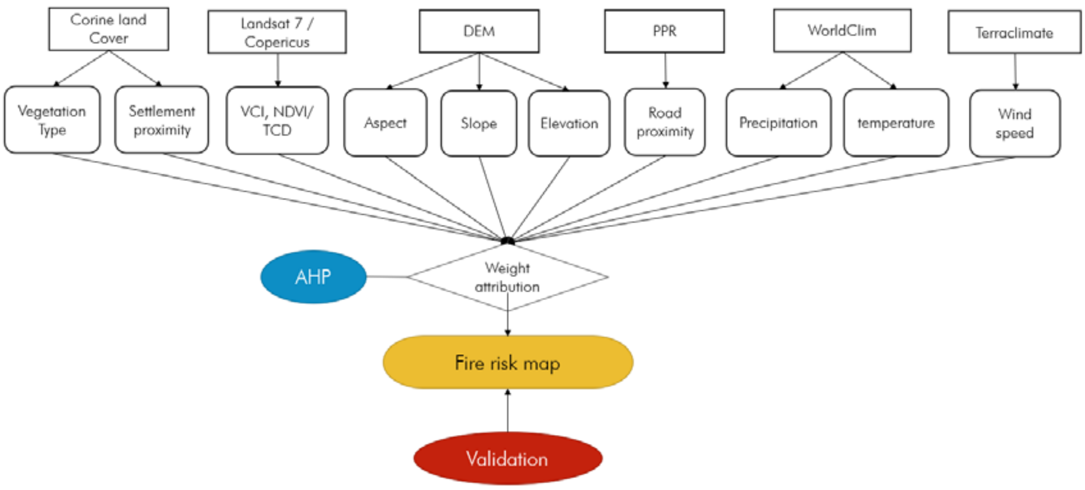

Figure 51 Workflow of methodology applied

6.3 FACTOR CRITERIA

Factor criteria are the maps created following a set of rules that contribute to the incident of wildfire. This rules are based on previous studies of different fields; criteria rules (ranks) were created based on literature review depending on the rules each factor was normalized from one to five were one is lower risk for the spread of the fire and five is the higher risk. Classes and ratings are shown in Table 1 . Elevation was classified according (Hayes, 1942) and(Gigović et al., 2018), considering the tendency of fire ignition al lower elevation. For the Slope was classified according (Walelegn & Mengist Zeleke, 2019), for the Aspect the was considered the general characteristic of a lower ignition in north facing slope(Busico et al., 2019). In the land use was considered only the vegetation , the urbanized / impervious surface was not considered , because the study is focused on fire risk in open territory, the different value were classified according (Gigović et al., 2018; Walelegn & Mengist Zeleke, 2019). The NDVI was classified to understand the vegetation typology, density and condition according(Akbar et al., 2019). The VCI will indicate the moisture content of vegetation so higher value wil bring lower risk of ignition(Vallejo-Villalta et al., 2019). with tree cover density higher density means more biomass to burn so higher risk to manage and control the fire(Walelegn & Mengist Zeleke, 2019). The Human factor was categorized according the general cocept that the risk is inversely proportionate to the distance(Busico et al., 2019). After weighted al the factor were summed and a fire risk map were generated. Last

Criteria	Data type, format, and Source
Elevation	DEM 25m*25*m, Raster file from Geoportale Piemonte http://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/DTM25/DTM25.zip
Slope	Raster file generated from DEM (25m*25*m)
Aspect	Raster file generated from DEM (25m*25*m)
Land Use	Corine Land cover, Shapefile from Copernicus Land Portal (2018) https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download
NDVI	Raster file generated from Landsat 7 ETM+ Image (30m *30m) https://earthexplorer.usgs.gov/
VCI	Raster file generated from Landsat 7 ETM+ Image (30m *30m) https://earthexplorer.usgs.gov/
TCD	Tree cover density map, raster file from Copernicus Land Portal (2015) Mosaic table(E40N20) https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/
Road Proximity	PPR - AUTOSTRADE E STRADE STATALI, REGIONALI E PROVINCIALI (TAV. P4), Shapefile from Geoportale Piemonte http://www.datigeopiemdownload.it/direct/Geoportale/RegionePiemonte/PPR/grafo_viabilita_mar2010.zip
Trail proximity	Ppr - Rete sentieristica (tav. P5) Shapefile from Geoportale Piemonte https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/PPR/rete_sentieristica.zip
Settlement Proximity	Corine Land cover, Shapefile from Copernicus Land Portal (2018) https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download
Precipitation	Total precipitation , raster File , (mm) total montly precipitation, from Worldclim (4.5km* 4.5km)(October 2016- 2017) https://www.worldclim.org/data/monthlywth.html
Temperature	mean temperature , raster File calculated in GIS , (C°) average minimum and maximum montly temperature , from Worldclim 4.5km* 4.5km)(October 2016- 2017) https://www.worldclim.org/data/monthlywth.html
Wind	Wind Speed , raster file , (m/s) average monthly wind speed from Climatology Lab (4.5km* 4.5km)(October 2016- 2017) https://www.climatologylab.org/terraclimate.html

Table 1 criteria, data type , format and souce of the factor used

Criteria	Intesity of risk				
	1	2	3	4	5
	Very low	Low	Moderate	High	Very high
Elevation	>800 m	600-800 m	400-600 m	200-400 m	0-200
Slope	0-5°	5-15°	15-25°	25-35°	>35°
Aspect	0-70°	70-140°	>280°	210-280°	140-210°
Land Use	141,142,211,221 ,222,332	231,242	321,322,312	333,324,313	243,311
NDVI	-0,14 - 0,14	0,14 - 0,18	0,18 - 0,27	0,27 - 0,36	0,36 - 0,74
VCI	100 - 80	80 - 60	60 - 40	40 - 20	20 - 0
TCD	0 - 20%	20 - 40 %	40 - 60 %	60 - 80 %	80 - 100 %
Road Proximity	>400 m	300-400 m	200-300 m	100-200 m	< 100 m
Trail proximity	>400 m	300-400 m	200-300 m	100-200 m	< 100 m
Settlement Proximity	>400 m	300-400 m	200-300 m	100-200 m	< 100 m
Precipitation	1154 - 1337 mm	971 - 1154 mm	788 - 971 mm	604 - 788 mm	421 - 604 mm
Temperature	-4,2 - -0,15 C°	-0,15 - 3,9 C°	3,9 - 7,9 °	7,9 - 12,03 C°	12,03 - 16,09 C°
Wind	1, 06 - 2 m/s	2 - 2,9 m/s	2,9 - 3,8 m/s	3,8 - 4,7 m/s	4,7 - 5,7 m/s

Table 2 Ranking rinsk of the factor

The number in the classification of the land use represent the code of the Corine land cover(Table 3) .This nomenclature is a 3-level hierarchical classification system and has 44 classes at the third and most detailed level(Kosztra György et al., 2017). At all the other class that are not present in the upper table 2 was assigned the lower risk value.

Level 1	Level 2	Level 3
1 Artificial surfaces	11 Urban fabric	111 Continuous urban fabric
		112 Discontinuous urbanfabric
	12 Industrial, commercial and transport units	121 Industrial or commercialunits
		122 Road and rail networks and associated land
		123 Port areas
		124 Airports
	13 Mine, dump and construction sites	131 Mineral extraction sites
		132 Dump sites
		133 Constructionsites
	14 Artificial, non-agricultural vegetated areas	141 Green urban areas
		142 Sport and leisure facilities
2 Agricultural areas	21 Arable land	211 Non-irrigated arable land
		212 Permanently irrigated land
		213 Rice fields
	22 Permanent crops	221 Vineyards
		222 Fruit trees and berryplantations
		223 Olive groves
	23 Pastures	231 Pastures
	24 Heterogeneous agricultural areas	241 Annual crops associated with permanent crops
		242 Complex cultivation patterns
		243 Land principally occupied by agriculture, with significant areas of natural vegetation
		244 Agro-forestry areas
3 Forest and semi natural areas	31 Forests	311 Broad-leaved forest
		312 Coniferous forest
		313 Mixed forest
	32 Scrub and/or herbaceous vegetation associations	321 Natural grasslands
		322 Moors and heathland
		323 Sclerophyllous vegetation
		324 Transitionalwoodland-shrub
	33 Open spaces with little or no vegetation	331 Beaches, dunes, sands
		332 Bare rocks
		333 Sparsely vegetated areas
		334 Burnt areas
		335 Glaciers and perpetualsnow
4 Wetlands	41 Inland wetlands	411 Inland marshes
		412 Peat bogs
	42 Maritime wetlands	421 Salt marshes
		422 Salines
		423 Intertidal flats
5 Water bodies	51 Inland waters	511 Water courses
		512 Water bodies
	52 Marine waters	521 Coastal lagoons
		522 Estuaries
		523 Sea and ocean

Table 3 Land use classification numencalture

6.3.1 Criteria rules description

I. ELEVATION

It is commonly assumed that territories at higher elevations will be colder than those at lower elevations. High elevation means also greater rainfall so a wetter environment with shorter fire season and lower fire severity (Rathaur, 2006). As well oxygen density decreases, and the amount of fuel also decreases due to shallow soil depth and wind(Walelegn & Mengist Zeleke, 2019).(Figure 52)

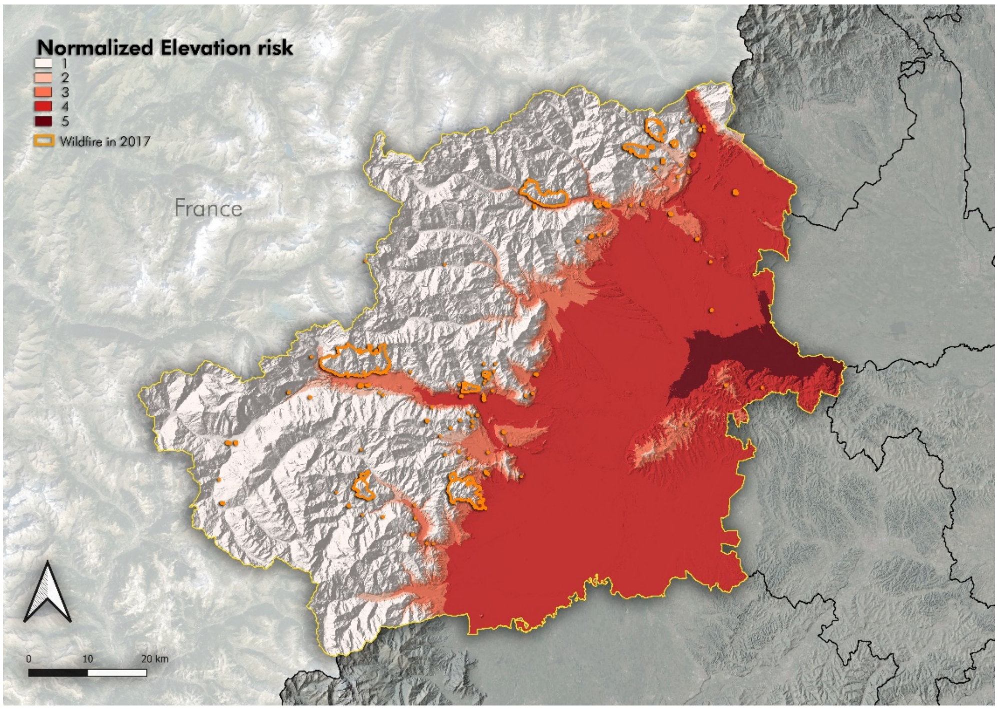

Figure 52 Elevation risk Map created by the author on GIS

II. SLOPE

The slope affects the behaviour of the flames. A steep slope may speed up the spread of the fire because of loss of water and more adjacent convective preheating(Kumari & Pandey, 2020). Slope has an impact on the ability and speed of firefighter and equipment movement, and as a result, on how quickly fires can be put out. The velocity at which a fire spreads can be doubled by a 10% slope increase(Gigović et al., 2018). Therefore, higher slopes were given higher index values. .(Figure 53)

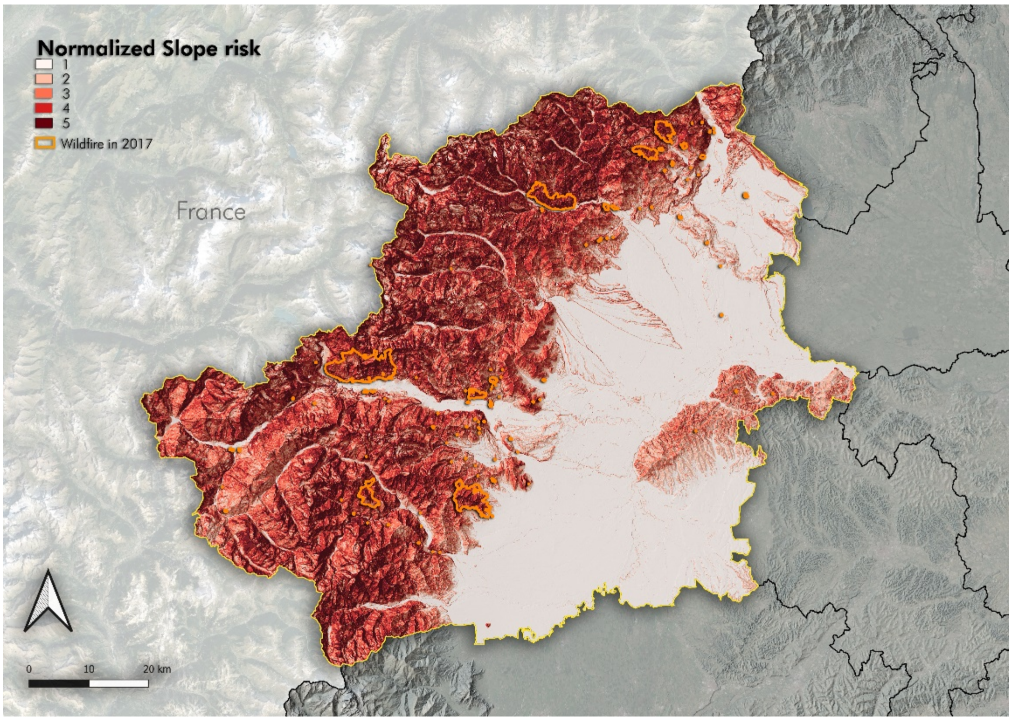

Figure 53 Slope risk Map created by the author on GIS

III. ASPECT

Aspect is the key factor for the ignition of the wildfire, by the fact that sun radiation exposure throughout the day is drying especially the south facing slope more than the north facing one. The most vulnerable are the south-west the least vulnerable are those that face north- east. The aspect have influence on vegetation type, generally drier condition of southern facing slope create more suitable environment for the growth of more vulnerable plant species(Kumari & Pandey, 2020). .(Figure 54)

