POLITECNICO DI TORINO

Engineering Department

Master of Science in Civil Engineering

Career: Structure and Infrastructure

Thesis of Master’s Degree:

From Hazards to Mitigation: An innovative and Simplified Multi-Criteria Risk Assessment for Infrastructure in the Orco Valley.

Relator:
Prof. Anna Osello

Correlator:
Ing. Davide Aschieri

Candidate:

Cristian Camilo Pérez Andrade - s274587

2025

ACKNOWLEDGEMENTS

I would like to express my immense gratitude to my mother, who is one of the most important person in my life, for allowing me to travel and study in Italy, and for continuing to push me to levels I never thought I would reach, her continued support and encouragement inspires me to seek to be the best version of myself. I also thank my siblings for trusting me, believing in me, and admiring me in the way they have told me they do, as they encourage me to continue growing so I can contribute more to our family and the world.

I thank once again the friends I made in Turin, who have become my second family in this foreign land; I consider myself very lucky to know and be surrounded by such incredible people.

The enjoyment of this project has exceeded my initial expectations; Each page of this thesis represents not only the effort and dedication of the last few months, but also the culmination of so many years of study; I particularly believe that this master's degree not only made me grow in technical or professional matters, but rather, it has been a Master of myself, of my emotions, abilities, and my mind; process that has marked my life forever, since in its course I managed to overcome difficult events of all kinds along the way.

This thesis represents the pinnacle of my academic career and marks the threshold of my personal and professional career. I extend my sincere gratitude to everyone who has supported and guided me throughout this arduous but rewarding journey.

I also extend my gratitude to my relator and co-relator, who provided me with excellent guidance throughout this thesis project. I appreciate the opportunity to be part of this project, as it was an experience that I really enjoyed and really learned from.

Finally, thank you all for making this possible.

ABSTRACT

Civil engineers play a critical role in the construction and maintenance of infrastructures that shape every aspect of communities. To ensure the safety and effectiveness of these crucial projects, they conduct risk assessments to identify potential hazards and vulnerabilities in structures and surrounding area. The results of risk assessment help to mitigate such hazards, especially those associated with natural disasters. This thesis project focuses on the Orco Valley, a narrow mountain valley in the Piedmont region known for its rich history and infrastructure. Located near Italy's oldest national park, Gran Paradiso, the valley features like medieval towns, churches, modern municipalities, major infrastructure works, including hydroelectric plants, highlighting the economic and engineering importance of the valley. By analyzing the risks in this area, the project aims to contribute to the safety and sustainability of this unique environment.

This thesis project will employ two main tools: GIS for territorial analysis and BIM for integration with existing civil works, with the aim of comprehensively assessing risks and developing more resilient and safer infrastructure, despite the challenges inherent in the complex case study, which will be further explored in this thesis. A dual approach will be used for risk assessment; initially, a qualitative method will prioritize risk factors by severity and probability to optimize resource allocation; subsequently, a quantitative experimental design with a GIS model will establish cause-and-effect relationships between the nature of the risk, infrastructure characteristics, area specificities, exposure, and consequences of hazards, based on observations, research, and official data.

Risk analyses in the Orco Valley identified critical points for the electricity distribution networks in the face of various threats. Specifically, Goritti is the area most vulnerable to flooding, Rosone to landslides, Villa to avalanches, and Pont-Canavese to forest fires. In all these cases, the primary concern lies in the direct impact on a small hydroelectric plant and nearby distribution networks, which are considered more critical than the general networks.

This thesis developed an innovative and simplified method for assessing infrastructure risk in the Orco Valley, combining qualitative risk factor analysis with quantitative GIS models, utilizing public data and multi-criteria analysis for effective natural hazard management. The study generated hazard probability maps based on historical data to predict scenarios, delineate risk zones, and validate predictive models, thereby identifying vulnerabilities and proposing mitigation solutions for specific Points of Interest (POIs). It also demonstrated that mitigation works are crucial for infrastructure resilience, even without pre-existing 3D models thanks to the use of open-source intelligence (OSINT).

The core innovation lies in this integration of qualitative and quantitative analysis for a simplified risk assessment, which optimizes resource allocation and offers a practical tool to engineers and authorities, reducing costs and time. Furthermore, the work suggests significant improvements in the way public entities, such as the Piedmont Region, provide GIS information, promoting greater utility, interoperability, and evidence-based decision-making, which in turn empowers citizens and strengthens risk management and sustainable territorial development policies. Despite the inherent limitations of qualitative data collection and the challenges of BIM-GIS integration, the simplified model proved effective and reliable, providing valuable information and contributing to community protection.

Key words:

Risk Assessment, Potential Risk Factors, Mountain Valley, Hydroelectric Infrastructure, Natural Hazards, Area Features, Exposition, Consequences, GIS Methodology, BIM Methodology, Civil Works Context, Innovative Method, Simplified Method, Qualitative Design, Quantitative Design, Public Data, Multi-Criteria Analysis, Hazards Management, Historical Data, Infrastructure Resilience, Open-Source Intelligence,

CONTENT INDEX

FIGURES INDEX

TABLE INDEX

1. INTRODUCTION

1.1. Problem Statement

One of the many purposes of Civil Engineering is to plan, build and maintain Civil Works. These civil works can be structural/infrastructure works, environmental works, geotechnical works and sustainable development works; these works have a significant impact on people's lives, as they provide means to live, transport, work, study, recreation, and provide distribution services such as water, energy, gas, among others.

Given the importance of these civil works for the lives of people and communities, it is necessary to assess the risk to which they and their surrounding area are subjected, since these assessments can be helpful in identifying and mitigating potential unwanted hazards. Risk assessment can be carried out through hazard analysis, vulnerability analysis and risk analysis. (Rogers, 2012)

The hazard analysis identifies potential hazards to which civil work and the territory are exposed. The vulnerability analysis assesses the vulnerability of civil work and the surrounding area to the identified hazards. The risk analysis combines the results of hazard analysis and vulnerability analysis to estimate the probability that a harmful event will occur and the magnitude of the damage it could cause. (M. Halpern, 2018) From now on, we will call these concepts that we have just described as Potential Risk Factors, for a better understanding of the work carried out during this thesis project.

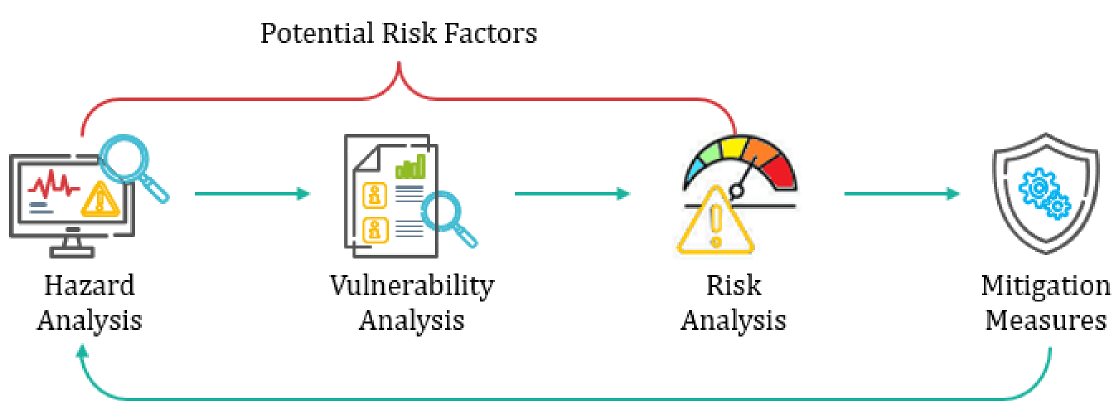


Figure 1. Risk Assessment Procedures.

The results of the risk assessment can be used to develop mitigation measures, such as stricter construction requirements, mitigation infrastructure, and emergency plans; given that, stricter construction requirements can help to make civil works more resistant to risk, mitigation infrastructure can help to reduce the impact of the identified risk, and the emergency plans can help to protect people and property in case different disasters occur. In summary, risk assessment for civil work and territory is an important procedure for protecting people and property from different hazards. (Rogers, 2012)

There are three important sources from which risks could come and affect people and their property; The first would be related to natural events, such as meteorological and geographical conditions (earthquakes, floods, storms, wildfires, etc.); the second would be related to human actions and activity (construction accidents, equipment malfunctions, human errors, etc.); and the third would be related to the specific risks of the project (material defects, design defects, construction defects). (M. Halpern, 2018) These sources are also known in the literature as environmental conditions, safety conditions and technical conditions respectively.

After having considered the importance of risk assessment for civil work and the territory, having exposed how to estimate and mitigate these harmful events, and identifying the multiple sources from which they may come, is now the moment to indicate the location of the project. The development of this thesis project will be carried out in Italy, over a mountain valley called Orco in the Piedmont Region. Different methodologies will be used that serve today as work tools for a complete and more organized realization of the project. These methodologies are Geographic Information Systems (GIS) and Building Information Modeling (BIM). With the integration of these two methodologies, we will be able to collect all the necessary information and develop this thesis project in a more interoperable and multidisciplinary way, obtaining more precise results.

1.2. Objectives

1.2.1. Overall Objectives

The main objective of this thesis project is to simplify and innovate risk assessment by integrating multicriteria analysis, utilizing information published by official entities, specifically for the Orco Valley area. Using GIS and BIM methodologies, a comprehensive assessment of natural risks will be provided, suggesting mitigation measures for undesired events. This multicriteria decision-making technique allows for the weighing of different factors and the making of informed decisions.

1.2.2. Specific Objectives

1. Determine the natural hazards that occur in the Orco Valley, as well as prioritize them based on their severity and probability.
2. Establish the points of interest (POI's) and evaluate the specific characteristics of the infrastructures to determine their inherent weakness, as well as their possible exposure to hazards and consequences that could occur if they are affected by one of them.
3. Evaluate the geomorphological characteristics in the Orco Valley to determine its vulnerability to natural hazards.
4. Define the areas and the POI's with the highest risk according to the results obtained and suggest different possible solutions for risk mitigation.
5. Present innovative methodologies applied around the world today for the solution, evaluating their implementation, management and interoperability.
6. Final considerations, discussions and conclusions.

1.3. Case Study and Background

As mentioned above, this thesis project is located in the Orco Valley, a mountain valley in the Piedmont Region; the location of the case study area is close to the Parco Gran Paradiso, that it's one of the oldest national parks in Italy. The valley is particularly narrow, especially in the central part, where there are some hydroelectric energy plants; of which its main hydroelectric plant is in Rosone, in the Locana village, and its main lake is Lake Ceresole, which is at the top zone of the valley.

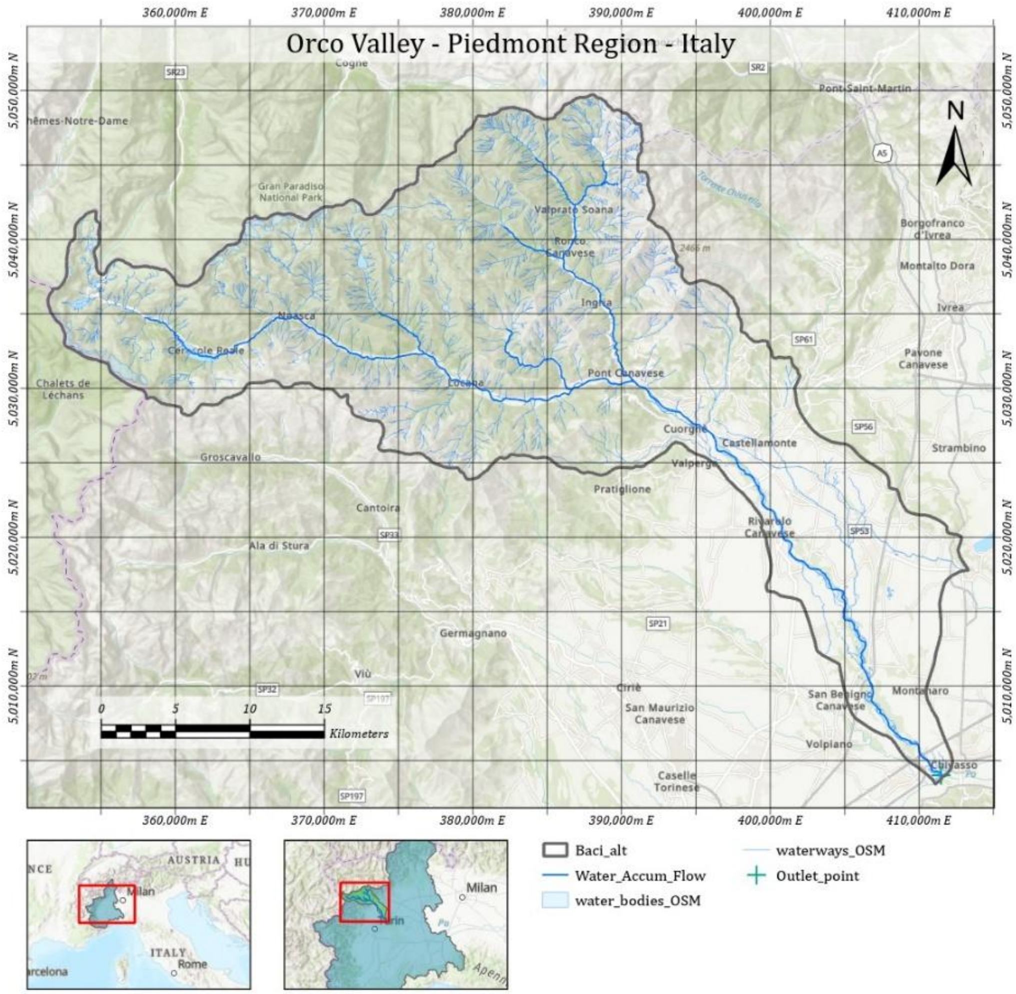


Figure 2. Basins Picture

The valley is full of lakes, some natural alpine, other artificial ones, among which are Lake Ceresole, Lake Serrù, Lake Agnel, Lake Telessio, Lake Valsoera, Lake Eugio, Lake Motta, Lake Gelato, and Lake Rosset; The reservoirs, formed by artificial dams, are designed to feed the hydroelectric power plants in the Orco Valley, and are developed according to the sequence indicated:

- The two Agnel and Serrù tanks feed the Villa Di Ceresole energy plant, from which wastewater flows to the Ceresole tank.
- The Ceresole deposit, together with the Lake Telessio, and waters of the Valsoera deposit, feeds the Rosone Energy Plant.
- The Bardonetto energy plant receives the wastewater from the Rosone Energy Plant, as well as the waters of the Orco.
- The Pont-Canavese hydroelectric energy station receives its water from the Bardonetto power plant.

Figure 3. The Ceresole Reale Dam and Villa Ceresole Hydroelectric Power Station

In addition, in the Orco Valley there is a harmonious mix of history, nature and human development. Medieval towns with their stone houses and narrow streets bear witness to the past; historic churches reflect religious heritage and farms display agricultural character. Modern municipalities thrive alongside these historic gems; roads, bridges and services connect communities, serving both residents and tourists attracted by the nearby Gran Paradiso Park. However, this delicate balance is threatened by natural hazards. To protect this valuable environment, we will examine the valley's history of such events and explore the use of GIS and BIM to assess risks and integrate mitigation strategies.

As can be seen, this valley contains highly significant infrastructure for the area. Specifically, essential infrastructure for renewable energy generation, such as hydroelectric power; these include dams, hydroelectric plants, electrical transformation cabins, aqueducts, and electrical distribution networks. Therefore, we have defined these infrastructures as our potential points of interest (POIs). With all the characteristics of the case study fully recognized, we will conduct exhaustive research and a literature review, focusing on methodologies and considerations of different risk cases for infrastructure and the territory that have been used worldwide. By covering all dimensions of the problem, a solution will be provided that seeks to address the need for estimating and mitigating damaging events and provide added value to the study area.

2. Research Context

This section aims to put the main topic of this thesis project into a general context, providing information on their concepts for their correct development and understanding. This contextualization is essential to develop a solid foundation for the case study since some concepts will be applied and developed during this thesis project. These concepts are the same ones that were briefly mentioned in the introduction but will now be described in a more detailed manner here in this section.

2.1. Civil Works

As previously stated, Civil Works play a vital role in the development of communities, as they form the foundation on which economies and social activities function. These projects can be the construction, maintenance, improvement, and repair of physical systems for the use of the civilian population; these are categorized as structural/infrastructure works, environmental works, and geotechnical works. This makes the impacts of civil projects wide-reaching, affecting economic growth, social equity, environmental sustainability, and public safety. (ASCE, 2017) Below is a general description of civil works, especially those that are included in the case study of this thesis project.

2.1.1. Structure and Infrastructure Works

Structural works, such as bridges and buildings, among others, form the backbone of infrastructure projects; they are permanent structures designed to bear loads and ensure stability, using different types of materials. Infrastructure projects, on the other hand, are typically large-scale undertakings that involve planning, engineering expertise and financing. They encompass infrastructure like transportation, energy, water systems and communication systems. (Smith & Pinto, 2018) For this specific case study, we will delve into the infrastructure found within the Orco Valley, as well as the structures that are part of the potential POI's that were previously mentioned.

2.1.1.1. Transportation Works

Transport network infrastructures are the physical structures that enable the movement of people and goods. They are essential for the functioning of modern societies, facilitating economic activity, social interaction, and international trade. The infrastructure works that can be found in the transportation networks are roads, highways, bridges, airports, tunnels, seaports, public transport systems, among others. By addressing a sustainable transport infrastructure, we can create more efficient, equitable, and environmentally friendly transportation systems. (Bamford & New, 2012)

2.1.1.2. Energy Works

Energy infrastructure are the systems, networks, and equipment that generate, transmit, distribute, and store energy. Power plants harness a variety of resources, including coal, natural gas, hydropower, solar power, wind power, and nuclear power, to produce electricity. High-voltage power lines transport this electricity long distances to distribution centers, which then distribute it to homes, businesses, and industries. A strong energy infrastructure is vital to economic development, providing reliable, affordable energy to fuel industries. It also improves quality of life by powering essential services such as lighting, heating, cooling, and communications. (Borrelli, 2018)

The infrastructure works that can be found in the Orco Valley for the energy systems are power generation plants, electrical transformation cabins, the transmission lines and the distribution network. A description of these physical systems is given below.

- Power plants are essential for the modern world, transforming various energy sources, from fossil fuels to renewables and nuclear power, into the electricity that keeps homes and industries running. These facilities utilize coal, gas, oil, or also renewable options like hydro, wind, solar, geothermal, and nuclear power, depending on factors like cost, resource availability, environmental regulations, and the need for a secure and diverse energy supply. (Rajput, 2014)

- Electrical transformer cabinets perform an essential task, like adjusting voltage levels in power distribution systems. This is a crucial step to protect electrical components, controlling the flow of power, and ensuring a safe and efficient supply of electricity to homes, businesses, and industries. These cabinets are found in various locations, including substations, residential areas, and industrial facilities. However, due to the presence of high-voltage components, it is essential that they are handled with the utmost care and only by qualified professionals. (Fink & Beaty, 2017)

- Transmission lines are the “highways” of electricity, transporting power from power plants to substations. These conductors, whether overhead or underground, ensure the efficient flow of electricity over long distances. Different types of lines, including overhead, underground, and high-voltage lines, minimize energy loss. Distribution networks, meanwhile, are the final leg of the journey, transporting power from substations to homes and businesses. (Saadat, 2010)

2.1.1.3. Hydraulic Works

Water system infrastructure or hydraulic works ensures a reliable supply of clean water and proper wastewater management. It encompasses collection systems such as dams and wells, drinking water and wastewater treatment plants, storage tanks, distribution networks, and disposal systems. This critical infrastructure ensures access to clean water, protects public health, supports economic development, and safeguards the environment. (Mays, 2010) The infrastructure works that can be found in the Orco Valley for water systems are water treatment plants, reservoirs, dams and aqueducts. Below is a description of these physical works.

- Water treatment plants purify raw water from lakes, rivers or even seawater into clean and safe drinking water. To do this, they employ a series of physical, chemical and biological processes to remove impurities. This multi-step process typically involves clarification, sedimentation, filtration, disinfection and storage. Pipes, on the other hand, are essential for long-distance fluid transportation. The choice of pipe material, diameter, pumping stations and control systems is crucial for efficient and safe operation. Pipes serve a variety of functions, including urban water transportation. (Mays, 2010)

- Reservoirs, which are man-made lakes formed by dams, play a multifaceted role beyond water storage, including flood control, power generation, irrigation, recreation, and ecosystem benefits. They feature dams and inlets and outlet structures to regulate levels and flows, as well as spillways for safety. Although sedimentation can reduce their capacity, they also create new habitats. Dams, on the other hand, are barriers that control water flow to create these reservoirs. They serve multiple purposes such as irrigation and flood control; however, their construction can displace populations and wildlife, alter water quality and ecosystems, and pose safety risks if they fail. (Russell, 2014)

- Aqueducts ensure the delivery of clean, safe water from natural sources to our homes and industries. This intricate network involves collecting water from rivers, lakes or underground sources; transporting it through canals and pipelines; purifying it through treatment plants; storing it in reservoirs and finally distributing it through a network of pipelines. This essential infrastructure ensures access to clean water, drives economic development, protects public health and improves overall quality of life. (Metcalf & Eddy, 2014)

Figure 4. Infrastructure of the Serru Lake.
Source: https://maps.app.goo.gl/yYcGmYsVAz1MCqmeA

2.1.1.4. Communication Systems

Communication systems infrastructure is the intricate web that keeps the world connected. They bridge vast distances through phone calls, messages, internet, and more, but face obstacles such as the digital divide, security, and privacy. These ever-evolving systems rely on a complex infrastructure with a central core efficiently routing data, and access networks using cables, towers, and various technologies to connect individuals. Standardized protocols ensure everything runs smoothly, allowing wired and wireless connections to flow information without problems. From traditional phone lines to modern mobile data, telecommunication networks are constantly innovating to keep us all connected. (Forouzan, 2018)

2.1.2. Environmental Works

Environmental work encompasses both the assessment of the potential impact of projects on the environment and the active protection of natural resources. It involves evaluating proposed projects to minimize their negative effects. It also focuses on proactive initiatives such as tree planting, wetland restoration, renewable energy development, and pollution reduction. But in addition to this, flood and landslide risk management work are also considered environmental works. (Pellow, 2014)

- Floods and landslides are closely related due to factors such as rainfall and soil saturation, posing significant threats to public health, the environment, and various sectors such as civil engineering and agriculture. Flood control, a type of environmental engineering, aims to lessen the impact of these disasters through complex systems. Dams, levees, coastal defenses, and early warning systems are all tools used in flood control to prevent, control, and manage floods; these multifaceted strategies work together to shield communities, infrastructure, and property from flood's devastation; this can involve protecting cities with levees, widening rivers to improve flow, and strengthening coastlines against storm surges. (Jain, 2012)

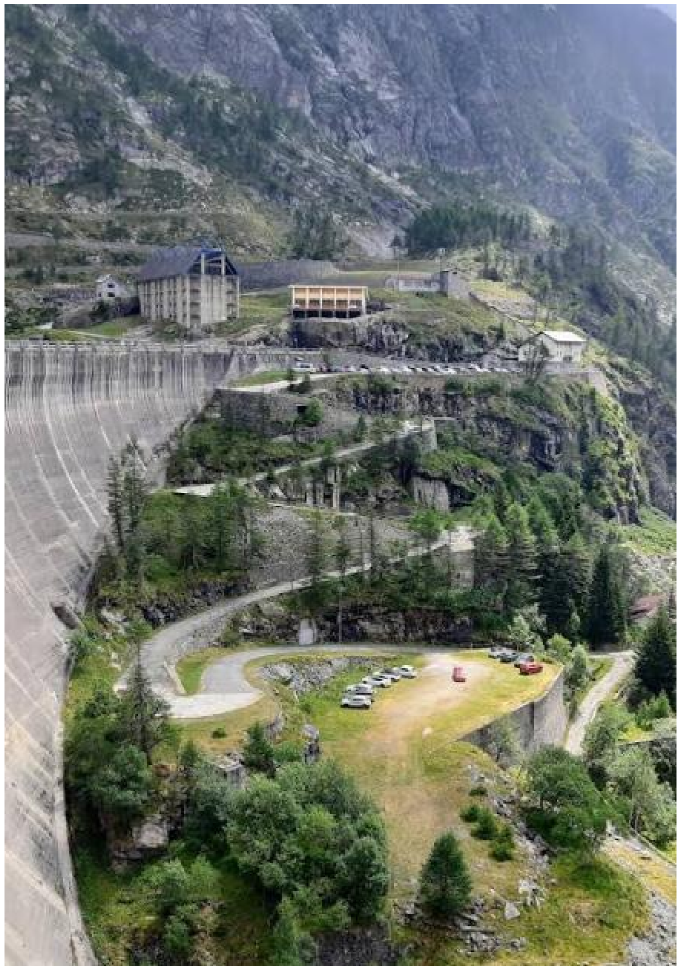


Figure 5. Telessio Power Plant.
Source: https://maps.app.goo.gl/PKgyudonGKtBvNKR8

2.1.3. Geotechnical Works

Geotechnical work is a specialized field of civil engineering that focuses on challenges related to soil and rock behavior for safe and sustainable infrastructure. By using various techniques like drilling, testing, and simulations, geotechnical engineers unlock the secrets of earth materials under different conditions; this knowledge forms the foundation for designing and building robust infrastructure that can endure anything thrown its way. (Bowles, 2008) Below a description is made for the civil works that could be found in the case study zone for the geotechnical works, like earthworks and slope stability.

- Earthworks are massive construction projects that sculpt the earth itself, serving a multitude of purposes in various sectors; from building infrastructure and land reclamation to resource extraction, supporting agriculture, and environmental restoration. Cuts, embankments, fills, terraces, and dams are just some of the many forms they take, and require various techniques such as excavation, compaction, transportation, and erosion control. (Fowkes, 2013)

- Slope stability seeks the resistance of inclined surfaces to movement or collapse, it is a critical concept in fields such as geotechnics, civil engineering, forestry, and environmental sciences; directly affects the safety of structures, landscapes, and infrastructure built on or near slopes. Landslides, rock falls, and debris flows are examples of slope failures caused by various factors such as soil properties, slope geometry, water conditions, vegetation, and human actions. (Bell, 2014)

- Stability against avalanches and rockfalls is essential to ensure the safety of people and infrastructure in mountainous regions. These natural phenomena, triggered by factors such as heavy rainfall, earthquakes, climate change and erosion, pose significant threats. Geological surveys, early warning systems, engineering works, sustainable forest management and emergency plans are essential to mitigate these risks. Hydroelectric power plants, which are particularly vulnerable due to their location, require specific measures such as protective barriers, diversion tunnels, continuous monitoring and anti-seismic design. (Donald D. Evans & L.F. Thomas, 2013)

2.2. Potential Risk Factors

Considering what were defined in the problem statement of this thesis project, we will call Potential Risk Factors the fundamental variables to develop the risk assessment (hazard analysis, vulnerability analysis and risk analysis), for a better understanding of the work carried out; taking advantage of the Potential Risk Factors previously identified, this step delves into those that have not yet been fully explored within the context of this thesis project. This involves collecting information, analyzing historical data and identifying critical elements for risk assessment.

2.2.1. Hazards Analysis

A hazard analysis for civil works and the surrounding area involves a systematic process to identify and evaluate the potential hazards that they might face (C.G. Knight, 2017). As previously mentioned, the origin of hazards can be natural (environmental events), human (security actions) or project-specific (technical actions). It should be noted that although other types of hazards are mentioned, the intention of this thesis project only focuses on those caused by natural and environmental events.