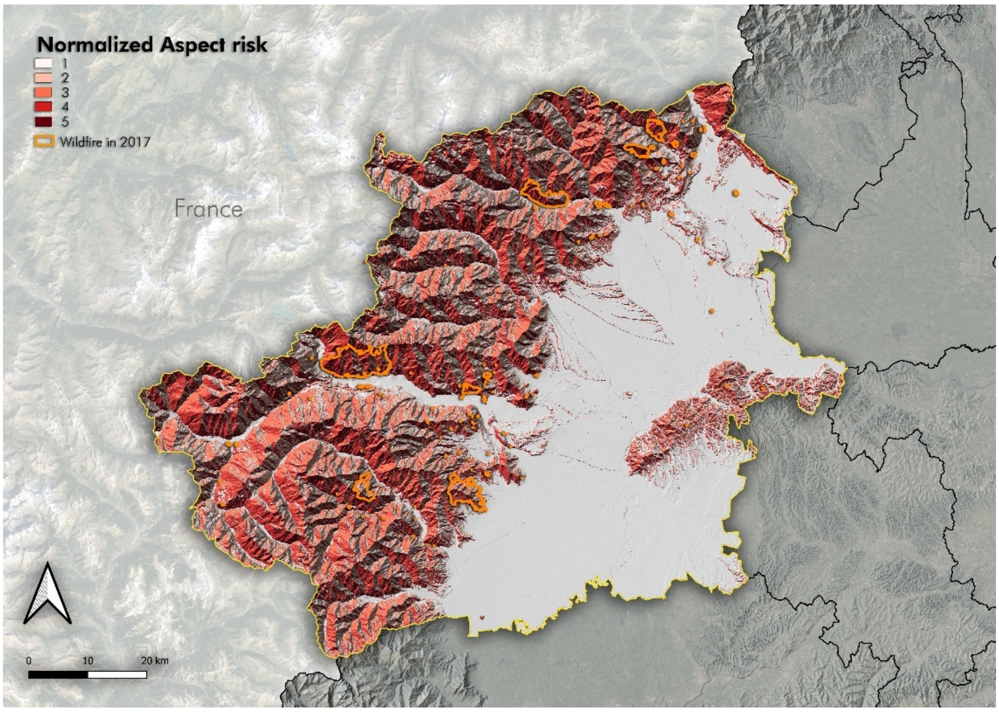

Figure 54 Aspect risk Map created by the author on GIS

IV. LAND USE

Type and characteristic of the vegetation are that affect the spread of forest fire, is crucial because it represent the total fuel available for the wildfire. Fuel plays an important role in determining the relative risk and probable behaviour of fire. Fuel type describe specific-specific ignition property(Kumari & Pandey, 2020).But as well the land use make clear the management of the land, for instance an agricultural land irrigated by human have a lower score. .(Figure 55)

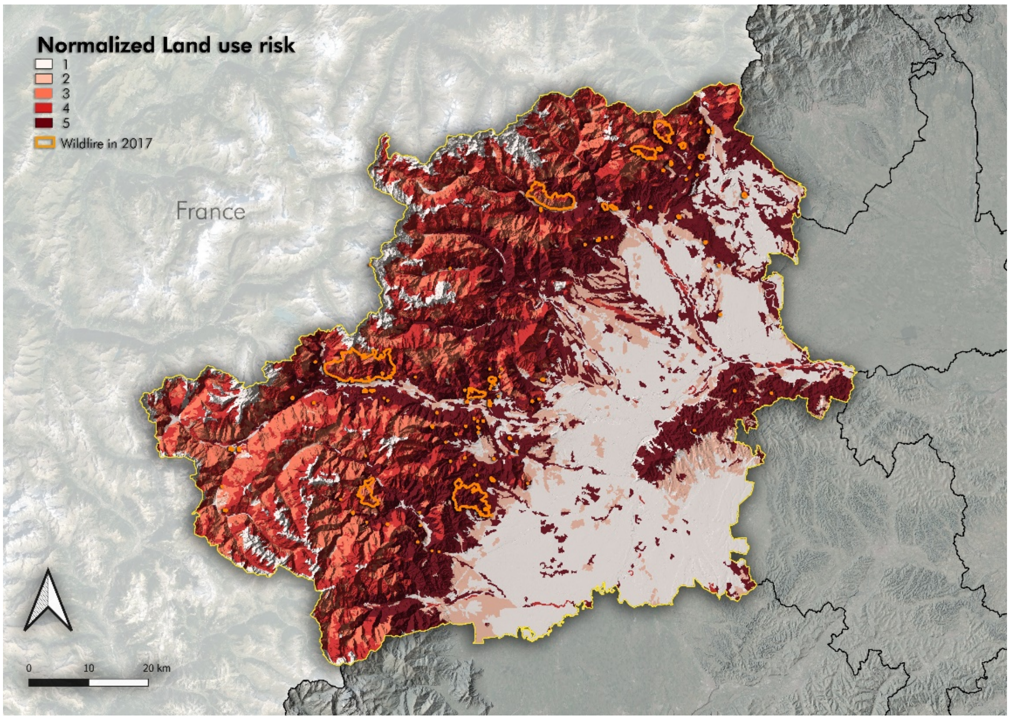

Figure 55 Land use risk Map created by the author on GIS

V. NDVI (Normalized Difference Vegetation Index)

Low greenness in compared to the surrounding landscape may support initiating forest fire(Ahmed et al., 2019).(Figure 56)

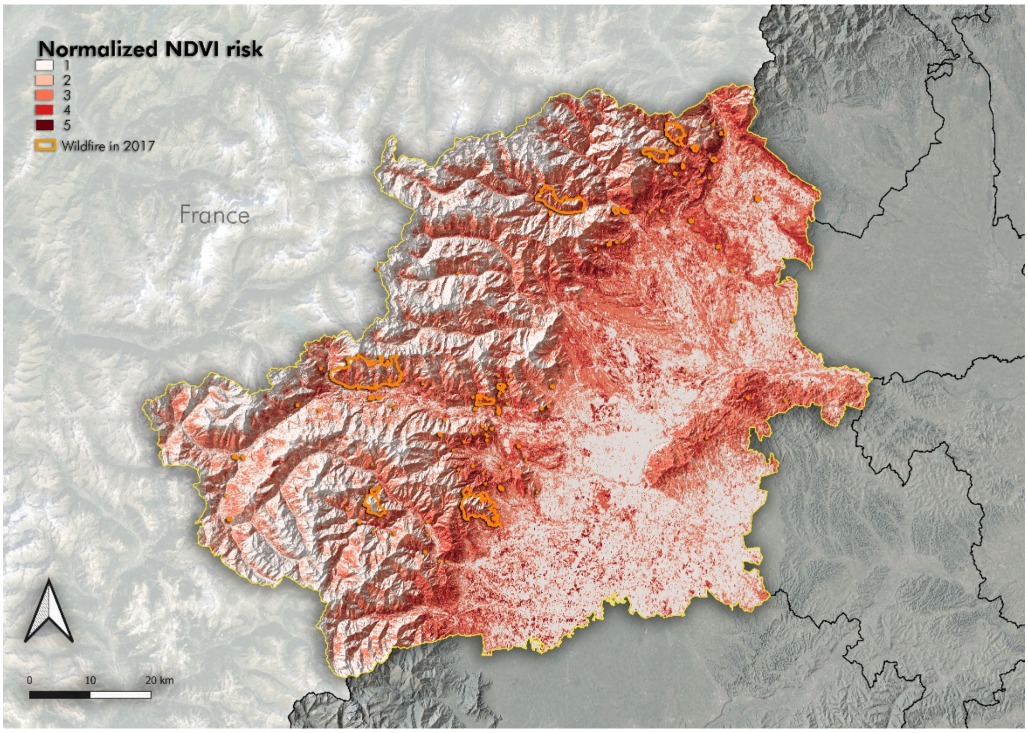

Figure 56 NDVI risk Map created by the author on GIS

VI. VCI (Vegetation Condition Index)

Because climatic signals are minimized by using the climatic extremes, VCI reflects vegetation moisture conditions and vegetation adaptation to weather changes. It's a good indicator weather influence on vegetation, and hence vegetation condition, health, and productivity. It gives a somewhat accurate evaluation of adverse vegetation conditions, particularly those related to the influence of drought(F. Kogan et al., 2003). (Figure 57)

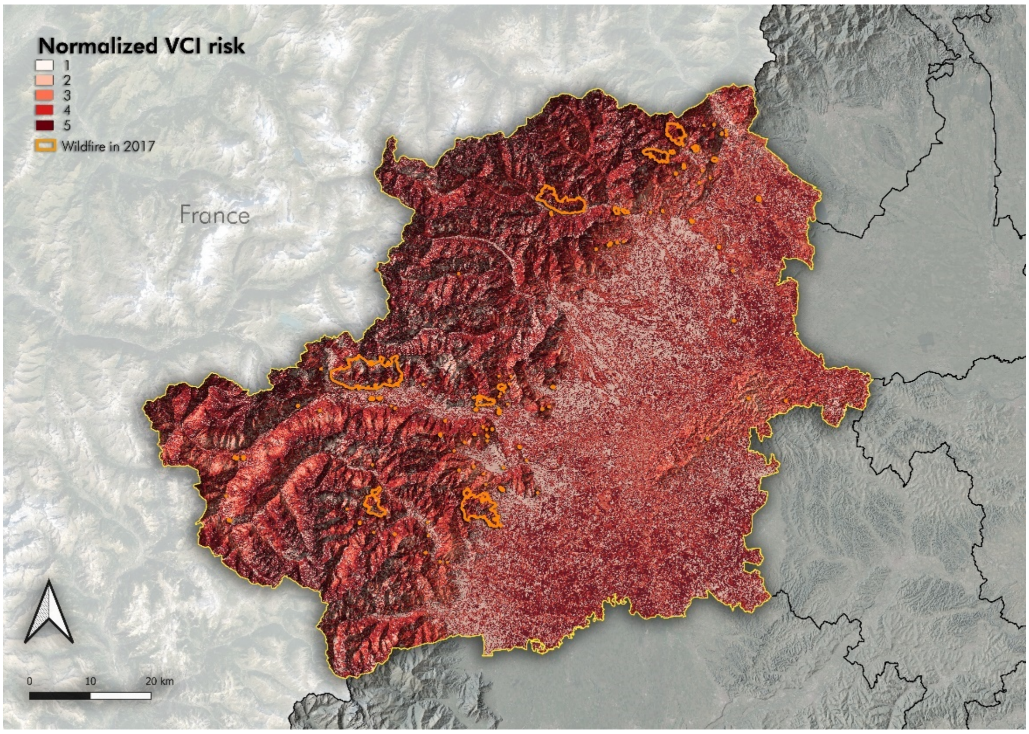

Figure 57 VCI risk Map created by the author on GIS

VII. TCD (Tree Cover Density)

High Densities of biomass imply more fuel; then more flammable it is. When there is more combustible material present in a particular area (due, for example, to the accumulation of litter), the quantity of heat produced by the fire proportionally grows(Vadrevu et al., 2010). (Figure 58)

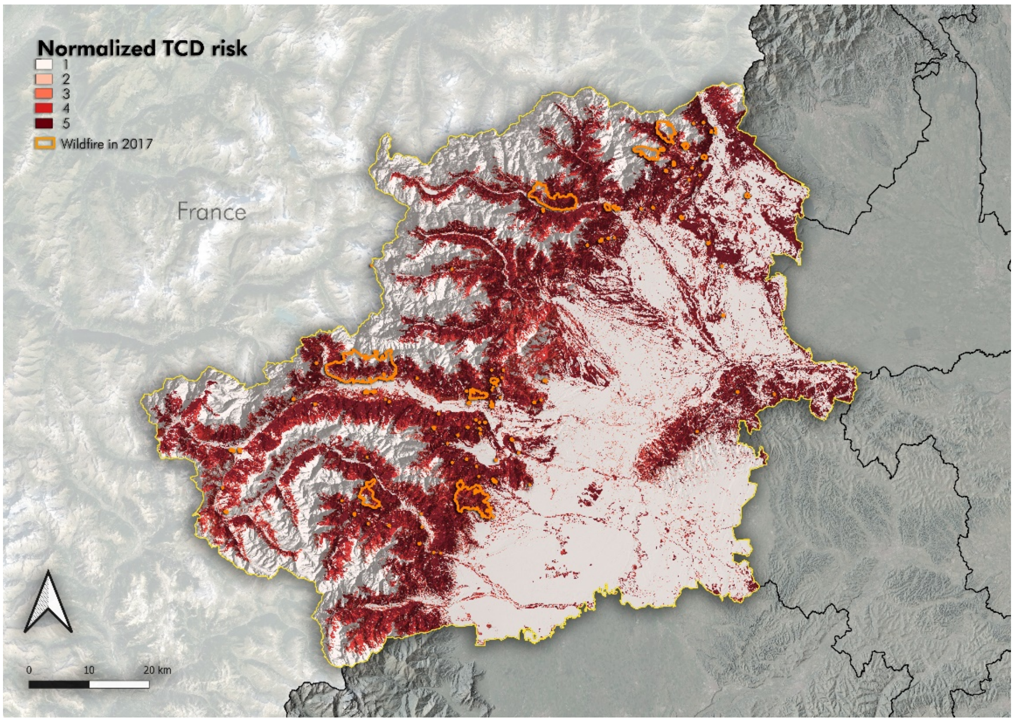

Figure 58 TCD risk Map created by the author on GIS

VIII. Road Proximity

Mapping fire hazards should take transportation into account. More intensive human activity is indicated by proximity to transportation systems. There is a potential probability for hiking and camping. In addition, the air flow along transportation lines is moving more quickly because of the movement of the cars on the roads(Jiang, 2011). (Figure 59)