The Orco Valley has a long history of dangerous landslides, with records showing 36 major events and at least 250 deaths since the 18th century. In May 2013, a rockfall near a populated area (Locana) highlighted the current risk. Studies by the CNR-IRPI Institute for a Civil Protection Plan (CPP) revealed that a significant part of the valley is susceptible to landslides. Large landslides, which could reach millions of cubic meters, could affect 85 square kilometers (15% of the area), while shallow landslides would cover an additional 19 square kilometers. Stream networks throughout the valley are prone to debris flow, even during periods of low activity, due to factors such as insufficient channel capacity. Additionally, cold winters with fluctuating temperatures, ranging from -6°C to 22°C, contribute to avalanches, physical rock erosion, and debris accumulation, further exacerbating landslide risks. (Mercalli & Cat Berro, 2005)

The analysis of the framework to be developed is in the Orco Valley, characterized by rushing rivers and steep slopes, faces increased vulnerability to flooding and landslides, particularly during the spring and autumn rainy seasons. Heavy rain and spring thaws can cause flash flooding in valley rivers and streams, especially in areas with steeper slopes. Floodplains along the Orco, Soana, and Levanna rivers, along with unstable or sparsely vegetated slopes, are most susceptible to these events. Consequently, flooding and landslides pose a threat to infrastructure, agricultural land, property, access routes, and even cause casualties in extreme situations. (Turconi, 2015)

The valley's mountainous terrain also introduces the risk of unpredictable rockfalls and snow avalanches, which also threaten people, infrastructure, and property in exposed areas such as cliff bases, slopes, and hiking trails. Other challenges facing the Orco Valley are soil erosion, particularly in deforested areas where agricultural practices are insufficient, as it reduces soil fertility and clogs rivers with sediment, damaging infrastructure. Considering droughts, although less frequent than floods, can significantly affect water availability for people, agriculture, and industry, especially during dry summers. Additionally, hot, dry summers combined with dry vegetation increase the risk of wildfires threatening the valley's forested areas. (Turconi, 2015)

Figure 6. Residual deposit of a debris flow from the Orco Valley.
Source: Copernicus Paper.

Risk sources are mainly concentrated on low-flow (50.2%) and high-flow (47.3%) channels. The risks of landslides and avalanches represent 1.2% and 1.3%, respectively. This relatively low value can be misleading, since, after more than 37 years of low snowfall, the winter of 2008-2009 saw heavy snowfall on almost all valley slopes, with depths exceeding 10 m at 2,296 m above sea level. Large avalanches affected several points on the valley's main road; the largest severely disrupted the regional highway for a distance of almost 250 m. (Turconi, 2015)

The triggering factor for river flooding and most landslides is considered here as "exceptional rainfall events." This definition applies to meteorological and hydrological events that cause detrimental effects on the landscape. The research concludes that events of a given magnitude and process are repeated periodically in the same locations and with the same physical behavior, indicating long-term instability. The most important variable is human colonization, the effects of which can increase potential damage or risks. (Turconi, 2015)

Turconi's work allows for a detailed classification of the entire area based on historical risk conditions at any given location and time, as well as current verified natural and anthropogenic conditions. Due to severe risk processes, many lives have been lost in the area: at least 250 deaths have been recorded since the 18th century, in 36 events with different dates/processes. Snow avalanches account for 59%, river floods 21%; debris flows and rockfalls are responsible for 12% and 8% of fatal events, respectively. (Turconi, 2015)

The risk of earthquakes in Italy varies according to the regions and is classified into four zones. While Northern Italy is generally in the lowest risk zones (3 and 4), it is essential to remember that this is a general classification and that specific locations within each zone may have different risks. It is always important to be prepared for earthquakes, regardless of your location. (Turconi, 2015) Below is a classification and description of the hazards found in the case study area.

- Natural / Environmental Events

These kinds of hazards are naturally occurring events that have the potential to cause damage, disruption, or even loss humans of life; they can be caused by various factors like earthquakes, weather patterns, or wildfires. Earthquakes are geological events characterized by the release of energy in the form of seismic waves. Weather patterns are the recurring sequences of weather conditions in a specific region over a period of time. Wildfires are uncontrolled fires that burn in vegetation such as forests, grasslands, bushes or even croplands. (C.G. Knight, 2017)

- Avalanches and rockfalls are slides of snow or rock that are caused by the accumulation of material on a slope. They can occur in mountains, glaciers, or even in urban areas. Avalanches and rockfalls can be caused by natural factors, or by human factors, such as cutting down trees or building in prone areas. (Bruthans, 2009)

- Landslides, triggered by gravity and often water, occur when unstable slopes give way. While common in mountainous, coastal, and unstable soil areas, they can happen anywhere. Natural factors and human activities like construction in vulnerable areas can both contribute to landslides. The risk of landslides increases with slope steepness, with high risk for slopes exceeding 40 degrees, moderate risk for slopes between 25-40 degrees, and low risk for gentler slopes. However, slope angle isn't the only factor; soil type, moisture content, vegetation, and past landslide history also play significant roles in landslide susceptibility. (T.Dev & I.Yang, 2015)

The key distinction between avalanches, rockfalls and landslides lies in the material that is moved. While avalanches involve the rapid descent of earth, rocks or mainly snow, landslides involve only the movement of earth. Additionally, avalanches tend to be faster than landslides, reaching speeds of up to 300 kilometers per hour. This difference in speed often translates into the greater destructive potential of avalanches, making them more difficult to handle compared to landslides. (Bell, 2014)

- Flooding poses a major threat to structures through two main mechanisms. Overflowing rivers can accumulate debris, intensifying the force of the water against buildings. This combined weight, along with the increasing force of the water itself, can damage or even destroy structures. Additionally, flooding can erode the land that surrounds and supports buildings through a process called scouring. While natural erosion occurs, flooding significantly accelerates due to increased water volume and intensity, which could lead to rapid collapse. (Van der Tak & Aerts, 2013)

Figure 7. Representative image of natural hazards in the Orco Valley.
Source: https://www.youtube.com/watch?v=Yj2fLDY9LPo

The probability of a natural event occurring in a particular area can be estimated using a combination of methods, including historical records, statistical analysis, and computer modeling. It is also important to take into consideration that a strong meteorological event has a return period of 20 to 25 years, and the small ones have a return period of 6 to 8 years. (Tamea, 2021)

- Droughts, characterized by prolonged periods of abnormally dry weather, can be caused by reduced precipitation, increased temperatures, or changes in wind patterns. These periods of drought have a wide range of consequences. Reduced water availability means less surface water in rivers, lakes, and reservoirs, along with lower groundwater levels. This impacts agriculture, causes crop failures, and affects food production and livelihoods. (Biswas, 2010)

- Wildfires are uncontrolled fires in forested or naturally vegetated areas that can devastate ecosystems, damage property and endanger lives. They can be triggered by natural causes such as lightning, volcanic eruptions or spontaneous combustion, or by human activities such as accidents or intentional acts. Factors such as fuel availability; weather conditions and topography influence their spread. These fires cause significant biodiversity loss, soil erosion, air pollution and property damage, while contributing to climate change. (Flannigan, 2013)

- Human / Safety Actions

These kinds of hazards are unforeseen incidents that occur during the construction or functioning of civil work, and that result in damage to the integrity of people or damage related to civil work itself. The most common types of incidents are caused by falls from heights, collision accidents, electrocution accidents, excavation accidents, equipment malfunction, and machinery accidents. (Wiesner, 2014) Considering what was said above and as this is not the topic of this research nor for the purpose of this thesis, these concepts will not be described.

- Project-Specific / Technical Action

These kinds of hazards are related to technical specifications or specific aspects of the project, among which we can find material defects, design defects, and damage due to lack of maintenance. (Hibbeler, 2010) Considering what was said above and as this is not the topic of this research nor for the purpose of this thesis, these concepts will not be described.

2.2.2. Vulnerability Analysis

Vulnerability analysis delves into how susceptible the civil works and surrounding area to potential hazards are; this involves a multi-criteria assessment of the impact of several variables on the identified hazards, these variables could be the inherent weakness of each type of work (POI's) and geomorphological vulnerabilities of the area (Slope, Land Cover/Use, Height, etc.), Basically painting a picture of potential risks to consider. (FEMA, 2012) The vulnerabilities found in the case study are described below.

- Inherent Vulnerabilities of POI's

The inherent vulnerabilities are those related to their design, construction or materials, which make them susceptible to damage or failure due to natural or man-made events. These vulnerabilities can be physical, functional or social. (Rossiter, 2014)

  - Dams, crucial for water supply, power generation, and flood control, are vulnerable to a variety of factors. Design flaws, construction errors, and material degradation can weaken their structure. Natural forces such as earthquakes, floods, and droughts further threaten their integrity. Human errors, such as operational mistakes can also compromise their safety. (FEMA, 2004)

  - Hydropower plants, while clean and renewable, are susceptible to various vulnerabilities. Their dependence on hydrological conditions makes them vulnerable to drought, flooding, and sedimentation. Geological hazards such as earthquakes and landslides further threaten their infrastructure. Extreme weather events such as storms and heat waves can also impact their operations. (ICOLD, 2010)

  - Electrical transformer cabinets, vital to the distribution network, are susceptible to various threats. Physical hazards such as collisions, falling objects, corrosion, vandalism and fires can damage the cabinet and its components. Electrical overloads, short circuits, poor grounding and electromagnetic interference pose risks to the power supply. Security breaches such as unauthorized access and lack of maintenance can lead to accidents and equipment failures. (Hambley, 2014)

Figure 8. Hydropower plant of Bardonetto.
Source: https://maps.app.goo.gl/2GRWnnHaDZBuuhXZ6

- Electric distribution networks, crucial for modern life, are vulnerable to various threats. Natural disasters like earthquakes and floods, alongside human-caused issues like vandalism and collisions, can damage infrastructure. Additionally, factors like equipment aging, overload, and human error can lead to disruptions. To mitigate these risks, robust design, regular maintenance, and redundancy in the system are essential. (S. Pahwa - S. Doolla & N. Amjady, 2010)

- Aqueducts face inherent vulnerabilities that can lead to failures or disruptions. These weaknesses originate from natural, human, and technical factors. Pollution from point and diffuse sources, natural disasters like droughts, floods, and earthquakes, and infrastructure deterioration due to corrosion, obstructions, and wear are common threats. Inadequate management, including lack of maintenance and poor planning, further exacerbates these risks. (David W. Metcalf & Eddy, 2014)

- Geomorphological Vulnerabilities

Geomorphological vulnerabilities in a catchment are the inherent characteristics of the terrain that make it susceptible to geological processes such as landslides, erosion, flooding, etc. The main geomorphological vulnerabilities are the slope, basins with steep slopes are more prone to landslides and erosion; geology, the nature of the rocks and soils influences the stability of the slopes and the susceptibility to erosion; seismicity, the movements of the earth, increases the susceptibility of a basin to disasters such as landslides and floods; hydrology, the frequency and intensity of rainfall, the presence of rivers and lakes and seasonal variability influence erosive processes and flooding; vegetation, vegetation cover plays a crucial role in soil stability and the regulation of water flow; and land cover or land use, human activities such as deforestation, agriculture and urbanization can increase vulnerability by altering natural processes. (Saunders & Fallon, 2019)

2.2.3. Risks Analysis

Risk analysis combines the results of hazard analysis and vulnerability analysis to estimate the probability that a damaging event may have on a POI or their surrounding area, also being a systematic process for managing risks associated with civil works and territories. (Rogers, 2012)

In addition to the estimation of potential damage, risk analysis provides a comprehensive understanding of the risks involved. Various methodologies, such as multi-criteria analysis, probabilistic analysis (frequency and magnitude of extreme events), and scenario analysis (future events to assess their potential impacts), are used to analyze historical data, mathematical models and geospatial information to assess these risks. (Muller, 2016)

One of the qualities of risk analysis is that it allows for risk classification according to its origin, severity, and probability of occurrence. This classification helps to categorize and prioritize which factors require greater attention in the investigation. High-risk factors are those that require immediate attention and allocation of resources to minimize potential damage. On the contrary, lower-risk factors may require less urgent measures; this categorization and prioritization allows for effective focus on mitigation and preparation efforts, ensuring a comprehensive approach to the project. (Mª. Martínez, 2015)

The development of the risk assessment will be carried out later. A review of the state of art of the hazards, vulnerabilities and risks described above will be presented in the following, as well as the methodologies that can be used to address these types of problems today.

3. Literature Review

This chapter delves into the potential risk factors described above, emphasizing the state of the art, what is being done around the world, and what challenges have been encountered. All this since risk assessment and technology play an important role today, due to the ability to identify potential problems and prioritize solutions.

3.1. Hazards Review

Literature review on natural hazards is a crucial step in scientific research as it helps us understand the current state of knowledge, identify gaps, and create a sound theoretical framework. By reviewing existing research, we can justify the need for our own study, avoid duplication of efforts, and select appropriate research methods. Furthermore, it helps to interpret results and generate new hypotheses, which contributes to the overall advancement of knowledge in the field of natural hazards.