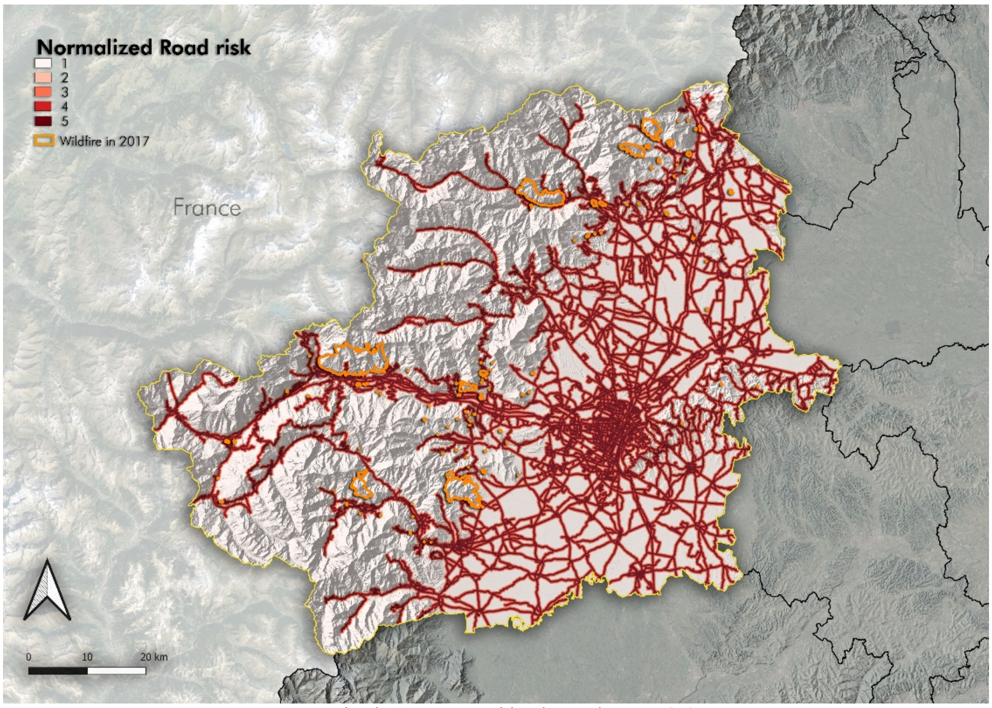

Figure 59 Road risk Map created by the author on GIS

IX. Trail Proximity

Because of human presence and an increase in resting sites, proximity to trail sections increases the chance of starting a fire(Walelegn & Mengist Zeleke, 2019). A camping site is defined as a location where fire is often used. People enjoy BBQ in the spring and summer, and coal fire is always utilized in barbecue. Furthermore, camping areas are typically surrounded by gorgeous landscape, such as trees and forests. When the wind blows, it is simple for a coal fire to go out of control(Jiang, 2011). (Figure 60)

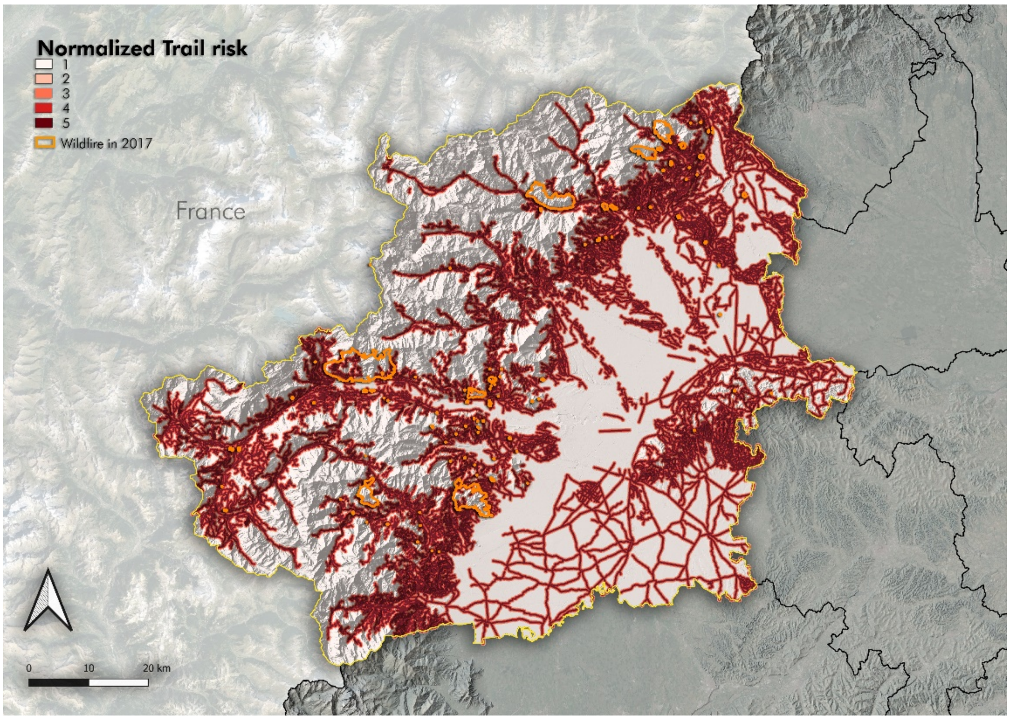

Figure 60 Trail risk Map created by the author on GIS

X. Settlement Proximity

Because of cultural and habitation traditions, forested regions surrounding human settlements are more prone to are more prone to fire(Subedi et al., 2022). This factor was extrapolated from the Corine land cove considering dissolving the 11 Urban fabric, 12 Industrial, commercial and transport units ,13 Mine, dump and construction sites. At this category was given a value of zero, this is the reason of the hole in the map.(Figure 61)

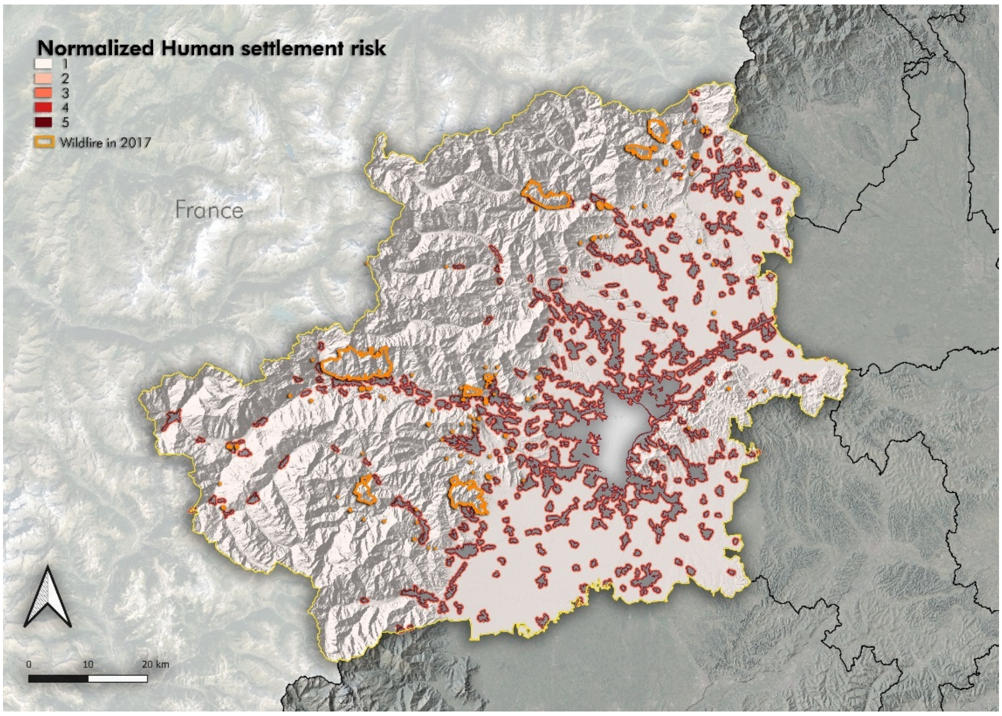

Figure 61 Human settlement risk Map created by the author on GIS

XI. Precipitation

Higher values (in mm) contribute to high moisture in fuels, thus are a negative indicator of fire spread(Vadrevu et al., 2010). It appears in the form of air humidity, humidity of habitat and fuel. If fuel is dry, fire will spread faster(Gigović et al., 2018). (Figure 62)

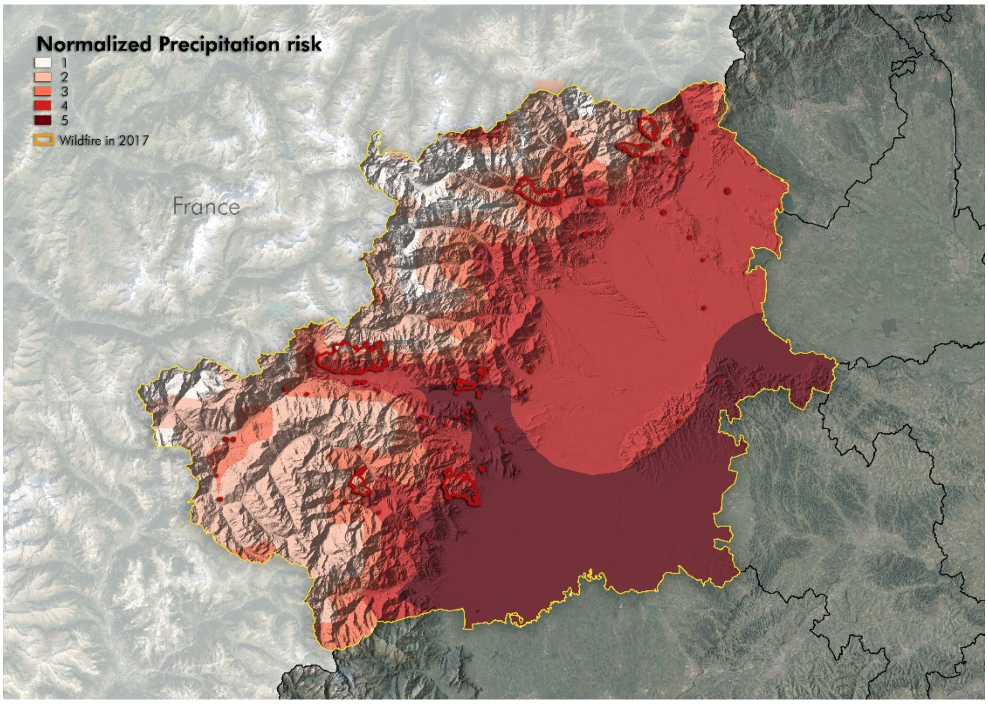

Figure 62 Precipitation risk Map created by the author on GIS

XII. Temperature

Air temperature is one of the most important climate factors. Fires can occur at any temperature, but their number depends on increasing of the temperature(Gigović et al., 2018). (Figure 63)

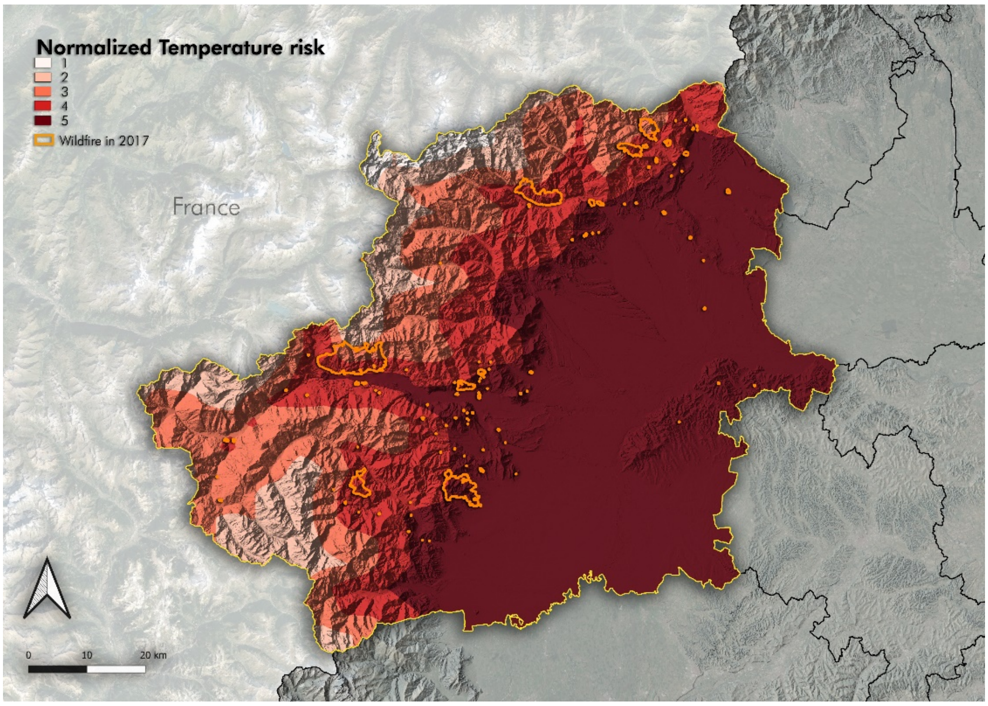

Figure 63 Temperature risk Map created by the author on GIS

XIII. Wind

Hence, highly wind-exposed areas have a higher chance of igniting and spreading the fire, and the vegetation is dried quickly (Walelegn & Mengist Zeleke, 2019).(Figure 64)

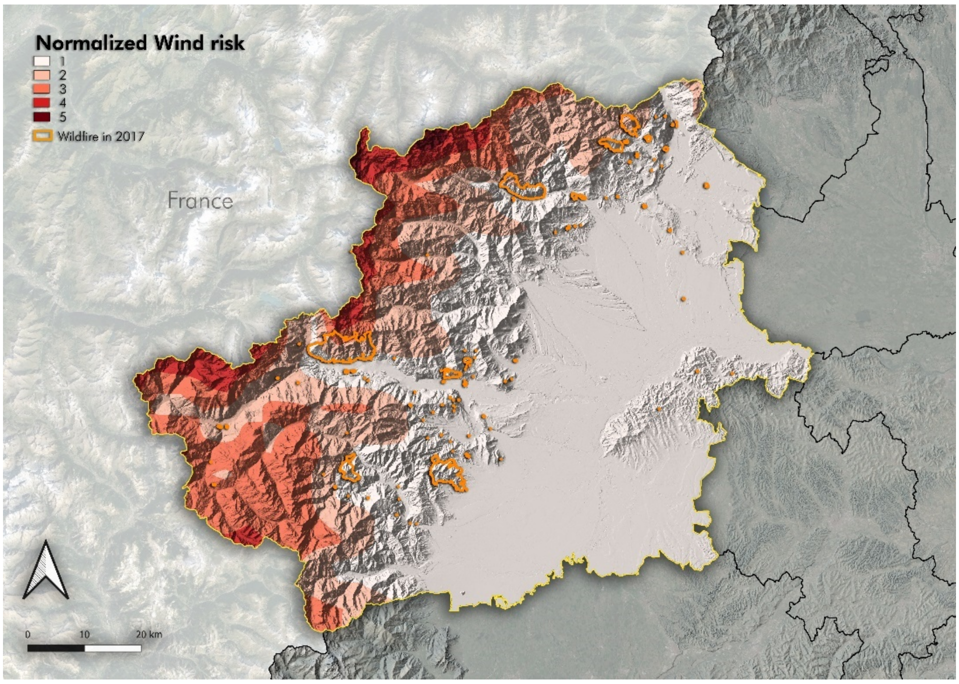

Figure 64 Wind risk Map created by the author on GIS

6.4 WEIGHTED LINEAR COMBINATION

To the Normalized maps produced for all the factor criteria (Elevation, Slope, Aspect, Land use, NDVI, VCI, TCD, Road Proximity, Trail Proximity, Settlement Proximity, Precipitation, temperature and wind) was assigned ad weighting factor according to their relative significance on fire ignition and propagation. In numerous fire- related MCDA, vegetation are considered the most decisive factor followed by topography , climate and socioeconomic are the generic categories in importance order in the context of forest fire spread(Gigović et al., 2018).