3.1.1. Flooding

The state of the art for flooding involves a combination of technological advancements and traditional engineering approaches to tackle this ever-present threat. These approaches are focused on flood forecasting / monitoring, flood risk management, and emerging technologies. Flooding remains a major challenge; climate change requires adaptive flood management strategies to address the increasing frequency and intensity of extreme weather events. Additionally, continued investment is needed to maintain and upgrade aging leaves, dams and drainage systems. By adopting new technologies alongside traditional practices, and promoting community preparedness, resilience can be built and significantly reduce the devastation caused by floods. (V.Kumar & H.Azamathulla, 2020)

- Flood Forecasting / Monitoring

Flood forecasting uses real-time data on rain, snow and soil moisture to provide a clear picture of potential hazards. Advanced modeling then creates high-resolution flood simulations, leveraging Earth observation satellites GIS, drone imagery, and networks of meticulously placed sensors that monitor water levels, river flow, and dam integrity. This comprehensive approach using all of these tools working together provides crucial real-time data to issue early warnings and assess flood severity and ultimately protect communities. (V.Kumar & H.Azamathulla, 2020)

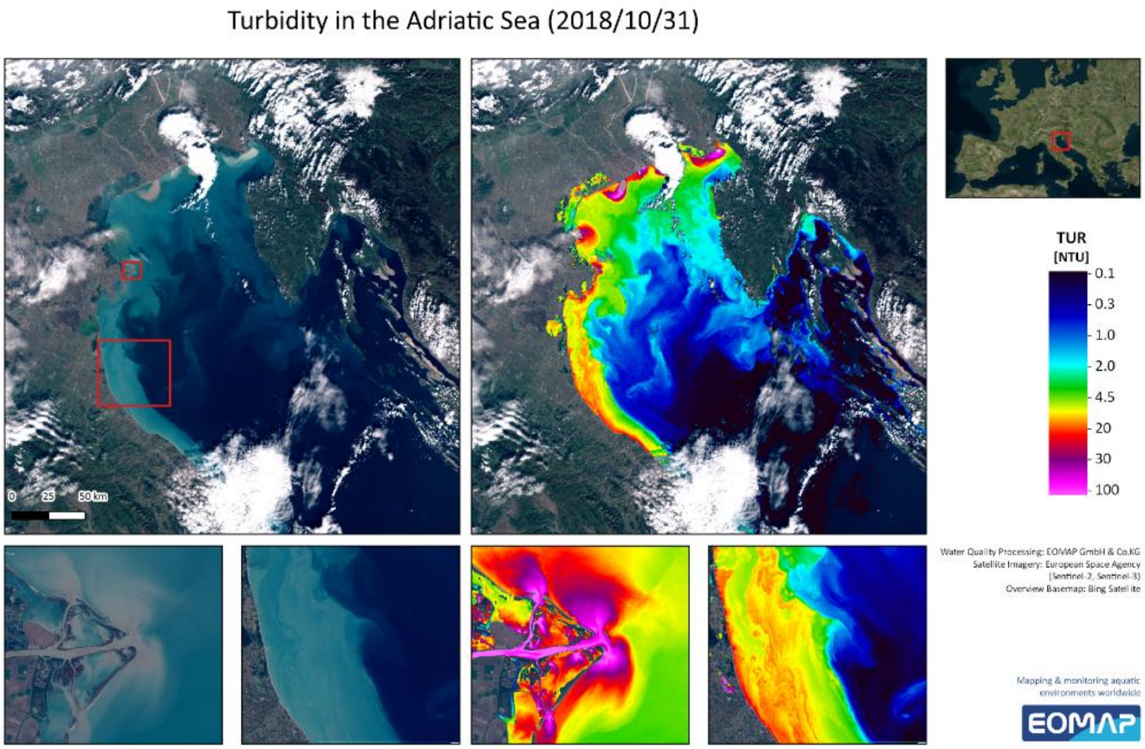


Figure 9. An example of flood forecasting and monitoring.
Source: https://www.eomap.com/using-satellite-data-for-flood-monitoring/

- Flood Risk Management

Effective flood risk management recognizes the reality of flooding and aims to minimize its impact. It is a multifaceted approach that uses both traditional and nature-based solutions. Traditional methods such as leaves, flood walls and diversion channels physically block and divert flood water away from populated areas. Nature-based solutions such as wetland restoration and tree planting along riverbanks offer a more natural approach by absorbing flood water and reducing peak flow, reducing the burden on traditional infrastructure. Additionally, implementing land use planning with zoning regulations helps prevent future damage by restricting development in high-risk floodplains. (M.Hammond & A.Chen, 2013)

- Flood Emerging Technologies

Flood prediction is getting a high-tech upgrade. Machine learning algorithms are being used to analyze past flood data, leading to more accurate predictions of future floods; in addition, the Internet of Things (IoT) is playing an important role, as sensor networks connected to IoT can provide real-time information about the state of infrastructure and possible weaknesses during floods. (M.Reza & D.Ryu, 2020)

3.1.2. Landslides

The state of the art for landslides involves a combination of technological advancements and traditional methods working together to reduce risk and save lives; these approaches are focused on landslides identification / monitoring, landslides risk management, and emerging technologies. Fighting landslides requires a multifaceted approach; and combining these cutting-edge technologies with traditional methods and fostering collaboration between researchers, engineers and communities is key to building resilience and saving lives. (M.Kannan, 2023)

- Landslides Identification / Monitoring

Landslide identification and monitoring are proactive efforts using a combination of cutting-edge technology and traditional methods. Real-time data on slopes, soil properties and rainfall are collected using various techniques. Advanced modeling software creates simulations to identify areas at risk, while satellite and drone imagery GIS with LiDAR detects subtle changes that indicate potential landslides. Additionally, sensor networks embedded in the slopes provide real-time readings on soil movement and water infiltration. Traditional tools such as extensometers, inclinometers and piezometers also provide valuable data on slope stability. This comprehensive approach enhances proactive mitigation strategies by enabling the prediction of landslide severity and the issuance of timely warnings. (D.Han & B.Chae, 2017)

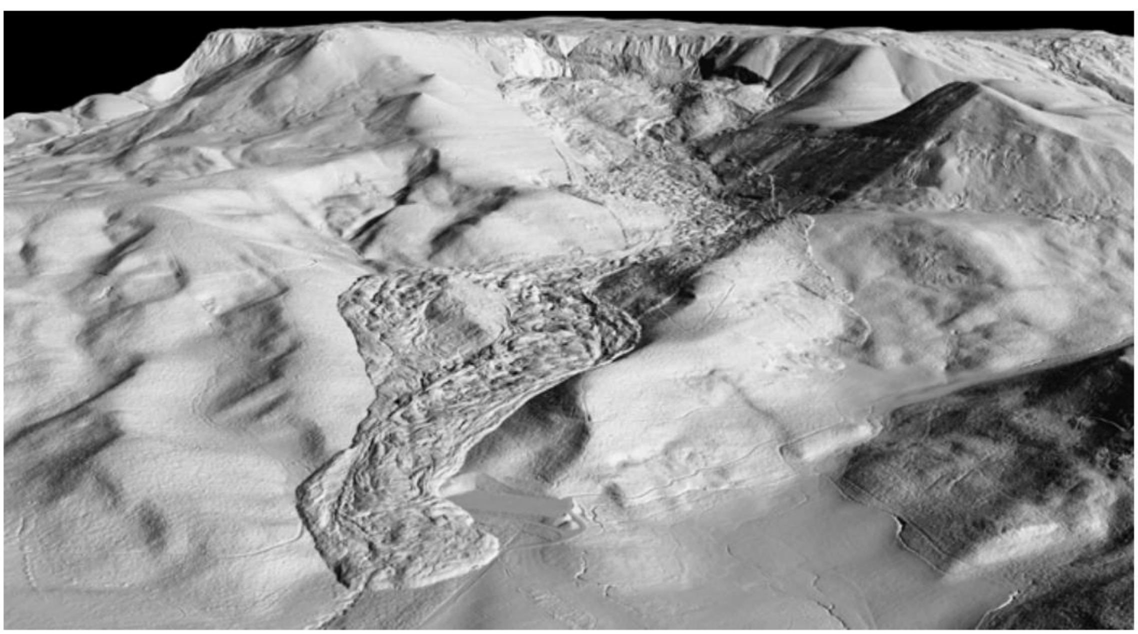
- Landslides Risk Management

Landslide risk management is not just about repairing damage; recognizes these events as inevitable and focuses on reducing their impact.

This proactive approach uses several strategies, such as early warning systems that trigger evacuations based on real-time data. Slope stabilization techniques, such as improved drainage, retaining walls, and deep-rooted vegetation, help prevent shallow landslides. Additionally, anchoring systems and solid drainage address the problem of water accumulation, a major trigger of landslides. Finally, land use planning regulations move development away from high-risk areas and promote responsible land management practices, minimizing the overall risk of landslides. (Blakemore, 2023)

- Landslides Emerging Technologies

Landslide prevention takes a high-tech approach with tools like artificial intelligence and machine learning; these algorithms analyze historical data and sensor information in real time to identify landslide-prone areas with exceptional accuracy. LiDAR technology joins the fight by creating detailed 3D models of the terrain, further refining landslide risk assessment. The Internet of Things (IoT) also plays a vital role, with its network of sensors constantly monitoring slopes for early signs of movement, enabling rapid response. Finally, a technique called InSAR, which uses radar to detect tiny ground movements, provides crucial early warnings before landslides occur. (O.Inabi & M.Attou, 2023)



Grand Mesa Landslide. Image Courtesy: Quantum Spatial

Figure 10. An example of Landslides Emerging Technology.
Source: https://www.geospatialworld.net/blogs/lidar-preventing-mitigating-landslides/

3.1.3. Avalanche / Rockfalls

While avalanches and rockfalls pose a constant threat in mountainous regions, advances in detection, prediction and mitigation are improving safety. These efforts encompass real-time avalanche monitoring, risk management strategies, and exploration of new technologies. However, the impact of climate change on snowfall and temperature presents new challenges. Scientists need to continually adapt their forecast models and mitigation measures to maintain accuracy. This requires integrating data from weather stations, remote sensors and historical records. Ultimately, public awareness and education are paramount for both residents and visitors in avalanche zones, ensuring the safety of mountain communities. (D.McClung & P.Schaerer, 2015)

- Avalanche and Rockfalls Detection / Monitoring

Avalanche and rockfalls detection / monitoring uses a combination of cutting-edge technology and human expertise. Meteorologists analyze weather data, wind patterns and slope angles, while constantly improving models predict avalanche risk. Real-time monitoring combines machine learning that analyzes weather station readings and satellite images GIS, with LiDAR slope maps and Doppler radar to detect avalanches and trigger immediate alerts. (V.Sharma & S.Kumar, 2019)

- Avalanche / Rockfalls Risk Management

Avalanche and rockfalls risk management uses controlled detonations to trigger small avalanches and release accumulated tension, preventing larger and more destructive ones; Other strategies that can be used are fences and walls, these structures help redirect wind-blown and reduce the amount of material that accumulates in prone areas. Finally, avalanche and rockfalls diversion channels can divert the material flow away from populated areas or infrastructure. (Bruthans, 2009)

- Avalanche / Rockfalls Emerging Technologies

Avalanche safety gets a high-tech boost with emerging technologies. Drones equipped with sensors can collect detailed data from dangerous areas, keeping humans out of harm's way. Additionally, the Internet of Things (IoT) comes into play with sensor networks embedded in the slopes, Provide real-time information on the conditions of the snow cover or rock beds, with their possible avalanche triggers. (C.Guillén & F.Techel, 2022)

Figure 11. An example of Avalanche / Rockfalls Management.
Source: https://www.cittimesh.com/products/engineeringmaterials/rockfall-barriers/index.html.

3.1.4. Wildfires

Cutting-edge wildfire research and management involves a multifaceted approach. Improved prediction and early detection rely on advanced models, real-time data from satellites and drones, and AI-driven analytics. Firefighting techniques are evolving with the use of drones for reconnaissance and delivery, the development of fire-resistant materials, controlled burns, community engagement, and climate-informed planning. Emerging technologies, such as biotechnology and firefighting robots, offer exciting possibilities for future advances in wildfire prevention and mitigation. (Arno & Brown, 2014)

- Wildfires Enhanced Prediction and Early Detection

Improved wildfire prediction and early detection are achieved through a combination of advanced technologies. Sophisticated computer models leverage climate data, fuel moisture, topography, and historical fire behavior to predict wildfire risk and anticipate wildfire spread. Real-time data from satellites, aerial drones, and sensors provide crucial insights into fire activity, fuel conditions, and weather patterns, enabling rapid detection and response.

Additionally, artificial intelligence and machine learning algorithms analyze massive data sets to identify patterns, significantly improving the accuracy of wildfire predictions and early warning systems. (Arno & Brown, 2014)

- Wildfires Improved Firefighting and Suppression

Enhanced firefighting and suppression strategies involve the use of drones for reconnaissance, fire mapping, and supply delivery, improving firefighter safety. Research is focused on developing fire-resistant materials for buildings and vegetation to mitigate the impact of wildfires. Controlled burns strategically reduce fuel loads and create firebreaks. Community engagement, including education and evacuation planning, is vital for effective fire management. Finally, incorporating climate change projections into fire management plans is crucial to adapting to future wildfire risks. (Arno & Fiedler, 2006)

- Wildfires Improved Emerging Technologies

Emerging technologies are revolutionizing firefighting strategies. Biotechnology research is focusing on improving plant fire resistance and developing new fuel reduction methods. In addition, the field is seeing the rise of autonomous robots designed to help firefighters clear fire lines and deliver water, improving efficiency and potentially reducing human risk in dangerous firefighting situations. (Arno & Brown, 2014)

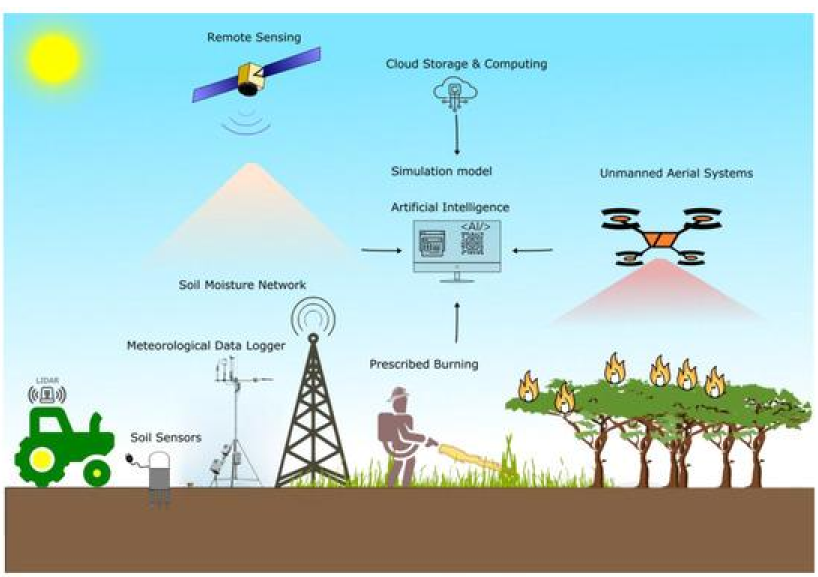


Figure 12. An example of Wildfires Management.
Source: https://www.mdpi.com/2571-6255/4/3/45

3.2. Vulnerabilities Review

Assessing infrastructure vulnerability is critical to ensuring safety and resilience. Visual inspections, historical data analysis, and modeling are essential tools for identifying damage, assessing conditions, and predicting potential failures. Vulnerability assessments help determine how infrastructure might be affected by natural or man-made threats, in addition to the resilience that measure its ability to withstand and recover from adverse events. Factors such as age, materials, design, maintenance, geographic location, and changes in use influence infrastructure vulnerability. By identifying and addressing weaknesses, we can build safer, more resilient, and more sustainable infrastructure. (Brebbia. Adeli & Butz, 2010)

3.2.1. Inherent Weaknesses

Infrastructure assessment has evolved significantly with the integration of advanced tools and technologies. Geographic information systems (GIS), remote sensing, building information models (BIM), the Internet of Things (IoT), artificial intelligence (AI), machine learning, virtual and augmented reality, vibration analysis, non-destructive testing, and numerical simulations are revolutionizing the way we analyze and manage infrastructure. These tools enable more accurate, efficient, and comprehensive assessments, leading to better decision-making in infrastructure management and maintenance. They facilitate early damage detection, optimize maintenance planning, assist in asset management, improve design and construction, and enhance risk management. Ultimately, these technologies contribute to increased safety, durability, and resource optimization in infrastructure management. (Cornell & Chopra, 2014)

3.2.2. Geomorphological Vulnerabilities

Geomorphological vulnerability assessments have advanced significantly through the integration of modern tools and technologies. GIS, remote sensing, numerical models, and artificial intelligence have revolutionized the way we analyze the factors influencing landslides, flooding, and coastal erosion. GIS creates detailed maps, models geomorphological processes, and integrates diverse data sources. Remote sensing, including satellite imagery, SAR, and LiDAR, provides valuable information on land cover, vegetation, soil moisture, and ground deformation. Numerical models simulate water flow, slope stability, and predict potential hazards.

Weather stations and deformation sensors collect real-time data on weather conditions and ground movements. Machine learning algorithms improve image classification and anomaly detection, while predictive models forecast extreme events and long-term risks. These tools allow us to make more accurate and detailed assessments, which inform decision-making for risk management and land use planning. (Géron, 2019)

3.3. Risk Analysis Review

Risk assessment is a crucial aspect throughout the entire civil engineering process, from project planning (where it helps identify design, construction and budget risks) to specific engineering fields (such as geotechnical evaluation of soil stability or structural evaluation of seismic or material risks). It even extends to infrastructure management, where it helps identify the deterioration of bridges, dams, roads and other physical systems, allowing for preventive maintenance. Standardized risk assessment practices are the best solution to these problems. While the benefits are clear (better decision making, efficient use of resources, and increased public safety), challenges include ensuring data quality, the inherent difficulty of predicting future events, and finding the right balance between mitigating risks. risks and associated costs. (ICE & Institute Faculty of Actuaries, 2021)

The field of risk assessment is constantly evolving and encompasses a diverse set of methods and technologies. This goes beyond simply identifying hazards. Advanced techniques, Big Data integration, and emerging technologies are intertwined to create a comprehensive picture of potential threats and vulnerabilities.

- Advanced techniques

Advanced techniques such as Probabilistic Risk Assessment (PRA) use statistics to calculate the probability and possible consequences of different risk scenarios. Failure Modes and Effects Analysis (FMEA) goes deeper, identifying potential weaknesses within a system and their impacts, allowing for proactive mitigation. Event tree analysis (ETA) takes a visual approach, mapping the possible consequences of a triggering event, helping decision makers understand the cascading effects of a risk; these methods provide a comprehensive understanding of potential risks, enabling informed decision making for effective risk management. (M.Coleman & H.Marks, 2019)

- Big data integration

Big data integration powered by machine learning opens a new level of risk assessment, the combination of data from different sources (e.g., weather, infrastructure, demographics) allows for a more comprehensive picture of potential risks. Machine learning algorithms, trained in historical data, can identify patterns and connections between risk factors and potential consequences, leading to more predictive assessments. Additionally, sensor networks and real-time data from embedded sensors provide valuable information on current risk conditions, enabling dynamic risk management; this combination of historical analysis and real-time data allows us to proactively anticipate and manage risks. (L.Wang & D.Chan, 2024)

- Emerging technologies for Risk Assessment

In the emerging technologies there is an immense potential to improve risk assessment. The Internet of Things (IoT) acts as a vast network of interconnected devices, providing a constant flow of data for risk assessment, enabling real-time monitoring and the development of early warning systems. Additionally, Augmented Reality (AR) and Virtual Reality (VR) can be leveraged to visualize potential risk scenarios, creating immersive training grounds for emergency response personnel; these advances offer interesting possibilities for proactive risk management. (P.Lagasse, 2023)

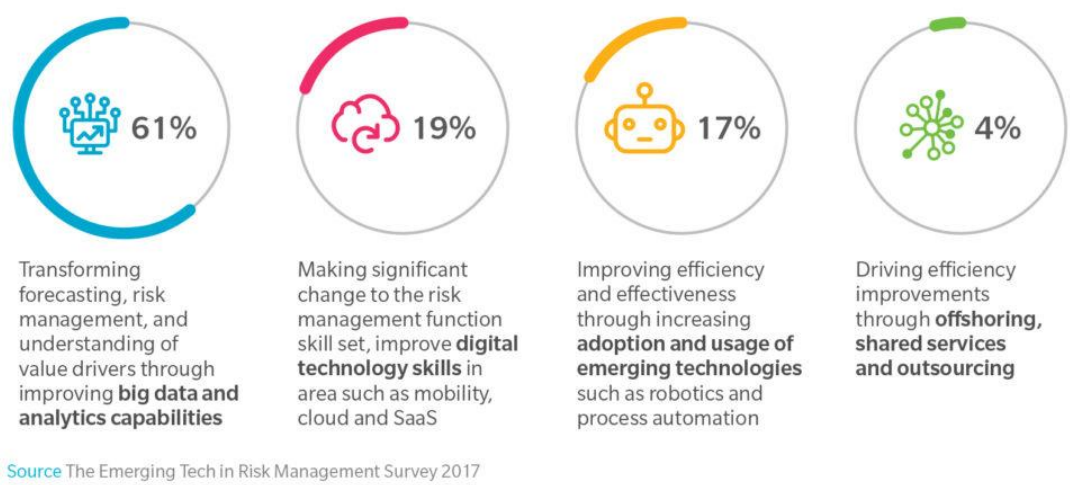


Figure 13. Emerging technology on risk assessment.
Source: https://www.brinknews.com/how-to-increase-the-tech-dividend-in-a-digital-future/

3.4. GIS Overview

GIS is a powerful methodology that has been evolving over the years, it can be used to solve a variety of problems effectively, taking advantage of the large amount of information, we find today. This methodology can be used to improve the efficiency, productivity, and quality of a case study area. Understanding the importance of these methodologies, it will be briefly summarized what it means and how it can be used today.

The GIS (Geographic Information System) methodology is a set of steps for the manipulation of geographic data. This data may include information on physical characteristics, such as topography, bodies of water, and land use, as well as socioeconomic information, such as population, housing, and income. GIS methodology can be used for various purposes, including urban planning, natural resource management, and scientific research. It is commonly known that the main steps of the GIS methodology and its design process begin with the formulation of research questions, data collection, creation of georeferenced data models and data storage, followed by analysis and visualization to a subsequent entry of the designed data into a GIS format. (Piras, 2020)

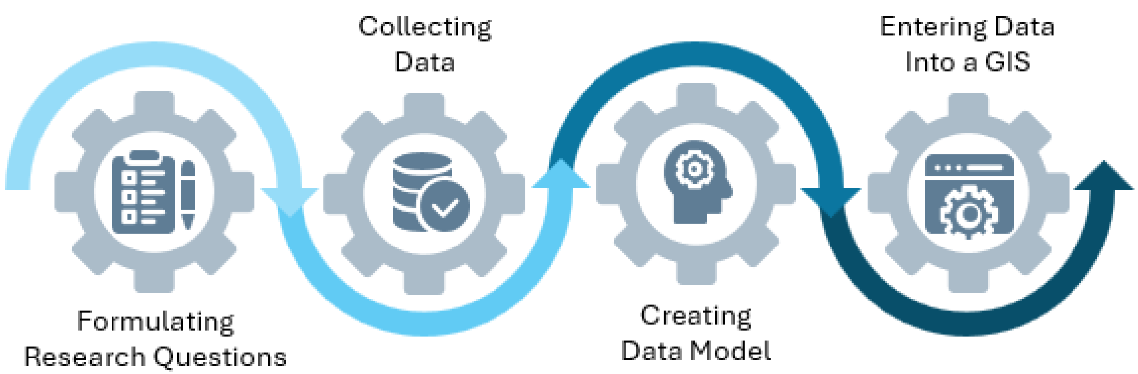


Figure 14. GIS Process for Data Input

To collect the necessary geographic data, it is important to ensure that it comes from reliable sources, these sources may include satellite images, field studies and official entities records. Once the data has been collected, it must be georeferenced, this can be done using a global coordinate system; after the data is georeferenced, it can be stored in a geographic information system (GIS); having a GIS stores information and with the help of GIS software, geographic data can be analyzed and visualized.

Data analysis is the heart of GIS methodology and acts as a powerful translator, transforming complex geographic data into clear maps and visuals. This improves informed decision making in various sectors. In urban planning, resource allocation, land use, environmental impact assessments, and even market analysis. During emergencies, GIS maps disaster zones and vulnerable populations, optimizing response routes. Organizations leverage GIS to choose optimal locations, understand customer demographics, and adapt marketing strategies. Finally, GIS helps in the conservation of ecosystems by visualizing the impact of climate change in different regions, supporting the development of mitigation strategies. (Paul A. Longley, 2010)

3.4.1. Data Environment and GIS Web Services

The data environment in a GIS is like the stage where all the action of a geographic analysis takes place. It is the set of rules, configurations and resources that define how spatial data is organized and used. By establishing a common coordinate system, uniform units of measurement and standardized data formats, the consistency and accuracy of the analyses is guaranteed. This environment facilitates the automation of tasks, improves efficiency and allows collaborative work with different data sources. In addition, by documenting and organizing the data in a catalog, the reproducibility of the results is ensured and their use in future projects is facilitated. In short, a well-configured data environment is essential to obtain high-quality results in any geographic analysis. (Congjian, 2013)

The data environment in a GIS we can find the GIS web services, that provide a dynamic and flexible way to access, visualize, and share geographic data online. These services enable users and applications to interact with spatial information, enabling applications ranging from interactive maps for urban planning and environmental analysis to complex spatial analysis such as distance calculations and scenario modeling. They also facilitate the development of web and mobile applications that leverage geographic data, fostering collaboration and information sharing among users and organizations. (Lee, 2010)

These web services, known as WMS, WFS, WCS, WMTS, CSW, and OGC API-Features, are essential tools in the GIS world. Each offers specific functionality to efficiently access and use geographic data. WMS provides map images, WFS allows access to individual data such as points or polygons, WCS facilitates the handling of raster images, WMTS optimizes the visualization of large areas, CSW is used to search and discover data, and OGC API-Features offers a simpler and more flexible interface to access vector data. Together, these services enable users to effectively visualize, analyze, and share geographic information through web applications and other platforms. (Goodchild, GIS for the 21st Century, 2007)

The choice of WMS, WFS, WCS, WMTS, CSW or OGC API - Features depends on the specific objective of each task. If you need to visualize a map, a WMS service is ideal. To perform spatial analysis or create interactive applications, a WFS is more suitable. If you work with images and 3D models, the WCS service is your best choice. When it comes to visualizing large areas with high resolution, WMTS is the right choice. To discover geographic data, CSW is the tool to use. Finally, if you are looking to develop modern and scalable web applications, OGC API - Features is the right choice. Choosing the right service involves considering factors such as task complexity, data volume, technical expertise, service performance, and data security. (Pyo, 2019)

3.4.2. GIS Literature Review

The world of Geographic Information Systems (GIS) is evolving rapidly and offers powerful tools to analyze, visualize and manage geospatial data. However, next-generation GIS faces obstacles on its path to widespread adoption; ensuring consistent, high-quality data across platforms and safeguarding sensitive information are ongoing challenges. Additionally, it is crucial to make GIS easy to use for a broader range of technical skills. Despite these limitations, by embracing and overcoming new technologies, next-generation GIS has the potential to become a powerful and versatile toolkit for solving complex spatial problems and shaping a well-informed future. (P.Pengju & H.Jianjun, 2023)

- Advanced Data Integration and Management

GIS has become a powerful tool for analyzing geospatial information thanks to several advances. Big data integration allows GIS to handle massive data sets from various sources, such as sensors, social networks, and satellite images, resulting in more complete insights. Cloud-based GIS leverages cloud computing for scalable storage, processing, and access to this data, enabling real-time updates and collaboration. Additionally, the Internet of Things (IoT) seamlessly integrates real-time sensor data from infrastructure and the environment into GIS, enabling dynamic analysis; these combined advances allow GIS to provide a comprehensive and up-to-date understanding of the world around us. (M.Waleed & S.Muhammad, 2023)

- Enhanced Visualization and User Experience

Geographic information systems (GIS) are experiencing exciting advancements that improve data visualization and user experience. 3D GIS enables the creation of immersive 3D models of landscapes and infrastructure, fostering a deeper understanding of spatial relationships. Virtual Reality (VR) and Augmented Reality (AR) are being explored to create interactive experiences. With virtual reality, users can explore virtual environments rich in geospatial data, while augmented reality overlays information on the real world. Finally, sophisticated mapping tools and data storytelling techniques are leading to the effective communication of even complex spatial information. (J.Bazargani & M.Zafari, 2022)

Figure 15. An example of GIS emerging application areas.
Source: https://www.linkedin.com/pulse/real-time-flood-monitoring-system-case-study-using-onmap-yeming-fan/

- Emerging Application Areas

Spatial data analysis is opening new paths in decision making in various sectors. Geographic information systems (GIS) are used now more than ever to inform urban planning, environmental management, and disaster response efforts. Artificial Intelligence (AI) is also making waves, with applications in automated feature extraction, pattern recognition, and even the prediction of spatial phenomena. In addition, GIS platforms are fostering citizen science initiatives, where the public can contribute geospatial data, promoting public participation and enriching data collection. (J.Bazargani & M.Zafari, 2022)

3.5. BIM Overview

Unlike traditional methods, Building Information Modelling (BIM) offers a collaborative approach to construction by creating a central digital model that spans the entire project lifecycle, from design to maintenance. This model fosters teamwork across all sectors, architects, engineers, constructors, and owners; enabling proactive problem resolution before the start of construction. This collaborative methodology improves communication, reduces errors, boosts efficiency and productivity, potentially reduces costs, and ultimately increases project value. As a promising development, BIM interoperability enables seamless data exchange between software applications, providing an accurate, object-based 3D virtual model that integrates essential information and properties with its visual representation. (Skibniewski, 2014)

Figure 16. Best-known Benefits of the BIM Methodology

In the other hand, Building Information Model (BIM) is a collaborative digital approach that begins with the collection of all project data, such as drawings, budgets, and specifications; to create a comprehensive digital model covering every aspect, from structure to systems. More than simple 3D images, BIM model stores and manages all project information throughout its entire lifecycle, supporting stages from design to operation and maintenance. Its core principles are digital representation, information sharing, reliability, informed decision-making, and construction cycle optimization, all facilitated by a Common Data Environment that ensures consistency, access, and efficient sharing of project data among all stakeholders. (Osello, 2021)

BIM software transforms the construction industry by offering numerous advantages. It minimizes costly rework by detecting clashes and accelerates projects through optimized workflows and improved collaboration. The software's 3D models enable accurate cost estimating, reducing material waste, and facilitating cost-effective design decisions. Furthermore, BIM acts as a central data storage, fostering better communication between stakeholders and improving client interaction through 3D visualizations. Its usefulness extends to facility management, simplifying maintenance. Beyond design, BIM facilitates the detailed modeling of prefabricated components, optimizing assembly, and integrates with workflows to streamline the construction sequence. It also facilitates the design of energy-efficient buildings and the tracking of sustainable materials, ultimately minimizing environmental impact through life-cycle assessments.