In the present study, the relative importance between the factors was based, taking into account the assumptions of the literature research on the topic, and secondarily taking into account the author's knowledge about the environmental and landscape condition of the province of Torino. The weighting factor attribution is a crucial step in MCDA; and in this study the numerical value of the weight was calculated according to the pair-wise comparison method (Figure 65). The factor considered the most important was the Land Use as it is linked to the fuel available for ignition, the second factor wad the different VI (vegetation index) the NDVI, VCI TCD, since they relate respectively to the vegetation condition, vegetation drought and vegetation structure. The third was the aspect that represent the solar energy available(Adaktylou et al., 2020). The slope follows and the human factors, to settlement proximity and wind was given the lower value by the fact that proximity to a large number of people make easier the detention of a fire, then for the wind the province literally protected by the alps and the wind is not too much strong.

	LAND USE	VEGETATION INDEX	ASPECT	SLOPE	TEMPERATURE	PRECIPITATION	TRAIL PROXIMITY	ROAD PROXIMITY	ELEVATION	WIND	SETTLEMENT PROXIMITY	WEIGHT
LAND USE	1	1	2	3	4	5	5	6	7	8	9	0,237
VEGETATION INDEX	1	1	2	2	3	3	4	5	6	7	7	0,195
ASPECT	0,5	0,5	1	1	2	3	4	4	5	6	6	0,136
SLOPE	0,333	0,5	1	1	2	2	3	3	4	4	5	0,112
TEMPERATURE	0,25	0,333	0,5	0,5	1	2	3	3	4	4	5	0,089
PRECIPITATION	0,2	0,333	0,333	0,5	0,5	1	2	2	3	4	5	0,068
TRAIL PROXIMITY	0,2	0,25	0,25	0,333	0,333	0,5	1	1	3	3	4	0,049
ROAD PROXIMITY	0,167	0,2	0,25	0,333	0,333	0,5	1	1	2	3	4	0,045
ELEVATION	0,143	0,167	0,2	0,25	0,25	0,333	0,333	0,5	1	2	3	0,03
WIND	0,125	0,143	0,167	0,25	0,25	0,25	0,333	0,333	0,5	1	2	0,022
SETTLEMENT PROXIMITY	0,111	0,143	0,167	0,2	0,2	0,2	0,25	0,25	0,333	0,5	1	0,017

Figure 65 Analytic hierarchic process matrix of factors

A comprehensive measurement of each factor was determined using a weighted hierarchical analysis (Analytical Hierarchy Process—AHP) method developed by Saaty(Saaty, 1994) by prioritizing and classifying the variables in a pairwise comparison scale, and then defining a linear hierarchy of importance among the factors. The parameters are ranked in order of significance, and therefore their weights may be obtained. Because the significance values assigned to the factor have a direct impact on the outcome, this is regarded as the most essential phase in the entire process. The consistency of the application was checked using the consistency ratio (CR), according to the following equation:

$$CR = CI/RI$$

where RI is the random index and CI is the consistency index. The consistency ratio has been calculated and is CR=0,0312

The forest fire risk map was developed according to the equation below that is based on the weighed linear combination.

FFR= 0,24 * [LAND USE] + 0,20 * [VI] + 0,14 * [ASPECT] + 0,11 * [SLOPE] + 0,09 * [TEMPERATURE] + 0,07 * [PRECIPITATION] + 0,05 * [TRAIL PROXIMITY] + 0,04 * [ROAD PROXIMITY] + 0,03 * [ELEVATION] + 0,02 * [WIND] + 0,02 * [SETTLEMENT PROXIMITY]

The Formula was used to create the following forest fire risk map but was substituted the respectively the VCI then the NDVI and then the TCD. In the calculation all the input layer was resampled to a 30mx30m for the production of the final map, equivalent to the spatial resolution of Landsat 7.

7 RESULT AND VALIDATION

The final forest fire risk map is constructed by multiplying the weight criteria derived from AHP with the score of each criterion in each cell. The final map is shown in the same score as the criterion from 1 to 5 based on the selected criteria and clusters. Larger values of cells score are characterized for location with high risk of fire ignition. In The figure below the area that are the most critical when a fire start are the ones from orange to red.

The next map represents the tree final output based on the 3 different vegetation indices. Just overlapping the fire data with the maps visually is possible to see the correlation between both. In the next paragraph the firefighting data will be used to validate the final map, considering the fact that a low risk is less the value 3(Adaktylou et al., 2020). The typology of the data collected by the firefighting after the occurrence of a wildfire were two: an aerial data the that comprehend all the wildfire bigger than 1 hectare; a point data that represent all the ignition point of a wildfire and the wildfire smaller than 1 hectare. The temporal resolution of the data is since 1997 till 2020 and was taken in consideration just the year 2017.

For the areal data was just calculated all the pixel value inside the surface of the burned area.

For the point data was created a buffer of 250m around the point and then was possible to calculate the value of the pixels inside the surface crated.

To have than a quantitative validation was calculated the number of the pixel greater and lower than 3 and greater than 4 and their respective percentage relative to the total number of the pixel

7.1 VCI FIRE RISK MAP

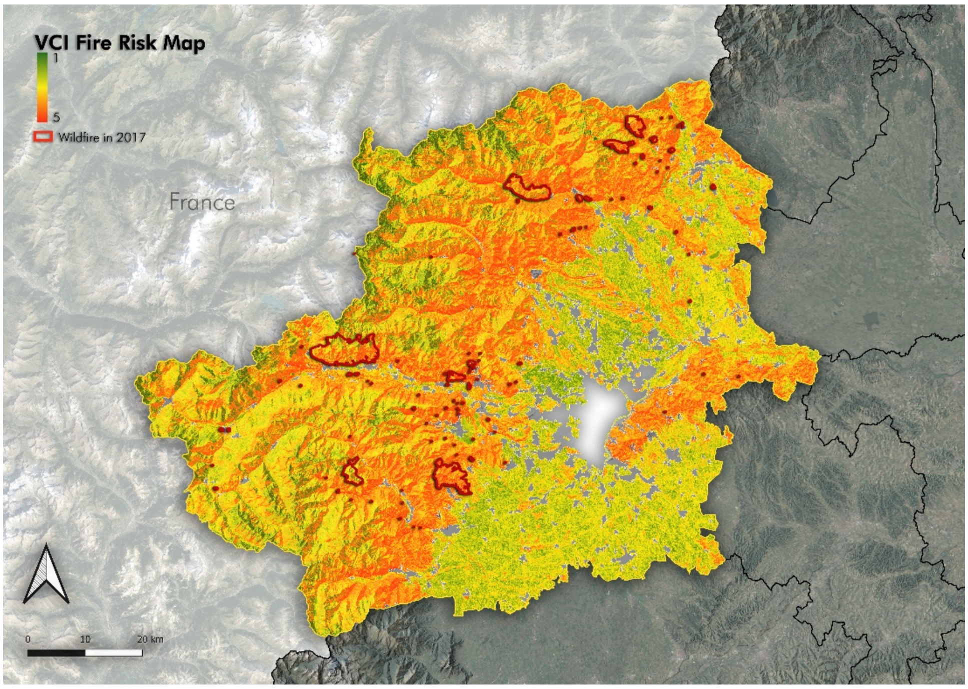

Figure 66 VCI FIRE RISK MAP created by the author on GIS spatial resolution 30x30

7.1.1 VCI Validation from burned area

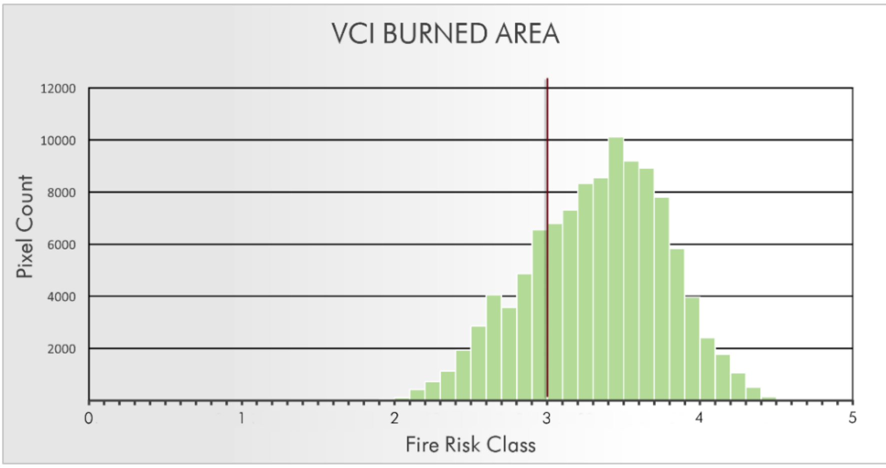

Figure 67 Histogram of VCI fire risk map from burned area , created by the author

TOTAL PIXELS	109031	100%
PIXELS LESS THAN 3 VALUE	19735	18,10%
PIXEL GREATER THAN 3 VALUE	89296	81,90%
PIXEL GREATER THAN 4 VALUE	9893	9,07%

Table 4 Value of Histogram of VCI fire risk map from burned area , created by the author

The Figure 66 shows the Fire risk map derived from the VCI satellite based data, the table 5 and the figure 67 shows then the number of pixel and the percentage of those that are inside the burned surface, the pixels bigger then tree are almost the 82% and a 18% are lower than 3. The high risk is showed in the collinear area where there is a big availability of biomass and vegetation, meanwhile lower value is recognized in the flatten where are present the agricultural field, and in the grassland in the mountain, moreover this value is lower like the other by the fact that small vegetation is more susceptible to drought condition.

7.1.2 VCI Validation from ignition point

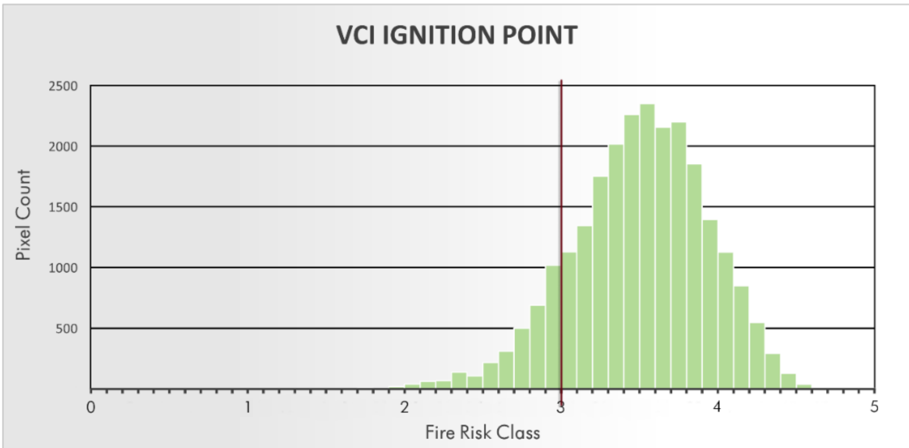

Figure 68 Histogram of VCI fire risk map from ignition point, created by the author

TOTAL PIXELS	24549	100%
PIXELS LESS THAN 3 VALUE	2143	8,73%
PIXEL GREATER THAN 3 VALUE	22406	91,27%
PIXEL GREATER THAN 4 VALUE	4360	17,76%

Table 5 Value of the Histogram of VCI fire risk map from ignition point , created by the author

More satisfactory is the validation of the map from the ignition point's buffer, the percentage of pixel lower than the value tree are the 8% meanwhile the greater one are approximately the 92% (Table 6) (Figure 68).

7.1.3 Discussion of VCI output

The area with higher risk in the province is not only due the fuel availability and it's major weight in the analysis , but also due the high risk value of other factor like high temperatures and lower precipitation in the collinear part of the territory.

At the same time those climate factor play a crucial role in the variation of VCI at different time and locations(Baniya et al., 2019). In fact, is recognized that the increase of temperature may extend the growth season and raise photosynthesis to its maximum. Meanwhile about the precipitation many studies demonstrate that VCI behaves slowly to variation in moisture condition this responsiveness is influenced by previously accumulated soil water storage. The VCI responds most strongly to long precipitation (moisture) deficiencies and appears to be less susceptible to short-term precipitation deficits(Quiring & Ganesh, 2010). It should be highlighted that the VCI is more difficult to understand than other drought indices since it gives an indirect measurement of moisture (drought) conditions. Anything that stresses the plants, such as insects, illness, and nutrient deficiency, can result in decreased plant growth, and a land degradation, as a result, lower VCI Values(Vicente-Serrano, 2007).

We have to remember that the VCI is a satellite-based index and the use of remote sensing to monitoring drought has al lot of advantages. Most of drought indices are derived from surface data and their spatial resolution depend on the density of the data collection network, and these dates usually are not available in real time. However, satellite data can provide near real time data with high spatial resolution. Furthermore, satellite-based drought/vegetation indices are developed on vegetation health rather than meteorological (e.g., precipitation) and environmental factors (e.g., soil moisture).

After this excursus of what and how VCI could be affected by different variable is clear that satellite-based vegetation indices are sensible to the vegetation status and it could affect, either in a positive or negative way the indices value, alternating the final output. So, in order to improve the assess of drought further studies can be conducted using multiple source remote sensing data and integrating this data as well with surface data correcting this misinterpretation error.