3.5.1. BIM Literature Review

Next-generation BIM sheds its document-heavy past in favor of a data-centric world, driven by better collaboration and integration across platforms. While BIM offers substantial benefits, obstacles remain. Seamless data exchange (interoperability) between different BIM software needs further refinement despite continuous progress. As BIM data explodes, clear ownership, access and security protocols become essential. By embracing these advances and addressing current challenges, BIM has the potential to revolutionize the industry, ushering in a future of collaborative, efficient and sustainable building design, construction and management. (I.Kim & K.Jung, 2018)

- Improved Collaboration and Integration

Open BIM standards, such as IFC (Industry Foundation Classes), ensure seamless collaboration between different BIM software, allowing for a more fluid exchange of information. Additionally, cloud-based BIM grants real-time project data access and collaboration for everyone involved, regardless of location; this transparency encourages better communication and streamlines project coordination. In essence, it creates a common data environment (CDE), a central hub for all project data, streamlining workflows and communication. (D.Bryde & M.Broquets, 2017)

- Advanced Modeling and Design Techniques

Construction is undergoing a revolution with advanced modeling techniques. AI-powered generative design creates a broader range of options more quickly, considering project constraints and performance needs. Prefabrication and modular construction take center stage, allowing for faster assembly and reduced waste on site. Finally, digital twins, digital replicas of physical buildings, are created to improve performance monitoring, maintenance planning, and overall facilities management throughout the building's lifecycle. (O.Madubuike & C.Anunba, 2022)

- About Sustainability and Efficiency

BIM enables the analysis of building models to assess energy use, water consumption and environmental impact, promoting sustainable design options from the start. Additionally, BIM can be integrated with life cycle assessment (LCA) to assess the environmental footprint of materials and construction processes over the life of a building. But the benefits of BIM go further; the data it generates can also be used to optimize building operations and maintenance, leading to long-term energy efficiency and reduced operating costs. Finally, integrating time (4D) and cost (5D) data into BIM models allows for better construction sequencing, cost estimation, and project scheduling. (J.Winczek, 2016)

- Emerging Technologies

BIM is adopting new technologies such as virtual and augmented reality (VR/AR) enables immersive design reviews, construction simulations and worker training, leading to better communication and decision making. Additionally, BIM can be integrated with Internet of Things (IoT) sensors, allowing real-time monitoring of building performance for data-driven maintenance and optimization. Finally, BIM paves the way for advances in robotics and automation within construction processes, improving safety, efficiency and quality control. (I.Kim & K.Jung, 2018)

Figure 17. An example of BIM emerging application.
Source: https://tebin.pro/news/the-impact-of-vr-virtual-reality-on-project-design-review/

4. Methodology

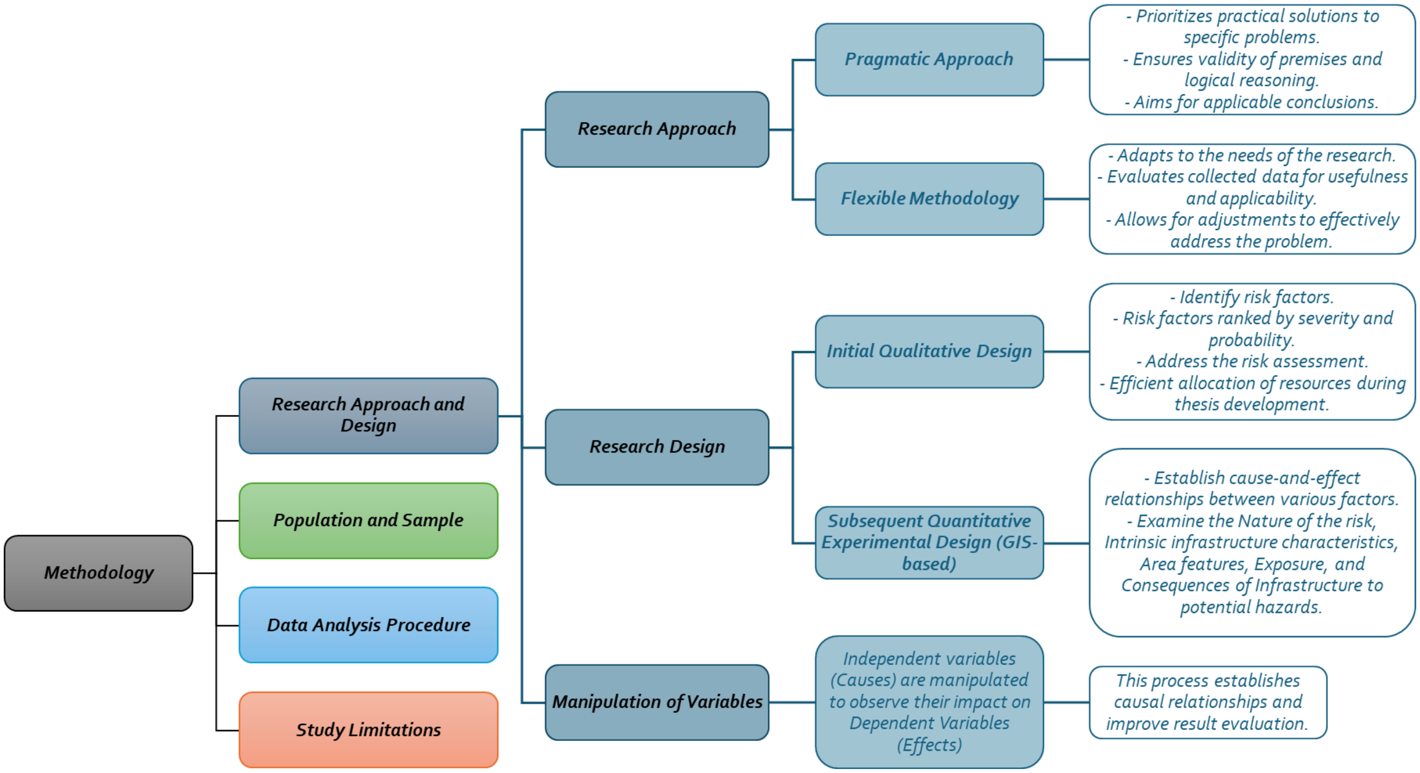
This section describes the process that has been developed to achieve the main objective of this thesis project, which is to provide a simplified and innovative perspective on the way a risk assessment is carried out. It indicates the means used to collect, analyse, operate and evaluate the data, both input and output. Making use of a multi-criteria analysis, in addition to presenting the justification of the processes implemented for the project. In this way we ensure that this methodology provides transparency in the processes implemented so that other researchers can replicate the study and verify the results, demonstrating that the research has been rigorous and reliable, giving validity through its relevance and meaning.

4.1. Research Approach and Design

This thesis project adopts a pragmatic approach, prioritizing practical solutions to specific problems and ensuring the validity of premises and logical reasoning to draw applicable conclusions. The methodology is flexible, adapting to the needs of the research, and the collected data are evaluated for usefulness and applicability, allowing for adjustments to effectively address the problem. The research combines an initial qualitative design to identify risk factors with a quantitative experimental design based on GIS models to establish cause-and-effect relationships between various factors (J.W.Creswell, 2014)

The qualitative design for risk factors were ranked according to their severity and probability to address the risk assessment. This qualitative approach is a valuable first step, as it allows for an efficient allocation of resources during the development of this thesis project. For the case of quantitative experimental design, the cause-effect relationships between various factors, such as the nature of the risk, intrinsic infrastructure characteristics, area features, exposure and consequences of the infrastructures to potential hazards. It is possible to manipulate the independent variables (considered the causes) to observe their impact on the dependent variables (the effects). By intentionally modifying these variables, the research aims to establish a causal relationship between them, allowing a better evaluation of results.

Table 1. Conceptual Map for Research Approach and Design



4.2. Population and Sample

In this case study, the population are the civil works described as possible POI's above, which are the infrastructure works that were considered most important within the Orco Valley. On the other hand, the selected samples are the natural hazards to which these infrastructures are possibly subjected. All this allows us to develop the project solution taking into consideration all the variables necessary for a design that meets the general and specific objectives of this thesis project.

4.2.1. Data Collection Methods

The instruments and techniques used for data collection in this thesis project are historical data, observations, and research carried out in the study area, gathering all possible information about the infrastructure and the territory. Information provided by official entities and scientific publications, presenting the most convenient handling of the tools currently used for the development of this type of project.

4.2.1.1. Definition of the Criteria

The definition of the criteria for data collection is the core of the research design; it establishes the pattern of information needed to be acquired and is defined in terms of the objective of the analysis, as well as the main objective and the secondary objectives. Broadly speaking, the criteria defined were the following:

- What is the catchment involved in the analysis?
- What are the water sources that are part of the basin and that could generate an undesirable event?
- What type of infrastructure is within the study area and what are its characteristics?
- What are the natural hazards that affect the study area and what are their characteristics?
- What are the variables that must be considered to calculate the materialization of the undesirable event?

As this is a GIS model, the data is composed of cartographic layers and, based on the criteria already defined, the corresponding data is collected. The data can be extracted from different sources, depending on different factors such as the type of data and the location of the problem to be addressed. The following table shows the definition of the criteria linked to their corresponding cartographic layer.

Table 2. Definition of criteria and collected data

CRITERIA	MAP LAYER
What is the catchment involved in the analysis?	Italy Catchments
What are the water sources that are part of the basin and that could generate an undesirable event?	Hydrology Network
What type of infrastructure is within the study area and what are its characteristics?	Zoning map
What are the natural hazards that affect the study area and what are their characteristics?	Hazards collection
What are the variables that must be considered to calculate the materialization of the undesirable event?	Digital elevation model, Land cover map, Soil type map, slopes, etc…

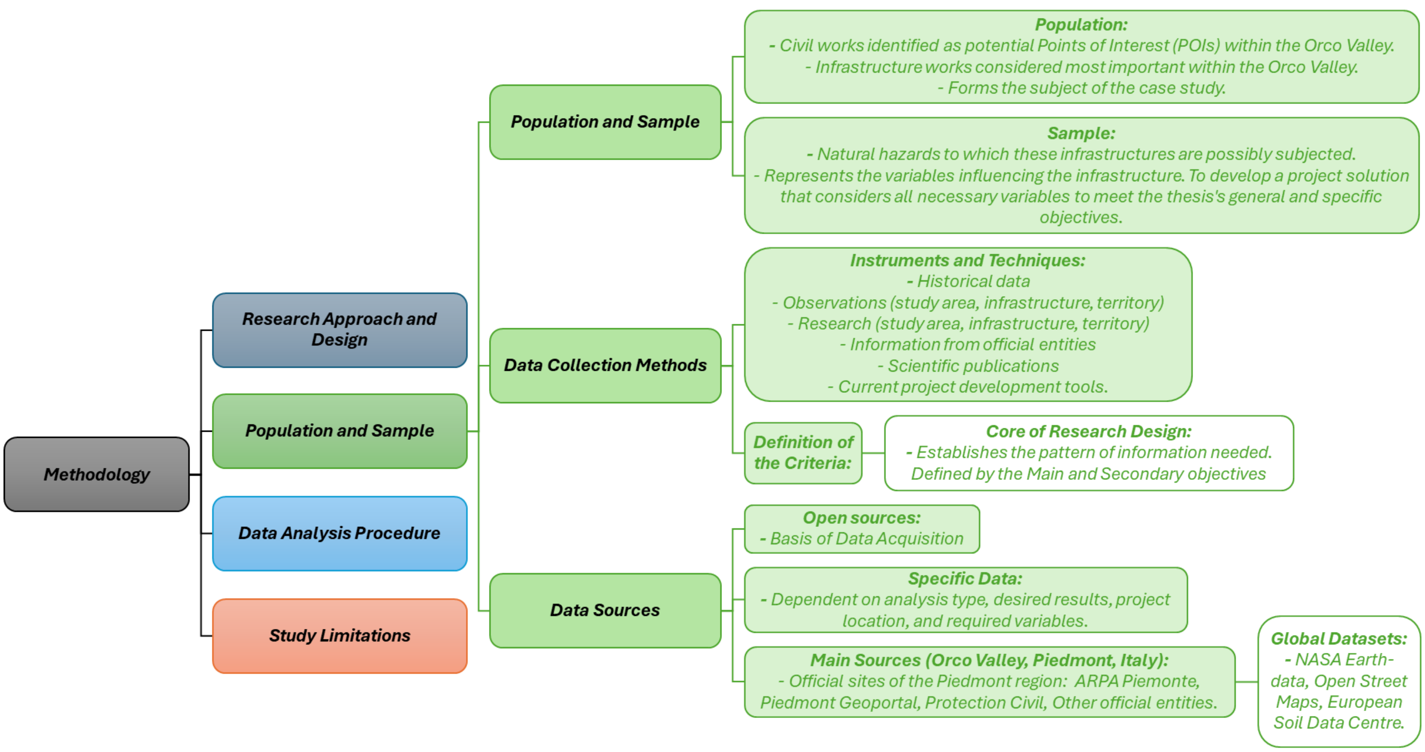
4.2.1.2. Data Sources

Data acquisition for this thesis project was based on open sources; the specific data needed depended on the type of analysis, the desired results, the location of the project, and the required variables. Since the study focused on the entire Orco Valley area, the main data sources came from official sites of the Piedmont region, Italy, including ARPA Piemonte, the Piedmont Geoportal, Protection Civil, among other official entities. In addition, global datasets from NASA Earth-data, Open Street Maps, and the European Soil Data Centre were also incorporated to improve the analysis, in particular for hydrological aspects, visualization, and representation of the real situation in the area. The information extracted from data sources was the starting point to the creation of the database.

Table 3. Data Source and Format

DATA DESCRIPTION	DATA SOURCE	FORMAT	EXTRACTED DATE
Country, Regions, Catchment	istat.it	Vector data	22/05/2024
Digital elevation model	search.earthdata.nasa.gov	Raster data	22/05/2024
Road Network	openstreetmap.org	Vector data	22/05/2024
Soil data	esdac.jrc.ec.europa.eu	Raster data	22/05/2024
Hazard collection	geoportale.arpa.piemonte.it geoportale.igr.piemonte.it regione.piemonte.it beta.idrogeo.isprambiente.it www.progettoiffi.isprambiente.it	Vector and Raster data	22/05/2024

Table 4. Conceptual Map for Population and Sample



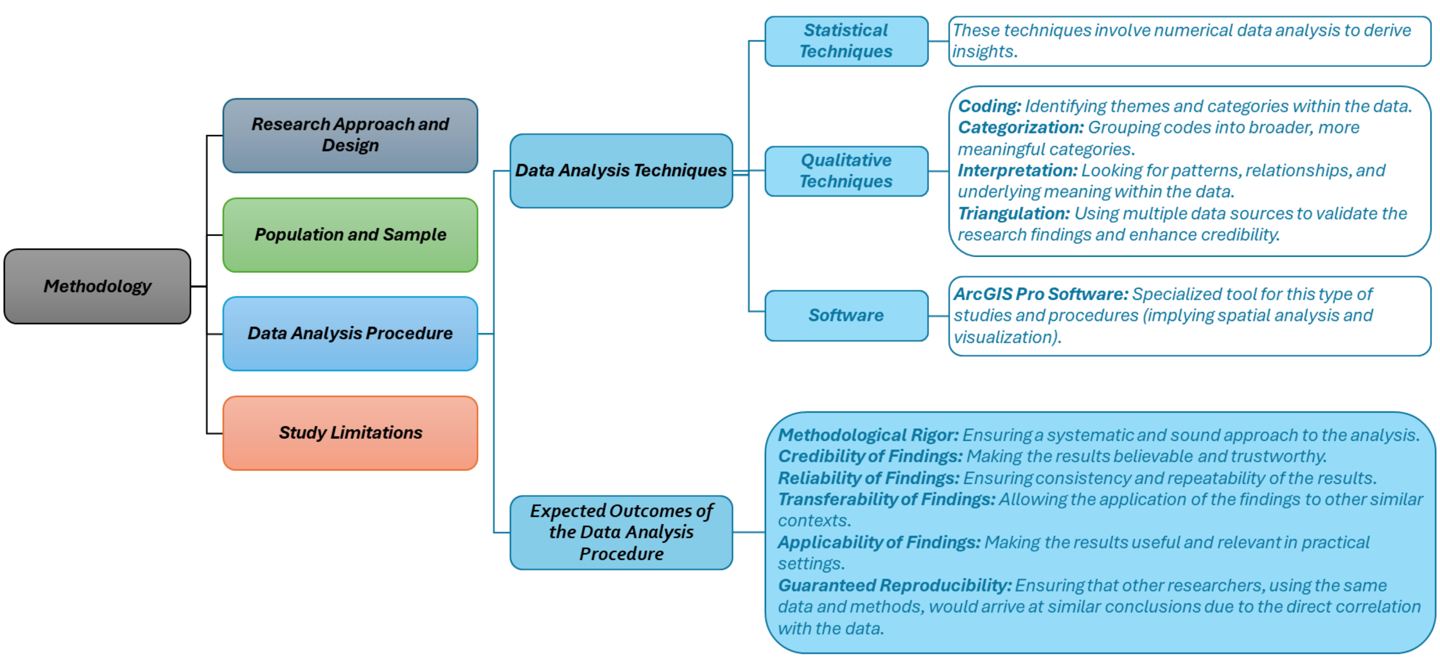
4.3. Data Analysis Procedure

The processing and analysis of the collected data will be carried out using appropriate statistical and qualitative techniques, which will allow us to determine and develop the risk assessment and identify possible weak points to consider during its execution. All this is possible since we have specifically defined the objectives of this case study and have also justified the relevance of the population and the sample for the project.

Among the data analysis techniques that will be used in this thesis project are: Coding, which will help us identify themes and categories in the data; Categorization, which will allow us to group the codes into broader categories; Interpretation, which looks for patterns, relationships and meaning in the data; Triangulation, which uses multiple data sources to validate the findings (N.Denzin & Y.Lincoln, 2018)**;** and finally ArcGIS Pro Software, As we have mentioned before, is specialized for this type of studies and procedures.

With the data analysis techniques and procedures mentioned in the previous paragraph, we will ensure that we apply methodological rigor, giving credibility and reliability in the findings. In addition, it will allow us to transfer and apply the findings to other contexts. All this is because of the direct correlation with the data, guaranteeing that other researchers would find the same conclusions.

Table 5.Conceptual Map for Data Analysis Procedure

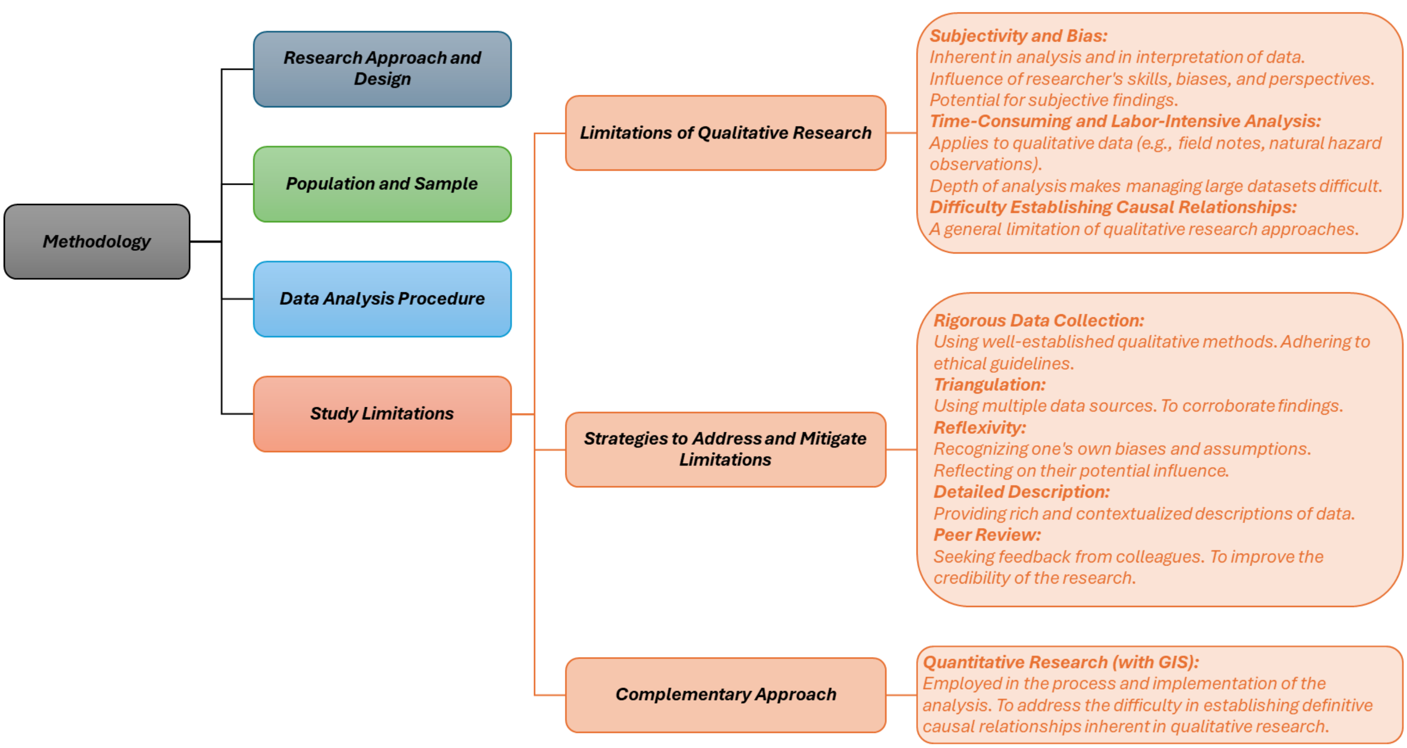


4.4. Study Limitations

While qualitative research offers valuable insights into natural hazard behaviours, it is not without limitations. These limitations relate to subjectivity and bias in the analysis, interpretation of the data, and the skills of the researcher, who may be influenced by their own biases and perspectives. This can lead to potential subjectivity in the findings. To mitigate this, researchers often use techniques such as triangulation and reflexivity. (Creswell J.W., 2014) Besides, analysing qualitative data, such as field notes and natural hazards, can be a time-consuming and labour-intensive process. The depth of analysis required can make it difficult to manage large data sets.

To address and mitigate the limitations, several strategies were employed such as Rigorous Data Collection, using well-established qualitative methods, and adhering to ethical guidelines; Triangulation, using multiple data sources to corroborate findings; Reflexivity, recognizing and reflecting on one's own biases and assumptions; Detailed Description, providing detailed and contextualized descriptions of data; Peer Review, seeking feedback from colleagues to improve the credibility of the research. (Creswell J.W., 2014) In addition, qualitative research has difficulties in establishing definitive causal relationships between variables. For this reason, this thesis project was complemented with quantitative research in the process and implementation of the analysis with GIS.

Table 6. Conceptual Map for Study Limitations



5. Risks Assessment

After having highlighted the importance of risk assessment, and after having carried out the research context, the literature review and the description of the methodology; we will proceed in this section with the realization of the work for the risk assessment. According to literature and different authors like (Rogers, 2012), (Mª. Martínez, 2015), and (M.Ashford & R.Wiley, 2019) there are several different methods that can be used to conduct this type of assessment; but summarizing all the information found, a general process can be applied that synthesizes all the process and it can be applied for any kind of risk assessment. This general process involves the following steps:

1. Define the Assessment Scope and Identification of Potential Natural Hazards.
2. Analysis and Prioritization of Potential Risk Factors.
3. Determine areas of interest and risk levels.
4. Suggestions for Implementation, Monitoring and Updates of Mitigation Strategies.

By conducting a thorough Risk Assessment, civil engineers can make informed decisions about how to design, construct, and maintain civil work projects in a safe and sustainable manner. Risk Assessment is an ongoing process throughout the project lifecycle, proactively adapting to changing project circumstances, new information and lessons learned; that in the same way is one of the main objectives of the BIM methodology.

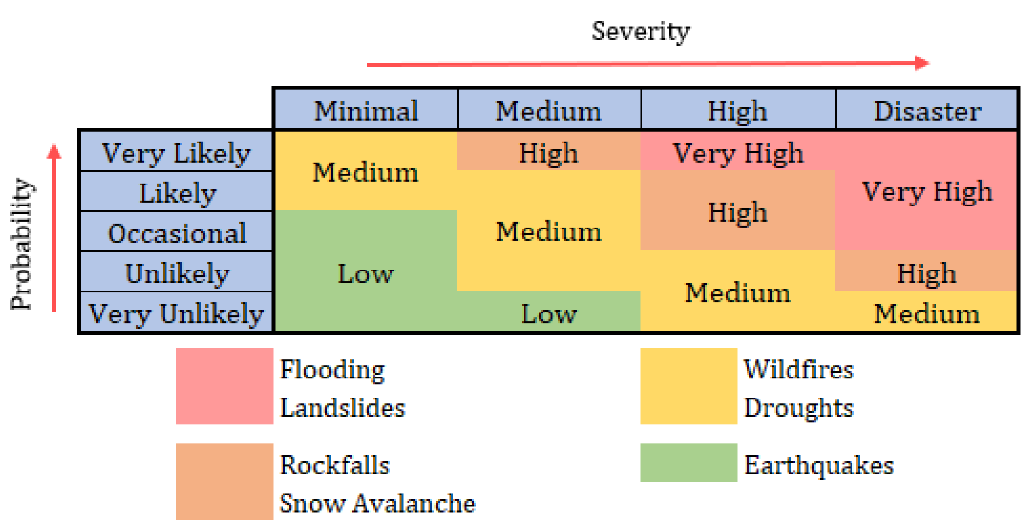
5.1. Define the Assessment Scope and Identification of Potential Natural Hazards

The first step is to clearly define the purpose of the assessment, considering the parties involved, the limits of the evaluation and the framework to be developed. Having this in mind, the purpose of this assessment is to analyze comprehensively the potential hazards, potential vulnerabilities and potential risks, the infrastructure works in the Orco Valley, and the surrounding area may face and thus suggest preventive measures to mitigate the risk of unwanted events; a purpose that is aligned with the general objectives described above.