7.2 NDVI FIRE RISK MAP

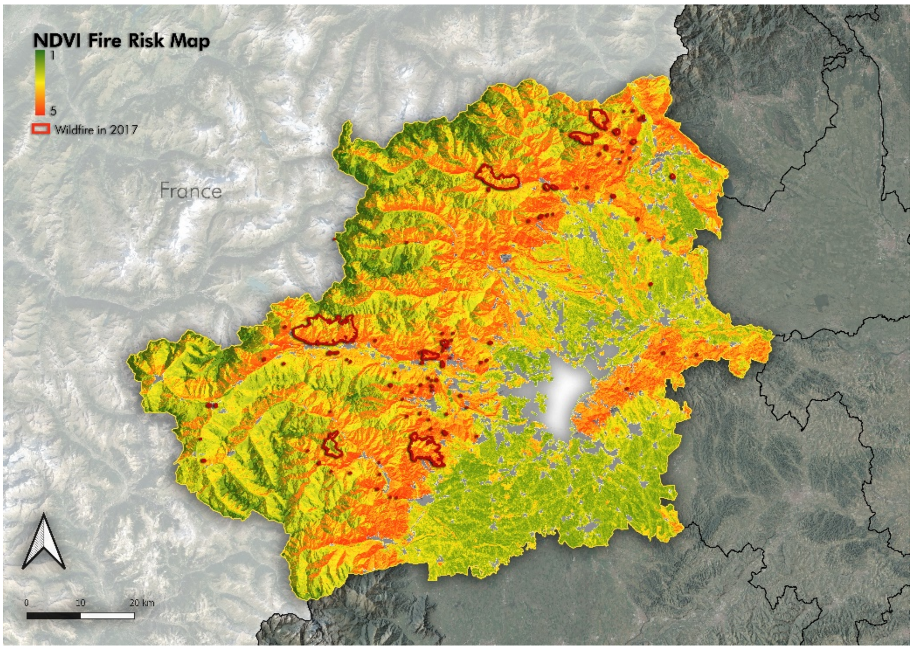

Figure 69 NDVI FIRE RISK MAP created by the author on GIS spatial resolution 30x30

7.2.1 NDVI Validation from burned area

The Figure 69 show the forest fire risk map derived from NDVI, the table 7 below and Figure 70 shows the number of pixel below the value 3 that there are the 23% of the total number of the pixel, and the pixel above the 3 value that are the 77% .

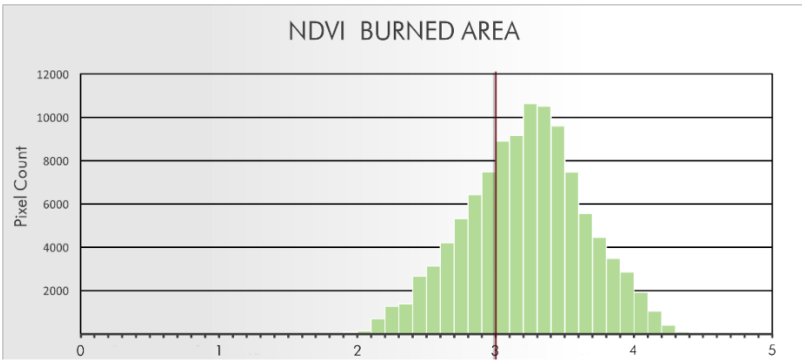

Figure 70 Histogram of NDVI fire risk map from burned area , created by the author

TOTAL PIXELS	109031	100%
PIXELS LESS THAN 3 VALUE	25397	23,29%
PIXEL GREATER THAN 3 VALUE	83634	76,71%
PIXEL GREATER THAN 4 VALUE	6382	5,85%

Table 6 Value of Histogram of NDVI fire risk map from burned area , created by the author

7.2.2 NDVI Validation from ignition point

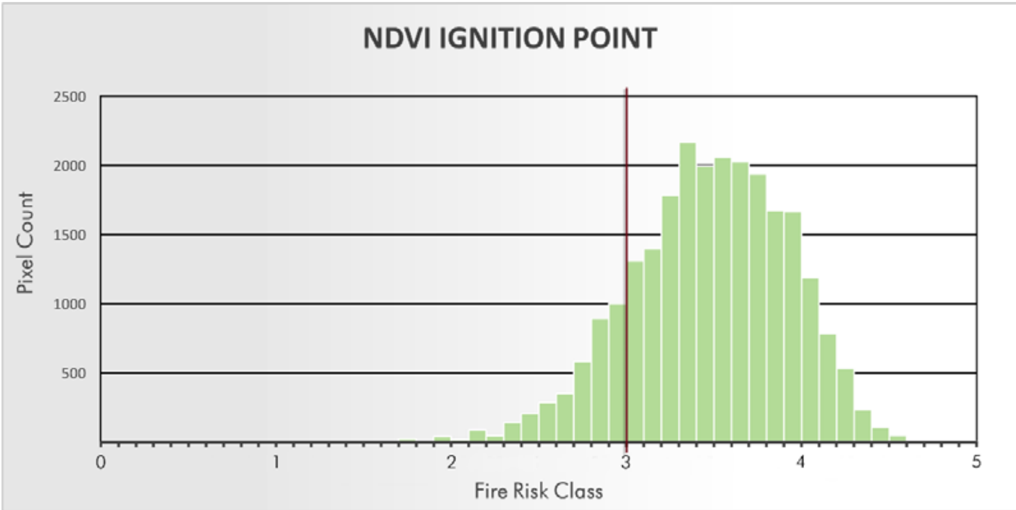

Figure 71 Histogram of NDVI fire risk map from ignition point , created by the author

TOTAL PIXELS	24503	100%
PIXELS LESS THAN 3 VALUE	2659	10,85%
PIXEL GREATER THAN 3 VALUE	21844	89,14%
PIXEL GREATER THAN 4 VALUE	4532	18,49%

Table 7 Value of the Histogram of NDVI fire risk map from ignition point , created by the author

In the table 8 and figure 71 in percentage of the pixel below tree is the 11% meanwhile the one bigger than 3 are the 89% this index are performing well but in relation to the other two final output is the one performing worse.

7.2.3 Discussion of NDVI output

Normalized difference vegetation index is the mostly used vegetation index, is used to the regional and global vegetation assessment, this index is related not only to the canopy structure but also to the canopy photosynthesis. NDVI, on the other hand, is sensitive to the influences of soil brightness, soil colour, atmosphere, cloud and cloud shadow, and leaf canopy shadow and necessitates remote sensing calibration(Xue & Su, 2017). Furthermore, vegetation structure and growth is driven principally by hydrothermal condition. And vegetation growth affect NDVI Value , according (Pei et al., 2019) there is a positive correlation between NDVI , temperature and precipitation, being more sensitive to the precipitation variation than to temperature variation(Chu et al., 2007) . With the increasing temperature in spring make starting the growing/vegetative period that NDVI reach its maximum value peak in July/ august and start to decrease in October when temperatures decrease , Reaching the lowest value in winter. Precipitation in the growing season boost vegetation growth and subsequently an increase in NDVI value. So after this is possible to recognise that the month of October is a particular month were the value is influenced by a lot of factor.

In the NDVI fire risk map was not considered a inter annual time series, so for that so for this reason, the maximum and minimum peak vegetation could not be considered in the analysis, hence consequently the maximum and minimum NDVI value. But was considered a data corresponding to the period before the big fire occurred in the 2017. This choice was not random but was made to understand the health of the vegetation, and biomass, but also the amount of moisture present in the plants. In fact, in that year there was a strong anomaly regarding temperatures and precipitation, with consequent effects on the forest ecosystem. although The NDVI value was not extrapolated to the best period, it still showed a satisfactory result. To improve it is also possible to integrate different VIs that help to assess the vegetation cover, vigour, and growth dynamics quantitatively and qualitatively, also plant water and abiotic/biotic stress levels, status a using different light spectra combinations, instrumentation, platforms, and resolutions.

7.3 TCD FIRE RISK MAP

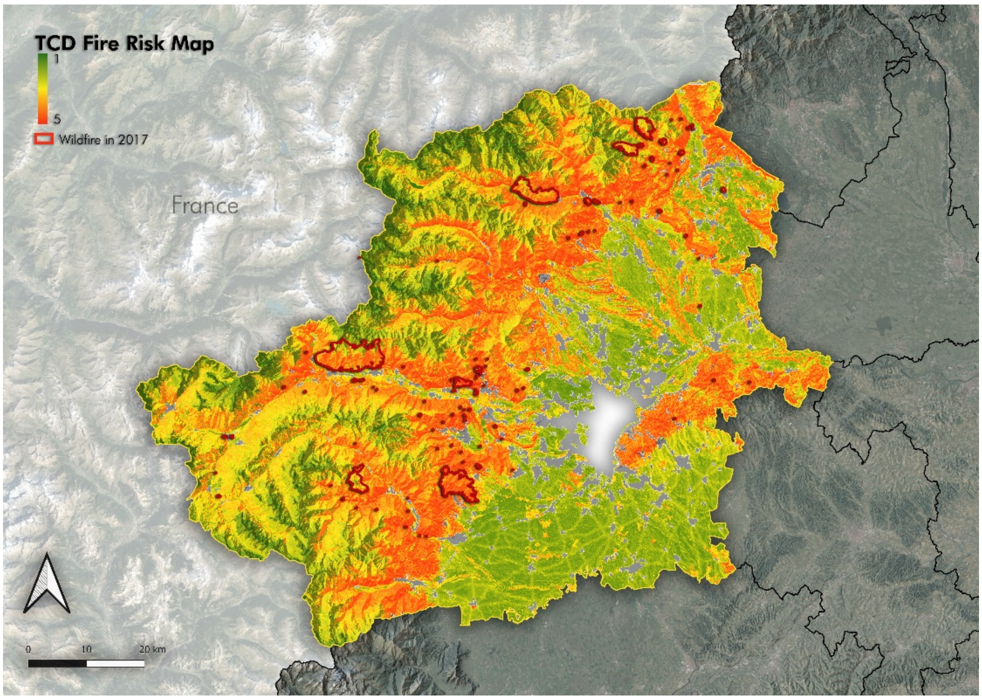

Figure 72 TCD FIRE RISK MAP created by the author on GIS spatial resolution 30x30

7.3.1 TCD validation from burned area

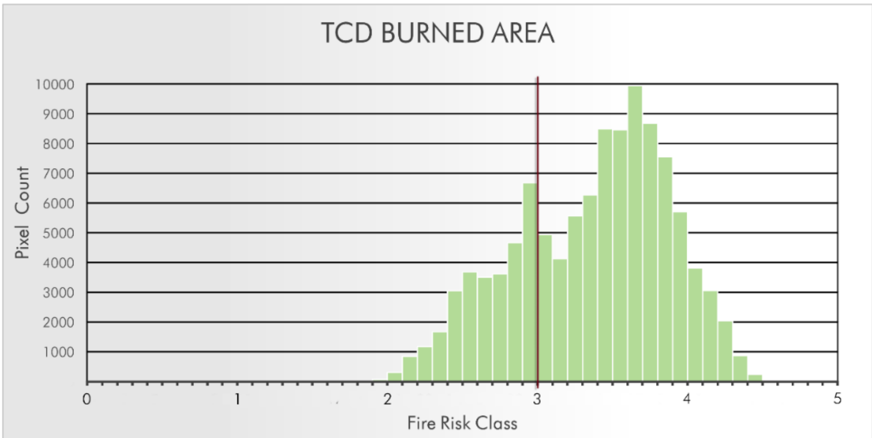

Figure 73 Histogram of TCD fire risk map from burned area , created by the author

TOTAL PIXELS	109031	100%
PIXELS LESS THAN 3 VALUE	22612	20,74%
PIXEL GREATER THAN 3 VALUE	86419	79,26%
PIXEL GREATER THAN 4 VALUE	15742	14,44%

Table 8 Value Histogram of TCD fire risk map from burned area , created by the author

The distribution of the pixel value in the TCD fire risk map appears with a more stretched distribution(Figure 73), the lower point value present in the map has a value lower than the value 2(Figure 73), in any case the percentage of the pixels lower than 3 is around the 21% and the one bigger than 3 are almost 79 % (Table 9).

7.3.2 TCD validation from Ignition point

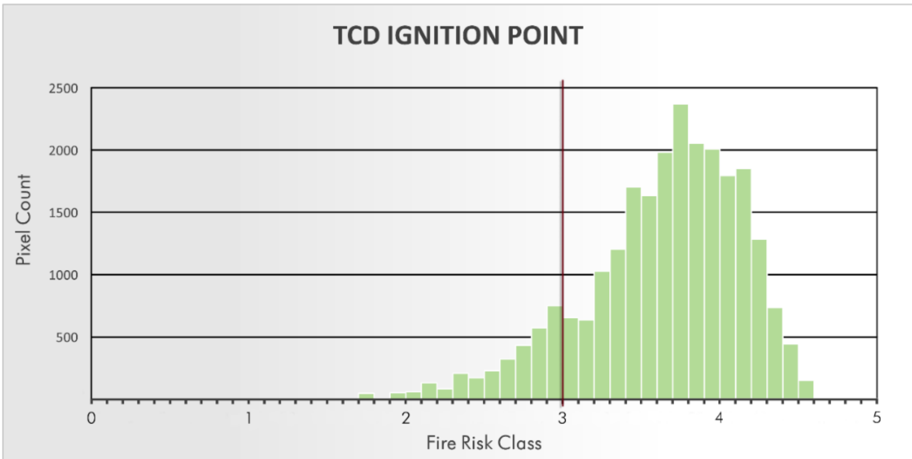

Figure 74 Histogram of TCD fire risk map from ignition point , created by the author

TOTAL PIXELS	24549	100%
PIXELS LESS THAN 3 VALUE	2308	9,40%
PIXEL GREATER THAN 3 VALUE	22241	90,59%
PIXEL GREATER THAN 4 VALUE	8250	33,60%

Table 9 Value Histogram of TCD fire risk map from ignition point , created by the author

Similar distribution of the figure 73 is present also in the validation figure 74,
Here the percentage of the point lower than 3 is 9% meanwhile the number of the pixels bigger than 3 are the 91%. Different to the other output the number of the pixels major than 4 appear higher in the areal data and the point data validation(Table 10).

7.3.3 Discussion of TCD output

The tree cover density provide the tree cover density in the range that goes from 0 to 100%; this forest product following the definition of forest provided by the FAO , where forest Is a land there more than the 10 ì% of tree canopy cover in an area of 0,5 ha and tree should reach a minimum height of 5m(FAO, 2020).

This data are from Semi-automatic classification of pre-processed multitemporal High Resolution (HR) satellite image data (Sentinel-2, Landsat 8) with reference year 2015 (+/- 1 year), resulting in scene-based first land cover classifications utilizing supervised and unsupervised functionalities. A time series analysis is being performed to extract tree cover. Following that, interactive manual modifications of the resulting tree cover mask were carried out and incorporated into a continuous mosaic. It is important to underscore the multi-temporality of the data , essentially the data in question is intended to show the amount of biomass as in NDVI ,but in this case we consider the best vegetation conditions.

CONCLUSION

Looking at all the final output is possible to say that this study demonstrates the ignition of a fire, according the proposed GIS's prediction, in the location where there Is an high/very high risk. The comprehensive benefits of the approach proposed in this document, as well as the corresponding GIS, demonstrating the ability to develop solely on geospatial information, these studies have demonstrated that it has the potential to contribute to forest fire prevention efforts as a useful and easy-to-use tool for forest fire management. The climate variable is the most dynamic factor that determine fire risk as it influence the moisture content in the vegetation. In this study the meteorological data was derived from the remote sensing and they are often characterized by not a really high spatial resolution, at the same time ground based meteorological data depends on the density of the station network. Hence, interpolation method need to be used to generate a spatially continuous variable; however, this approach might result in different outputs from different interpolation algorithms based on the same input variables.

In this study the remote sensing approach was used not only for the meteorological factor but also to estimate the vegetation condition in relation to their water count and health status, and the amount of biomass. The final maps produced for the study are not a prediction model or connected to some defined period. Are rather developed for a long term strategic forest fire planning and management, that is something missing in the province of Torino and also in Italy with this level of detail and approach, by the fact that the methodology used by the region is not differentiating the factor on the base of the influence on the wildfire behaviour but it put them all at the same level.

This kind of study then could be then applied to other part of the world, if dataset is available.

Forest fire risk mapping in one of the most important factor of forest fire management, and can be used to a civil protection agency, for instance to set up an appropriate firefighting infrastructure, improving road and other access routes or creating new water body; to the company that administrates public infrastructure such electric line, road or ray, for reduce the fire impact on those. Another application could be in relation to the cultural heritage area, providing a solution to make this area safer.

Every year, large wooded areas in the Mediterranean are burned, causes severe environmental and economic loss. The valued assets at danger include the wildland ecosystem as well as our collective cultural and historical heritage, which justifies the development of targeted strategies such as wildfire prevention where practicable and wildfire management when and where ignitions occur. To ensure the conservation of these significant natural and cultural assets, integrated solutions with a broad reach should be advocated in these two areas.

BIBLIOGRAPHY

Abatzoglou, J. T., Dobrowski, S. Z., Parks, S. A., & Hegewisch, K. C. (2018). TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958-2015. *Scientific Data*, *5*. https://doi.org/10.1038/sdata.2017.191

Adaktylou, N., Stratoulias, D., & Landenberger, R. (2020). Wildfire risk assessment based on geospatial open data: Application on chios, greece. *ISPRS International Journal of Geo-Information*, *9*(9). https://doi.org/10.3390/ijgi9090516

Ahmed, M. R., Hassan, Q. K., Abdollahi, M., & Gupta, A. (2019). Introducing a new remote sensing-based model for forecasting forest fire danger conditions at a four-day scale. *Remote Sensing*, *11*(18). https://doi.org/10.3390/rs11182101

Akbar, T. A., Hassan, Q. K., Ishaq, S., Batool, M., Butt, H. J., & Jabbar, H. (2019). Investigative spatial distribution and modelling of existing and future urban land changes and its impact on urbanization and economy. *Remote Sensing*, *11*(2). https://doi.org/10.3390/rs11020105

Angelini, Aurelio., & Pizzuto, Piergiorgio. (2007). *Manuale di ecologia, sostenibilità ed educazione ambientale*. Angeli.

Antão, M., & Carrilho, P. (2015). *THE USE OF ANALYTICAL HIERARCHY PROCESS IN SPATIAL DECISION SUPPORT SYSTEM FOR LAND USE MANAGEMENT A case study of the Zambezi river valley in Mozambique*.

Arndt, N. (2006). *PROBLEM OF FIRES ON EMBANKMENTS ALONG RAILWAY ROUTES IN AUSTRIA*. Institute of Soil Bioengineering and Landscape Construction.

Arndt, N., Vacik, H., Koch, V., Arpaci, A., & Gossow, H. (2013). Modeling human-caused forest fire ignition for assessing forest fire danger in Austria. *IForest*, *6*(6), 315–325. https://doi.org/10.3832/ifor0936-006

ARPA PIEMONTE, & REGIONE PIEMONTE. (2020). *Analisi del clima regionale del periodo 1981-2010 e tendenze negli ultimi 60 anni*.

Bajocco, S., Pezzatti, G. B., Mazzoleni, S., & Ricotta, C. (2010). Wildfire seasonality and land use: When do wildfires prefer to burn? *Environmental Monitoring and Assessment*, *164*(1–4), 445–452. https://doi.org/10.1007/s10661-009-0905-x

Baniya, B., Tang, Q., Xu, X., Haile, G. G., & Chhipi-Shrestha, G. (2019). Spatial and temporal variation of drought based on satellite derived vegetation condition index in Nepal from 1982–2015. *Sensors (Switzerland)*, *19*(2). https://doi.org/10.3390/s19020430

Bar-Massada, A., Radeloff, V. C., & Stewart, S. I. (2014). Biotic and abiotic effects of human settlements in the wildland-urban interface. In *BioScience* (Vol. 64, Issue 5, pp. 429–437). American Institute of Biological Sciences. https://doi.org/10.1093/biosci/biu039

Barmpoutis, P., Papaioannou, P., Dimitropoulos, K., & Grammalidis, N. (2020). A review on early forest fire detection systems using optical remote sensing. *Sensors (Switzerland)*, *20*(22), 1–26. https://doi.org/10.3390/s20226442

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018). Present and future köppen-geiger climate classification maps at 1-km resolution. *Scientific Data*, *5*. https://doi.org/10.1038/sdata.2018.214

Benson, R. P., Roads, J. O., & Weise, D. R. (2008). Climatic and Weather Factors Affecting Fire Occurrence and Behavior. In *Developments in Environmental Science* (Vol. 8, pp. 37–59). https://doi.org/10.1016/S1474-8177(08)00002-8

Bertani, R., Bovio, G., & Petrucci, B. (2016). *MANUALE PER L'APPLICAZIONE DELLO "SCHEMA DI PIANO A.I.B. NEI PARCHI NAZIONALI - 2016."*

Blasi, C., Bovio; Giovanni, Corona, P., Marchetti, M., & Maturani, A. (2004). *Incendi e complessità ecosistemica. Dalla pianificazione forestale al recupero ambientale*. (Ministero dell'ambiente e della tutela del territorio. S.B.I., Ed.).

Bouguettaya, A., Zarzour, H., Taberkit, A. M., & Kechida, A. (2022). A review on early wildfire detection from unmanned aerial vehicles using deep learning-based computer vision algorithms. In *Signal Processing* (Vol. 190). Elsevier B.V. https://doi.org/10.1016/j.sigpro.2021.108309

Burgan, R. E., Klaver, R. W., & Klaver, J. M. (1998). Fuel Models and Fire Potential From Satellite and Surface Observations. *International Journal of Wildland Fire*, *8*(3), 159–170. https://doi.org/10.1071/WF9980159

Busico, G., Giuditta, E., Kazakis, N., & Colombani, N. (2019). A hybrid GIS and AHP approach for modelling actual and future forest fire risk under climate change accounting water resources attenuation role. *Sustainability (Switzerland)*, *11*(24). https://doi.org/10.3390/su11247166

Butler, Bret. W., Anderson, W. R., & Catchpole, E. A. (2007). Influence of Slope on Fire Spread Rate. *The Fire Environment--Innovations, Management, and Policy;* , 75–82.

Camerano, P., Giannetti, F., Terzuolo, P. G., & Guiot, E. (2017). *La Carta Forestale del Piemonte*. www.ipla.org

Camerano, P., Gottero, F., Terzuolo, P. G., Varese, P., & Mondino, G. P. (2008). *Tipi forestali del Piemonte*. Blu edizioni . www.ipla.orgTestiacuradi:

Camia, A., Durrant, T., & Ayanz miguel, J. S. (2014). *The European Fire Database Technical specifications and data submission*.

Camia, A., Libertà, G., & San-Miguel-Ayanz, J. (2017). *Modeling the impacts of climate change on forest fire danger in Europe : Sectorial results of the PESETA II Project*. Publications Office. https://doi.org/doi/10.2760/768481

Cardona, O.-D., van Aalst, M. K., Birkmann, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R. S., Lisa Schipper, E. F., Tan Sinh, B., Décamps, H., Keim, M., Davis, I., van Aalst, M., Birkmann, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R., Schipper, E., … Midgley, P. (2012). Determinants of Risk: Exposure and Vulnerability. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (pp. 65–108). Cambridge University Press, Cambridge, UK,.

Ceppi, P., & Nowack, P. (2021). Observational evidence that cloud feedback amplifies global warming. *Proceedings of the National Academy of Sciences*, *118*(30), e2026290118. https://doi.org/10.1073/pnas.2026290118

Çetin, A. E., Dimitropoulos, K., Gouverneur, B., Grammalidis, N., Günay, O., Habiboğlu, Y. H., Töreyin, B. U., & Verstockt, S. (2013). Video fire detection – Review. *Digital Signal Processing*, *23*(6), 1827–1843. https://doi.org/https://doi.org/10.1016/j.dsp.2013.07.003

Chéret, V., & Denux, J. P. (2007). Mapping wildfire danger at regional scale with an index model integrating coarse spatial resolution remote sensing data. *Journal of Geophysical Research: Biogeosciences*, *112*(2). https://doi.org/10.1029/2005JG000125

Chia, E. K., Bassett, M., Nimmo, D. G., Leonard, S. W. J., Ritchie, E. G., Clarke, M. F., Bennett, A. F., & Peters, D. P. C. (2015). Fire severity and fire-induced landscape heterogeneity affect arboreal mammals in fire-prone forests. *Ecosphere*, *6*(10). https://doi.org/10.1890/ES15-00327.1

Chivian, E., & Bernstein, A. (2010). *How Our Health Depends on Biodiversity*. http://digitalcommons.imsa.edu/eco_disrupt

Christian MAYER, Stefan MAYR, Mortimer M. MÜLLER, Harald VACIK, Lena VILÀ-VILARDELL, Pierre CARREGA, Yvon DUCHE, Sébastien LAHAYEalk BÖTTCHER, Harald MAIER, Christian SCHUNK, avide ASCOLI, Augusto COTTERCHIO, Paolo FIORUCCI, Franco GOTTERO, Sergio PIRONE, Rolando RIZZOLO, Giorgio VACCHIANO, Eva VALESE, & Lothar ZIMMERMANN. (2020). *FOREST FIRES IN THE ALPS State of knowledge, future challenges and options for an integrated fire management*. www.alpine-region.eu/action-group-8

Chu, D., Lu, L., & Zhang, T. (2007). Sensitivity of Normalized Difference Vegetation Index (NDVI) to seasonal and interannual climate conditions in the Lhasa area, Tibetan Plateau, China. *Arctic, Antarctic, and Alpine Research*, *39*(4), 635–641. https://doi.org/10.1657/1523-0430(07-501)[CHU]2.0.CO;2

Cimini, D., Tomao, A., Mattioli, W., Barbati, A., & Corona, P. (2013). Assessing impact of forest Cover Change dynamics on High Nature Value farmland in Mediterranean mountain landscape. *Annals of Silvicultural Research*, *37*(1), 29–37. https://doi.org/10.12899/ASR-771

Climate Action Tracker. (2019). *Temperature* .

CNEL. (2000). *L'evoluzione della politica forestale italiana dalla legge Serpieri alle sfide europee: obiettivi e strategie*.

Collins, K. M., Penman, T. D., & Price, O. F. (2016). Some wildfire ignition causes pose more risk of destroying houses than others. *PLoS ONE*, *11*(9). https://doi.org/10.1371/journal.pone.0162083

Conedera, M., Cesti, G., Pezzatti, B., & Zumbrunnen, T. (2006, October 27). Lightning-induced fires in the Alpine region: An increasing problem. *V Interantional Conferences on Forest Fire Research*.

Corona, P., Lamonaca, A., & Chirici, G. (2008). Remote sensing support for post fire forest management. *The Italian Society of Silviculture and Forest Ecology*.

Corpo forestale dello stato. (2001). *Le cause degli incendi boschivi*.

Cossu, R., Petitdidier, M., Linford, J., Badoux, V., Fusco, L., Gotab, B., Hluchy, L., Lecca, G., Murgia, F., Plevier, C., Renard, P., Schwichtenberg, H., de Cerff, W. S., Tran, V., & Vetois, G. (2010). A roadmap for a dedicated Earth Science Grid platform. *Earth Science Informatics*, *3*(3), 135–148. https://doi.org/10.1007/s12145-010-0045-4

David Herring. (2020). *What is an "extreme event"? Is there evidence that global warming has caused or contributed to any particular extreme event?*

Dillon, G. K., Holden, Z. A., Morgan, P., Crimmins, M. A., Heyerdahl, E. K., & Luce, C. H. (2011). Both topography and climate affected forest and woodland burn severity in two regions of the western US, 1984 to 2006. *Ecosphere*, *2*(12). https://doi.org/10.1890/ES11-00271.1

Dimopoulou, M., & Giannikos, I. (2001). Spatial Optimization of Resources Deployment for Forest-Fire Management. *International Transactions in Operational Research*, *8*, 523–534. https://doi.org/10.1111/1475-3995.00330

Ebel, B. A. (2012). Impacts of Wildfire and Slope Aspect on Soil Temperature in a Mountainous Environment. *Vadose Zone Journal*, *11*(3). https://doi.org/10.2136/vzj2012.0017

Enley, M. E. (1974). *Fire as an ecologiacl factor in northeastern Minnesota* (No. 8990).

EOS Data Analytics inc. (2022). *NDVI*.

EPA. (2022, August 1). *Climate Change Indicators: Snow and Ice* . U.S. Environmental Protection Agency .

Eskandari, S., & Khoshnevis, M. (2020). Evaluating and mapping the fire risk in the forests and rangelands of Sirachal using fuzzy analytic hierarchy process and GIS. *Forest Research and Development*, *6*(2), 219–245. https://doi.org/10.30466/jfrd.2020.120862

Estes, B. L., Knapp, E. E., Skinner, C. N., Miller, J. D., & Preisler, H. K. (2017). Factors influencing fire severity under moderate burning conditions in the Klamath Mountains, northern California, USA. *Ecosphere*, *8*(5). https://doi.org/10.1002/ecs2.1794

European Commission. (2019). *Science for disaster risk management 2017 : knowing better and losing less* (I. Clark, K. Poljanšek, T. de Groeve, & M. Marin Ferrer, Eds.; 1st ed.). Publications Office of the European Union. https://doi.org/doi/10.2788/842809

Fang, L., Yang, J., Zhang, W., Zhang, W., & Yan, Q. (2019). Combining allometry and landsat-derived disturbance history to estimate tree biomass in subtropical planted forests. *Remote Sensing of Environment*, *235*, 111423. https://doi.org/https://doi.org/10.1016/j.rse.2019.111423

F.A.O. (1999). *International Handbook on Forest Fire Protection- Technical guide for the countries of the Mediterranean basin*.

FAO. (2020). *FRA 2020 TERMS AND DEFINITIONS* (No. 188).

Fernández-Guisuraga, J. M., Suárez-Seoane, S., & Calvo, L. (2019). Modeling Pinus pinaster forest structure after a large wildfire using remote sensing data at high spatial resolution. *Forest Ecology and Management*, *446*, 257–271. https://doi.org/https://doi.org/10.1016/j.foreco.2019.05.028

Finney, M. . A. (2006). An Overview of FlamMap Fire Modeling Capabilities. In P. L. Andrews & B. W. , Butler (Eds.), *Fuels Management—How to Measure Success:* U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Finney, M. A. (2005). The challenge of quantitative risk analysis for wildland fire. *Forest Ecology and Management*, *211*(1), 97–108. https://doi.org/https://doi.org/10.1016/j.foreco.2005.02.010

Forest Service. (2003). *Influence of Forest Structure on Wildfire Behavior and the Severity of Its Effects*.

Freebairn, A., Hagon, K., Turmine, V., Pizzini, G., Singh, R., Kelly, T., Jaime, C., Scherer, N., Siahaan, K., Hartelius, J., Natoli, T., Lagdameo, D. M., Bachofen, C., Emery, G.,

Swithern, S., & Fisher, D. (2020). *World disasters report 2020 : come heat or high water*.
Fréjaville, T., Curt, T., & Carcaillet, C. (2016). Tree cover and seasonal precipitation drive understorey flammability in alpine mountain forests. *Journal of Biogeography*, *43*(9), 1869–1880. https://doi.org/10.1111/jbi.12745
Gambino, R., Romano, B., Event, A., Hamilton, L., Sandwith, T., Rushworth, I., Krueger, S., Potter, D., Zunckle, K., Worboys, G., & Harmon, D. (2003, September 5). Territorial strategies and environmental continuity in mountain systems: The case of the Apennines (Italy). *1WORLD HERITAGE MOUNTAIN PROTECTED AREA FIELD WORKSHOPLinking Protected Areas along the Mountain Range*.
Gangemi, C. (2022, July 25). *Incendi in Sicilia, così l'"industria del fuoco" brucia migliaia di ettari in un anno* . Quotidiano Di Sicilia.
Gigović, L., Jakovljević, G., Sekulović, D., & Regodić, M. (2018). GIS multi-criteria analysis for identifying and mapping forest fire hazard: Nevesinje, Bosnia and Herzegovina. *Tehnicki Vjesnik*, *25*(3), 891–897. https://doi.org/10.17559/TV-20151230211722
GISGeography. (2022, May 29). *What is an Aspect Map?* https://gisgeography.com/aspect-map/
Glitzenstein, J. S., Platt, W. J., & Streng, D. R. (1995). Effects of Fire Regime and Habitat on Tree Dynamics in North Florida Longleaf Pine Savannas. *Ecological Monographs*, *65*(4), 441–476. https://doi.org/https://doi.org/10.2307/2963498
Gobiet, A., Kotlarski, S., Beniston, M., Heinrich, G., Rajczak, J., & Stoffel, M. (2014). 21st century climate change in the European Alps-A review. *Science of the Total Environment*, *493*, 1138–1151. https://doi.org/10.1016/j.scitotenv.2013.07.050
Google. (2022). *GoogleEarthEngine*.
Guglietta, D. (n.d.). *Valorizzazione e gestione delle risorse agroforestali*. UNIVERSITA' DEGLI STUDI DI NAPOLI "FEDERICO II."
Haines, D. A. (1982). Horizontal Roll Vortices and Crown Fires. In *JOURNAL OF APPLIED* (Vol. 21, Issue 6).
Hall, C. M., & Page, S. J. (2009). Progress in Tourism Management: From the geography of tourism to geographies of tourism - A review. *Tourism Management*, *30*(1), 3–16. https://doi.org/10.1016/j.tourman.2008.05.014
Harris, I., Jones, P. D., Osborn, T. J., & Lister, D. H. (2014). Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. *International Journal of Climatology*, *34*(3), 623–642. https://doi.org/https://doi.org/10.1002/joc.3711
Hayes, G. L. (1942). Differences in fire danger with altitude, aspect, and time of day. *Journal of Forestry.* , *40*(4), 418–323.
Heidari, H., Keshtkar, M., Moazzeni, N., Jafari, M., & Azadi, H. (n.d.). *Wildre Severity Zoning Through Google Earth Engine and Fire Risk Assessment: Application of Data Mining and Fuzzy Multi-Criteria Evaluation in Zagros Forests, Iran*. https://doi.org/10.21203/rs.3.rs-268484/v1
Held, I. M., & Soden, B. J. (2000). WATER VAPOR FEEDBACK AND GLOBAL WARMING. In *Annual Review of Energy and the Environment* (Vol. 25). Geophysical Fluid Dynamics Laboratory/National Oceanic and Atmospheric Administration. www.annualreviews.org

INFOCAM. (2020). *Forest Fire Risk through vegetation stress*. UNAP, Regional Forest Fires Service .

INNOTER. (2022). *DTM generation*. https://innoter.com/en/contacts/

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. *International Journal of Geographical Information Systems*, *9*(3), 251–273. https://doi.org/10.1080/02693799508902036

Jiang, B. (2011). *GIS-based Multi-criteria Analysis Used in Forest Fire Estimation: A Case Study of Northernmost Gä vleborg County in Sweden*.

Jiao, Z., Zhang, Y., Xin, J., Mu, L., Yi, Y., Liu, H., & Liu, D. (2019). A Deep Learning Based Forest Fire Detection Approach Using UAV and YOLOv3. *2019 1st International Conference on Industrial Artificial Intelligence (IAI)*, 1–5.

Kang, S., Kim, S., Oh, S., & Lee, D. (2000). *Predicting spatial and temporal patterns of soil temperature based on topography, surface cover and air temperature*. Seoul National University.

Keane, R. E., Burgan, R., & van Wagtendonk, J. (2001). Mapping wildland fuels for fire management across multiple scales: Integrating remote sensing, GIS, and biophysical modeling. *International Journal of Wildland Fire*, *10*(3–4), 301–319. https://doi.org/10.1071/wf01028

Keywood, M., Kanakidou, M., Stohl, A., Dentener, F., Grassi, G., Meyer, C. P., Torseth, K., Edwards, D., Thompson, A. M., Lohmann, U., & Burrows, J. (2013). Fire in the air: Biomass burning impacts in a changing climate. *Critical Reviews in Environmental Science and Technology*, *43*(1), 40–83. https://doi.org/10.1080/10643389.2011.604248

Khan, I., Roman, M., Khan, S., & Husain, S. (2018). *Forest Fire – As an Ecological Factor*.

Kirsanov, A., Rozinkina, I., Rivin, G., Zakharchenko, D., & Olchev, A. (2020). Effect of natural forest fires on regional weather conditions in siberia. *Atmosphere*, *11*(10). https://doi.org/10.3390/atmos11101133

Kogan, F. . N. (1995). APPLICATION OF VEGETATION INDEX AND BRIGHTNESS TEMPERATURE FOR DROUGHT DETECTION. *Space Res*, *15*(11), 273–1177.

Kogan, F., Gitelson, A., Zakarin, E., Spivak, L., & Lebed, L. (2003). *AVHRR-Based Spectral Vegetation Index for Quantitative Assessment of Vegetation State and Productivity: Calibration and Validation*.

Kosztra György, Büttner, B., Hazeu, S., & Arnold, G. (2017). *Updated CLC illustrated nomenclature guidelines*.

Koutsias, N., Xanthopoulos, G., Founda, D., Xystrakis, F., Nioti, F., Pleniou, M., Mallinis, G., & Arianoutsou, M. (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*(4), 493–507. https://doi.org/10.1071/WF12003

Krüll, W., Tobera, R., Willms, I., Essen, H., & Wahl, N. (2012). Early Forest Fire Detection and Verification using Optical Smoke, Gas and Microwave Sensors. *Procedia Engineering*, *45*, 584–594. https://doi.org/10.1016/j.proeng.2012.08.208

Kumari, B., & Pandey, A. C. (2020). Geo-informatics based multi-criteria decision analysis (MCDA) through analytic hierarchy process (AHP) for forest fire risk mapping in

Palamau Tiger Reserve, Jharkhand state, India. *Journal of Earth System Science*, *129*(1). https://doi.org/10.1007/s12040-020-01461-6

Lanza, A. (2002). *il cambiamento climatico* (il Mulino, Ed.).

Laschi, A., Foderi, C., Fabiano, F., & Cambi, M. (2019). Forest Road Planning, Construction and Maintenance to Improve Forest Fire Fighting: a Review. *Article in Croatian Journal of Forest Engineering*, *40*, 1. https://www.researchgate.net/publication/331409427

Lecina-Diaz, J., Alvarez, A., & Retana, J. (2014). Extreme fire severity patterns in topographic, convective and wind-driven historical wildfires of mediterranean pine forests. *PLoS ONE*, *9*(1). https://doi.org/10.1371/journal.pone.0085127

Lee, S., Cho, M., & Lee, C. (2016). An effective gap interpolation and filtering (GIF) method for landsat 7 ETM+ SLC-off Data. *Terrestrial, Atmospheric and Oceanic Sciences*, *27*(6), 921–932. https://doi.org/10.3319/TAO.2016.07.18.02

Lin, C.-Y., Shieh, P.-Y., Wu, S.-W., Wang, P.-C., & Chen, Y.-C. (2022). Environmental indicators combined with risk analysis to evaluate potential wildfire incidence on the Dadu Plateau in Taiwan. *Natural Hazards*, *113*(1), 287–313. https://doi.org/10.1007/s11069-022-05300-3

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M. J., & Marchetti, M. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecology and Management*, *259*(4), 698–709. https://doi.org/10.1016/j.foreco.2009.09.023

Loveland, T. R., & Dwyer, J. L. (2012). Landsat: Building a strong future. *Remote Sensing of Environment*, *122*, 22–29. https://doi.org/https://doi.org/10.1016/j.rse.2011.09.022

Lovreglio, R., Leone, V., Giaquinto, P., & Notarnicola, A. (2010). Wildfire cause analysis: Four case-studies in southern Italy. *IForest*, *3*(JANUARY), 8–15. https://doi.org/10.3832/ifor0521-003

Mantero, G., Morresi, D., Marzano, R., Motta, R., Mladenoff, D. J., & Garbarino, M. (2020). The influence of land abandonment on forest disturbance regimes: a global review. In *Landscape Ecology* (Vol. 35, Issue 12, pp. 2723–2744). Springer Science and Business Media B.V. https://doi.org/10.1007/s10980-020-01147-w

Markham, B. (2013, July). *Landsat 8* . NASA.

Martínez, J., Vega-Garcia, C., & Chuvieco, E. (2009). Human-caused wildfire risk rating for prevention planning in Spain. *Journal of Environmental Management*, *90*(2), 1241–1252. https://doi.org/10.1016/j.jenvman.2008.07.005

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Buendía, E. C., Shukla, P. R., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Pereira, J. P., Vyas, P., Huntley, E., … Malley; Juliette. (2020). *Climate Change and Land ; An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems Summary for Policymakers*.

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (2018). *Global warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. www.environmentalgraphiti.org

McLauchlan, K. K., Higuera, P. E., Miesel, J., Rogers, B. M., Schweitzer, J., Shuman, J. K., Tepley, A. J., Varner, J. M., Veblen, T. T., Adalsteinsson, S. A., Balch, J. K., Baker, P., Batllori, E., Bigio, E., Brando, P., Cattau, M., Chipman, M. L., Coen, J., Crandall, R., … Watts, A. C. (2020). Fire as a fundamental ecological process: Research advances and frontiers. *Journal of Ecology*, *108*(5), 2047–2069. https://doi.org/https://doi.org/10.1111/1365-2745.13403

Melesse, A. M., Weng, Q., Thenkabail, P. S., & Senay, G. B. (2007). Remote Sensing Sensors and Applications in Environmental Resources Mapping and Modelling. *Sensors*, *7*, 3209–3241. http://earth.google.com

Mercogliano, P., Villani, V., Raffa, M., & Barbato, G. (2021). *Torino e il CLIMA: passato e futuro*. CMCC – Centro Euro-Mediterraneo Sui Cambiamenti Climatici.

Merriam-Webster. (2022, August 12). *Stubble* . Merriam-Webster.Com Dictionary.

Miller, C., Plucinski, M., Sullivan, A., Stephenson, A., Huston, C., Charman, K., Prakash, M., & Dunstall, S. (2017). Electrically caused wildfires in Victoria, Australia are over-represented when fire danger is elevated. *Landscape and Urban Planning*, *167*, 267–274. https://doi.org/10.1016/j.landurbplan.2017.06.016

Mizutori, M. (2020). *Time to say goodbye to "natural" disasters* . United Nations Office for Disaster Risk Reduction.

Moreira, F., Vaz, P., Catry, F., & Silva, J. S. (2009). Regional variations in wildfire susceptibility of land-cover types in Portugal: implications for landscape management to minimize fire hazard. *International Journal of Wildland Fire*, *18*(5), 563–574. https://doi.org/10.1071/WF07098

Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Barbati, A., Corona, P., Vaz, P., Xanthopoulos, G., Mouillot, F., & Bilgili, E. (2011). Landscape - wildfire interactions in southern Europe: Implications for landscape management. In *Journal of Environmental Management* (Vol. 92, Issue 10, pp. 2389–2402). https://doi.org/10.1016/j.jenvman.2011.06.028

Moris, J. v., Conedera, M., Nisi, L., Bernardi, M., Cesti, G., & Pezzatti, G. B. (2020). Lightning-caused fires in the Alps: Identifying the igniting strokes. *Agricultural and Forest Meteorology*, *290*. https://doi.org/10.1016/j.agrformet.2020.107990

Morresi, D., Marzano, R., Lingua, E., Motta, R., & Garbarino, M. (2022). Mapping burn severity in the western Italian Alps through phenologically coherent reflectance composites derived from Sentinel-2 imagery. *Remote Sensing of Environment*, *269*. https://doi.org/10.1016/j.rse.2021.112800

Morrison, Peter. H. (2007). *Roads and Wildfires*. www.pacificbio.org

Mueller, S. E., Thode, A. E., Margolis, E. Q., Yocom, L. L., Young, J. D., & Iniguez, J. M. (2020). Climate relationships with increasing wildfire in the southwestern US from

1984 to 2015. *Forest Ecology and Management*, *460*. https://doi.org/10.1016/j.foreco.2019.117861

Murphy, P. J., Beaufait, W. R., & Steele, R. W. ,. (1966). FIRESPREAD IN AN ARTIFICIAL FUEL. In *University of Montana (Missoula, Mont. : 1965-1994). School of Forestry. Montana Forest and Conservation Experiment Station*. https://scholarworks.umt.edu/umforestrybulletin/17

NASA. (2022). *NASA's Landsat Program. The Landsat 7 Compositor*.

Neary, D. G. (2004). *Fire Effects on Soils*.

Normativa. (2022). *Legge-quadro in materia di incendi boschivi*. . Istituto Poligrafico e Zecca Dello Stato S.p.A.

Nova Scotia. (2021). *Basic Forest Fire Suppression Course*. Governament of Nova Scotia .

NWCG. (2021). *Fire Behavior Field Reference Guide, PMS 437* . National Wildfire Cordinating Group . https://www.nwcg.gov/publications/pms437/weather/estimating-winds-for-fire-behavior#TOC-definitions

Pei, Z., Fang, S., Yang, W., Wang, L., Wu, M., Zhang, Q., Han, W., & Khoi, D. N. (2019). The relationship between NDVI and climate factors at different monthly time scales: A case study of grasslands in inner mongolia, China (1982-2015). *Sustainability (Switzerland)*, *11*(24). https://doi.org/10.3390/su11247243

Pereira, P., Francos, M., Brevik, E. C., Ubeda, X., & Bogunovic, I. (2018). Post-fire soil management. *Current Opinion in Environmental Science & Health*, *5*, 26–32. https://doi.org/https://doi.org/10.1016/j.coesh.2018.04.002

Pérez-Cabello, F., Montorio, R., & Alves, D. B. (2021). Remote sensing techniques to assess post-fire vegetation recovery. In *Current Opinion in Environmental Science and Health* (Vol. 21). Elsevier B.V. https://doi.org/10.1016/j.coesh.2021.100251

Pérez-Invernón, F. J., Huntrieser, H., Soler, S., Gordillo-Vázquez, F. J., Pineda, N., Navarro-González, J., Reglero, V., Montanyà, J., van der Velde, O., & Koutsias, N. (2021). Lightning-ignited wildfires and long continuing current lightning in the Mediterranean Basin: Preferential meteorological conditions. *Atmospheric Chemistry and Physics*, *21*(23), 17529–17557. https://doi.org/10.5194/acp-21-17529-2021

Permanente, K., & The kresge fundation. (2016). *Climate Change 101: climate science basics*.

Pettinari, M. L., & Chuvieco, E. (2017). Fire Behavior Simulation from Global Fuel and Climatic Information. *Forests*, *8*(6). https://doi.org/10.3390/f8060179

Pickell, P. D., Hermosilla, T., Frazier, R. J., Coops, N. C., & Wulder, M. A. (2016). Forest recovery trends derived from Landsat time series for North American boreal forests. *International Journal of Remote Sensing*, *37*(1), 138–149. https://doi.org/10.1080/2150704X.2015.1126375

Pickett, S. T., & White, P. S. (1985). *The ecology of natural disturbance and patch dynamics*. ACADEMIC PRESS, INC.

Piralilou, S. T., Einali, G., Ghorbanzadeh, O., Nachappa, T. G., Gholamnia, K., Blaschke, T., & Ghamisi, P. (2022). A Google Earth Engine Approach for Wildfire Susceptibility Prediction Fusion with Remote Sensing Data of Different Spatial Resolutions. *Remote*

Sensing, *14*(3). https://doi.org/10.3390/rs14030672

Pittarello, F. (2019). *MODELLAZIONE NUMERICA DELLA DINAMICA DI COLATE DETRITICHE POST INCENDIO: ANALISI DELL'EVENTO DEL 7 GIUGNO 2018 NEL COMUNE DI BUSSOLENO (TO)*. Politecnico di Torino .

Pörtner, H.-O., Roberts, D. C., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., & Weyer, N. M. (2019). *The Ocean and Cryosphere in a Changing Climate A Special Report of the Intergovernmental Panel on Climate Change Edited by*.

Prasad, V. K., Badarinath, K. V. S., & Eaturu, A. (2008). Effects of precipitation, temperature and topographic parameters on evergreen vegetation greenery in the Western Ghats, India. *International Journal of Climatology*, *28*(13), 1807–1819. https://doi.org/10.1002/joc.1662

Protezione civile. (2022). *Piani regionali di previsione, prevenzione e lotta attiva agli incendi boschivi*.

Quiring, S. M., & Ganesh, S. (2010). Evaluating the utility of the Vegetation Condition Index (VCI) for monitoring meteorological drought in Texas. *Agricultural and Forest Meteorology*, *150*(3), 330–339. https://doi.org/10.1016/j.agrformet.2009.11.015

Rathaur, S. (2006). *Fire Risk Assessment for Tiger Prey-base in Chilla Range and vicinity, Rajaji National Park using Remote Sensing and GIS*.

Regione Piemonte. (2021). *PIANO REGIONALE PER LA PROGRAMMAZIONE DELLE ATTIVITÀ DI PREVISIONE, PREVENZIONE E LOTTA ATTIVA CONTRO GLI INCENDI BOSCHIVI*.

Regione Piemonte. (2022). *Geoportale*. https://www.geoportale.piemonte.it/geonetwork/srv/ita/catalog.search#/home

Saaty, T. L. (1994). *How to Make a Decision: The Analytic Hierarchy Process*.

San-Miguel-Ayanz, J., Costa, H., de Rigo, D., Libertà Giorgio, Vivancos, T. artés, Durrant, T., Nuijten, D., Löffler, P., & Moore, P. (2018). *Basic criteria to assess wildfire risk at the pan-European level*. https://doi.org/10.2760/228736

Schultz, C. J., Nauslar, N. J., Wachter, J. B., Hain, C. R., & Bell, J. R. (2019). Spatial, temporal and electrical characteristics of lightning in reported lightning-initiated wildfire events. *Fire*, *2*(2), 1–15. https://doi.org/10.3390/fire2020018

Spyratos, V., Bourgeron, P. S., & Ghil, M. (2007). *Development at the wildland-urban interface and the mitigation of forest-fire risk* (Vol. 104, Issue 36). www.pnas.orgcgidoi10.1073pnas.0704488104

Sriwongsitanon, N., Gao, H., Savenije, H. H. G., Maekan, E., Saengsawang, S., & Thianpopirug, S. (2016). Comparing the Normalized Difference Infrared Index (NDII) with root zone storage in a lumped conceptual model. *Hydrology and Earth System Sciences*, *20*(8), 3361–3377. https://doi.org/10.5194/hess-20-3361-2016

Steel, Z. L., Koontz, M. J., & Safford, H. D. (2018). The changing landscape of wildfire: burn pattern trends and implications for California's yellow pine and mixed conifer forests. *Landscape Ecology*, *33*(7), 1159–1176. https://doi.org/10.1007/s10980-018-0665-5

Steinfeld, D., Peter, A., Martius, O., & Brönnimann, S. (2022). *Assessing the performance of various fire weather indices for wildfire occurrence in Northern Switzerland*. https://doi.org/10.5194/egusphere-2022-92

Subedi, P. B., Ayer, K., Miya, M. S., Parajuli, B., & Sharma, B. (2022). Forest Fire Risk Zone Mapping of Aalital Rural Municipality, Dadeldhura District, Nepal. *Journal of Multidisciplinary Applied Natural Science*, *2*(2), 70–81. https://doi.org/10.47352/jmans.2774-3047.115

Sudmanns, M., Tiede, D., Lang, S., Bergstedt, H., Trost, G., Augustin, H., Baraldi, A., & Blaschke, T. (2020). Big Earth data: disruptive changes in Earth observation data management and analysis? *International Journal of Digital Earth*, *13*(7), 832–850. https://doi.org/10.1080/17538947.2019.1585976

The Royal Society. (2020). *Climate Change: Evidence & Causes*. https://www.nap.edu/catalog/18373]

Thompson, M. P., Gannon, B. M., & Caggiano, M. D. (2021). Forest roads and operational wildfire response planning. *Forests*, *12*(2), 1–11. https://doi.org/10.3390/f12020110

Tobias LANGANKE, C. (2018). *Copernicus Land Monitoring Service –High Resolution Layer Forest: Product Specifications Document*. Copernicus team at EEA.

Töreyin, B. U., Cinbis, R. G., Dedeoglu, Y., & Cetin, A. E. (2007). Fire detection in infrared video using wavelet analysis. *Optical Engineering*, *46*(6), 067204. https://doi.org/10.1117/1.2748752

Tucker, C. J. (1979). Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. In *REMOTE SENSING OF ENVIRONMENT* (Vol. 8).

Turetsky, M. R., Abbott, B. W., Jones, M. C., Anthony, K. W., Olefeldt, D., Schuur, E. A. G., Grosse, G., Kuhry, P., Hugelius, G., Koven, C., Lawrence, D. M., Gibson, C., Sannel, A. B. K., & McGuire, A. D. (2020). Carbon release through abrupt permafrost thaw. *Nature Geoscience*, *13*(2), 138–143. https://doi.org/10.1038/s41561-019-0526-0

Turner, M. G., Baker, W. L., Peterson, C. J., & Peet, R. K. (1998). Factors Influencing Succession: Lessons from Large, Infrequent Natural Disturbances. *Ecosystems*, *1*(6), 511–523.

Turner, M. G., Hargrove, W. W., & Gardner, R. H. (1994). Effects of fire on landscape heterogeneity in Yellowstone National Park, Wyoming. *Journal of Vegetation Science*, *5*(5). https://www.jstor.org/stable/3235886?seq=1&cid=pdf-

Tuttitalia. (2020). *Statistiche demografiche città metropolitana di Torino*. https://www.tuttitalia.it/piemonte/provincia-di-torino/statistiche/

UNDRR. (2017). *Online glossary*.

UNEP. (2020, January 22). *Story – Climate Change: Ten impacts of the Australian bushfires*. https://www. unenvironment.org/news-and-stories/story/ten-impacts-australian-bushfires

Urban, J. L., Zak, C. D., & Fernandez-Pello, C. (2015). Cellulose spot fire ignition by hot metal particles. *Proceedings of the Combustion Institute*, *35*(3), 2707–2714. https://doi.org/https://doi.org/10.1016/j.proci.2014.05.081

Vadrevu, K. P., Eaturu, A., & Badarinath, K. V. S. (2010). Fire risk evaluation using multicriteria analysis-a case study. *Environmental Monitoring and Assessment*, *166*(1–4), 223–239. https://doi.org/10.1007/s10661-009-0997-3

Valese, E., Conedera, M., Vacik ; Harald, & Japelj, A. (2011). *Wildfires in the Alpine region:*

first results from the ALP FFIRS project. http://www.alpffirs.eu
Vallejo-Villalta, I., Rodríguez-Navas, E., & Márquez-Pérez, J. (2019). Mapping forest fire risk at a local scale—A case study in Andalusia (Spain). *Environments - MDPI*, *6*(3). https://doi.org/10.3390/environments6030030
van Wagner, C. (1987). *Development and Structure of the Canadian Forest Fire Weather Index System*.
Veblen, T. T., Baker, W. L., Montenegro, G., & Swetnam, T. W. (2002). *Fire and Climatic Change in Temperate Ecosystems of the Western Americas*. Springer.
Vega, J. A., & Díaz-Fierros Viqueira, F. (1987). Wild fire effects on soil erosion. *Ecologia Mediterranea*, *13*(4), 119–125. https://doi.org/10.3406/ecmed.1987.1195
Veraverbeke, S., Verstraeten, W. W., Lhermitte, S., van de Kerchove, R., & Goossens, R. (2012). Assessment of post-fire changes in land surface temperature and surface albedo, and their relation with fireburn severity using multitemporal MODIS imagery. *International Journal of Wildland Fire*, *21*(3), 243–256. https://doi.org/10.1071/WF10075
Vetritto, G., Guglielmi, F., Giannino, C., Canzonetti, A., de Leo, M., Gualtieri, S., & la Nave, M. (2017). *I dossier delle Città Metropolitane*.
Vicente-Serrano, S. M. (2007). Evaluating the impact of drought using remote sensing in a Mediterranean, Semi-arid Region. *Natural Hazards*, *40*(1), 173–208. https://doi.org/10.1007/s11069-006-0009-7
Viegas, D. X., Bovio, G., Ferreira, A., Nosenzo, A., & Sol, B. (2000). Comparative study of various methods of fire danger evaluation in southern Europe. *International Journal of Wildland Fire*, *9*(4), 235–246. https://doi.org/10.1071/WF00015
VITTORIO EMANUELE, Mussolini, Corbino, Oviglio, Diaz, Thaon di Revel, Dè Stefani, & Carnazza. (1923). REGIO DECRETO LEGISLATIVO 30 dicembre 1923, n. 3267 «Riordinamento e riforma della legislazione in materia di boschi e di terreni montani». In *Gazetta Ufficiale* .
Walelegn, & Mengist Zeleke. (2019). *Wildfire Hazard Mapping using GIS-MCDA and Frequency Ratio Models*. University of GAVLE.
Weise, D. R., Biging, G. S., & Hall, M. (1994). *Effects of Wind Velocity and Slope on Fire Behavior*.
Westerling, A. L., Hidalgo, H. G., Cayan D.R., & Swetnam T.W. (2006, August 18). Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. *Science*, *313*(5789), 936–940. https://doi.org/10.1126/science.1130691
Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses : a guide to conservation planning*.
Wotton, B. M., Nock, C. A., & Flannigan, M. D. (2010). Forest fire occurrence and climate change in Canada. *International Journal of Wildland Fire*, *19*(3), 253–271. https://doi.org/10.1071/WF09002
Xue, J., & Su, B. (2017). Significant remote sensing vegetation indices: A review of developments and applications. In *Journal of Sensors* (Vol. 2017). Hindawi Limited. https://doi.org/10.1155/2017/1353691
Yakupoğlu, T., Dindaroğlu, T., Rodrigo-Comino, J., & Cerdà, A. (2022). Stubble burning and wildfires in Turkey considering the Sustainable Development Goals of the United

Nations. *Eurasian Journal of Soil Science*, *11*(1), 66–76. https://doi.org/10.18393/EJSS.993611

Zanut, D. (2022). *Fire & Explosion investigations* .

Živanović, S., Ivanović, R., Nikolić, M., Đokić, M., & Tošić, I. (2020). Influence of air temperature and precipitation on the risk of forest fires in Serbia. *Meteorology and Atmospheric Physics*, *132*(6), 869–883. https://doi.org/10.1007/s00703-020-00725-6

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