After having defined the purpose of the assessment, the identification of the Potential Natural Hazards is carried out. This data processing has been done from the descriptions made in the data analysis procedure section of this thesis project; in addition to the analysis of probability and severity of each of its components recorded within the Orco Valley. These identified hazards will be visually represented and prioritized using a hazard analysis matrix, a valuable tool for this type of assessment. The information considered for the creation of said matrix will be shown below.

- **Historical Impact:** The Orco Valley has a severe history of natural hazards, with 36 major landslide events and over 250 deaths since the 18th century.
- **Dominant Hazards:** Landslides, floods, rockfalls, and snow avalanches are the primary threats.
- **Susceptibility:** A significant portion of the valley is susceptible to landslides (85 sq km for large, 19 sq km for shallow). Stream networks are prone to debris flows.
- **Triggers:** Heavy rain, spring thaws, and cold winters with fluctuating temperatures are key triggering factors for floods, landslides, and avalanches.
- **Vulnerable Areas:** Floodplains along the Orco, Soana, and Levanna rivers, unstable/sparsely vegetated slopes, cliff bases, and hiking trails are particularly exposed.
- **Human Impact:** Human colonization significantly increases potential damage and risks from natural hazards.
- **Fatalities Breakdown (Historical):** Snow avalanches (59%), river floods (21%), debris flows (12%), and rockfalls (8%) are the leading causes of fatal events.
- **Other Risks:** Soil erosion, droughts, and wildfires also pose significant challenges.
- **Earthquake Risk:** Northern Italy (including Orco Valley) is generally in lower earthquake risk zones (3 and 4), but localized risks necessitate preparedness.

Table 7. Hazard Analysis Matrix



To develop this analysis matrix and identify potential hazards, data was collected through observation, research, and analysis of existing and historical information. The vertical component of the matrix (probability) was calculated by interpreting the historical events described in section ***2.2.1 Hazards Analysis***, from the research context of this thesis project, and the same applies for the horizontal component (severity). In addition to a previous study focused on landscape analysis for multi-hazard prevention in the Orco and Soana valleys in northwestern Italy, from Natural Hazards Earth System Sciences Discussions (NHESSD) (Turconi, 2015)

A risk matrix prioritizes actions based on probability and impact. Critical risks, such as floods and landslides, demand immediate attention due to their high probability and serious consequences. High-risk phenomena, such as avalanches, require monitoring and control despite their lower probability compared to the previous one, since their impact can be substantial. In contrast, medium-risk events, such as wildfires and droughts, occur with certain frequency but cause limited damage, requiring basic control measures. Finally, low-risk events pose little threat and can be ignored. While valuable, risk matrices have limitations and should be used in conjunction with other analyzes and management strategies for a comprehensive approach.

5.2. Analysis and Prioritization of Potential Risk Factors

Having said the above, we will analyze and prioritize the Potential Risk Factors within the study area from the most important to the least important, keeping in mind that the mentioned factors are hazard analysis, vulnerability analysis and risk analysis. Prioritization will be carried out using a method called analytical hierarchical process (AHP) to estimate the significance of each factor.

The Analytic Hierarchy Process (AHP) is a method for decision-making in complex problems with multiple criteria. It is based on decomposing the problem into a hierarchy of simpler subproblems, allowing for a systematic and quantitative evaluation of different options. The problem is defined and the key factors to be considered are then compared with peers to determine their relative importance, using a specific numerical scale. Through mathematical calculations, numerical values are assigned that represent the priority of each factor. It is essential to ensure the consistency of these comparisons to obtain reliable results. Finally, the alternative that best meets the most important criteria is selected, providing an informed and objective decision. (Busico, Giuditta, Kazakis, Colombani, & A., 2019)

The AHP is a valuable tool for complex decision making. Its advantages lie in its ability to structure complex problems, integrate qualitative and quantitative information, encourage the participation of multiple actors, and adapt to diverse situations. However, the

AHP also has some limitations. Subjectivity in pairwise comparisons can introduce biases into the results. In addition, the complexity of the method can increase significantly when working with a large number of criteria and alternatives, sometimes requiring the use of specialized software. The Analytic Hierarchy Process (AHP) method has proven to be a versatile tool in a wide range of applications. From the selection of the most suitable suppliers to the planning of complex projects, through to risk assessment and strategic decision making in the business field, the AHP has been used successfully. Even in natural resource management, this method has found its place, proving its usefulness in various contexts where structured, multi-criteria decision-making is required. (Belton V. & Thomas L., 2001)

5.2.1. Hazard Analysis

Mapping natural hazards involves a combination of office work (photointerpretation, geoprocessing) and field studies. Data sources include previous research and aerial photographs. The maps characterize a distinct sample (hazards) that occur in a particular area. Each sample consists of classes (attributes) and their associated probabilities of occurrence. (Mahler & Varanda, 2012)

This approach to determining probabilities is based on expert opinions. Given the qualitative nature of the data and the complex relationship between risk factors and natural hazards, experts infer probabilities based on their experience and judgment. They convey their confidence in the contribution of each attribute thanks to the probability associated with a certain event. While numerical values are assigned to these expert opinions, these judgments inherently carry some uncertainty. However, since we use data from official sources, we will rely on the validity of the published information. Verbal descriptions often provide a more intuitive starting point at first than the direct assignment of numerical probabilities. These verbal descriptions can then be translated into approximate probability values for each event within the model. (Fell & Hartford, 1997)

The following table presents a list of verbal descriptions with their values adapted from the studies according to (Lichtenstein & Newman, 1967). These values were assigned to each type of hazards to express confidence, through the judgment of each situation that contributes to the occurrence of a natural hazard.

Table 8. Verbal Description of Adapted Probabilities

Description	Deduced Probability
Very Low Probability	0.1
Low Probability	0.4
Medium Probability	0.5
High Probability	0.7
Very High Probability	0.9

The probability of the occurrence of a hazard is determined by analyzing its frequency and considering other relevant environmental factors. This involves categorizing and prioritizing information, often qualitative in nature. While initial assessments may be based on descriptive information, meaningful results can be obtained through interpretation and triangulation, and statistical techniques can be used to calculate a more robust probability of the occurrence of the hazard. This approach integrates frequency data with an understanding of the complex relationship between risk factors and natural hazards. The data collected for each hazard (samples) and all information related to the physical environment are shown below, as well as the results of prioritizing the information.

5.2.1.1. Flooding

- Very High-Risk Area (ARME) – Floods (PAI)

Area Rischio Molto Elevato (ARME) or Areas at Very High Hydrogeological Risk for its acronym in the Italian language, for the Floods hazards, taken from the Piano per l'Assetto Idrogeologico (PAI), that incorporate and expand the areas identified in the Extraordinary Plan PS267 of the Po River Basin Authority. Meta documentation available on the Geoportale Piemonte. Below is an image related to the information found.

Figure 18. Areas at Very High Hydrogeological Risk – Floods
Source: Geoportale Piemonte

- River Bands (Fascie Fluviali)

Fascie Fluviali or River zones, identified by the Piano per l'Assetto Idrogeologico (PAI) of the Po River basin, for the territorial scope of the Piedmont region. Meta documentation available on the Geoportale Piemonte. Below is an image related to the information found. Below is an image related to the information found.

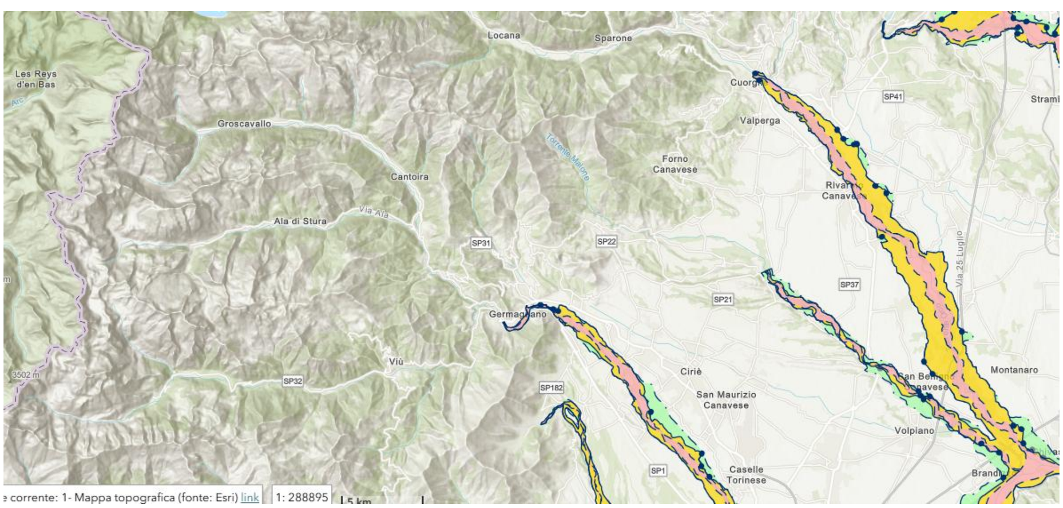


Figure 19. River Zones
Source: Geoportale Piemonte

- Area Floods (Esondazioni Areali)

Esondazioni Areali or Area Floods, from Piano di Gestione del Rischio Alluvionale (PIGRA) or Flood Risk Management Plan of the Piedmont Region for its acronym in the Italian language. The map shown here is created through a simple connection to the original service/dataset created and managed by the entity that owns the data. Meta documentation available on the ARPA Piemonte.

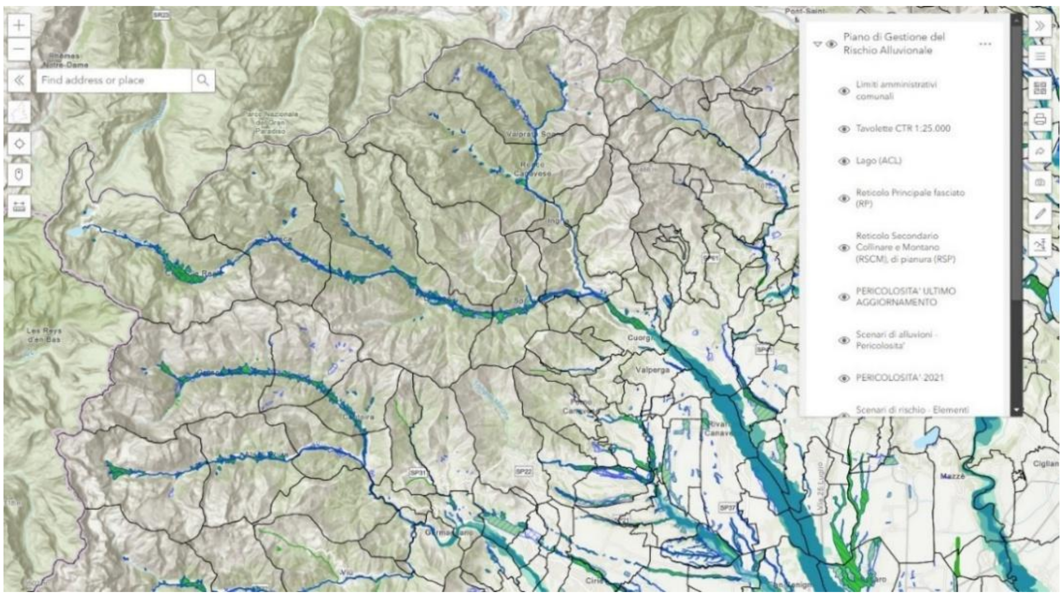


Figure 20. Area Floods
Source: Geoportale Piemonte

The following table presents the prioritization of the samples (hazards). This prioritization ranges from 5 to 1, with 5 being the highest priority and 1 the lowest. This prioritization, performed using the AHP methodology, seeks to generate a weighted average of the hazard levels present in the area. In addition, the attributes (classes) were categorized using the information presented in ***Table 8. Verbal Description of Adapted Probabilities,*** for the information found.

Table 9. Flood Categorization

Flood Categorization				
Samples	Prioritization	Fai	Description (Attributes)	Deduced Probability
F1 = ARME	5	0.40	Area Rischio Molto Elevato	0.9
F2 = Fascie Fluviali	4	0.40	Fascie Fluviali A	0.9
			Fascie Fluviali B	0.7
			Fascie Fluviali C	0.5
F3 = Esondazioni Areali	3	0.19	Esondazione Molto Elevata	0.9
			Esondazione Elevata	0.7
			Esondazione Media	0.5
FL = Land	1	0.01	Land with no hazard	0.1
		1.00		

5.2.1.2. Landslides

- Very High-Risk Area (ARME) – Landslides (PAI)

Area Rischio Molto Elevato (ARME) or Areas at Very High Hydrogeological Risk for its acronym in the Italian language, for the Landslides hazards, taken from the Piano per l'Assetto Idrogeologico (PAI), that incorporate and expand the areas identified in the Extraordinary Plan PS267 of the Po River Basin Authority. Meta documentation available on the Geoportale Piemonte. Below is an image related to the information found.

Figure 21. Areas at Very High Hydrogeological Risk – Landslides
Source: Geoportale Piemonte

- Landslide Phenomena Information System in Piedmont (Info Frane)

Sistema Informativo fenomeni Franosi (SIFraP) in Piemonte or Landslide Phenomena Information System in Piedmont for its acronym in the Italian language, that shows an inventory of landslide phenomena in the region. Meta documentation available on the ARPA Piemonte. Below is an image related to the information found.

Figure 22. Landslide Phenomena Information System in Piedmont
Source: ARPA Piemonte

- Alluvial Fans in Piedmont (Severita Fenomeno Atteso)

This morphological mapping of the “Conoidi Alluvionali” shows the information stored on the basins in their longitudinal sense, with their torrential characteristics, which means that such torrential events can saturate the soil, increasing the risk of landslides in mountainous areas or on sloping terrain. Information provided from the morphometric and lithological point of view, which allows us to categorize and consider for the calculation of the probability of landslides. Meta documentation available on the ARPA Piemonte. Below is an image related to the information found.

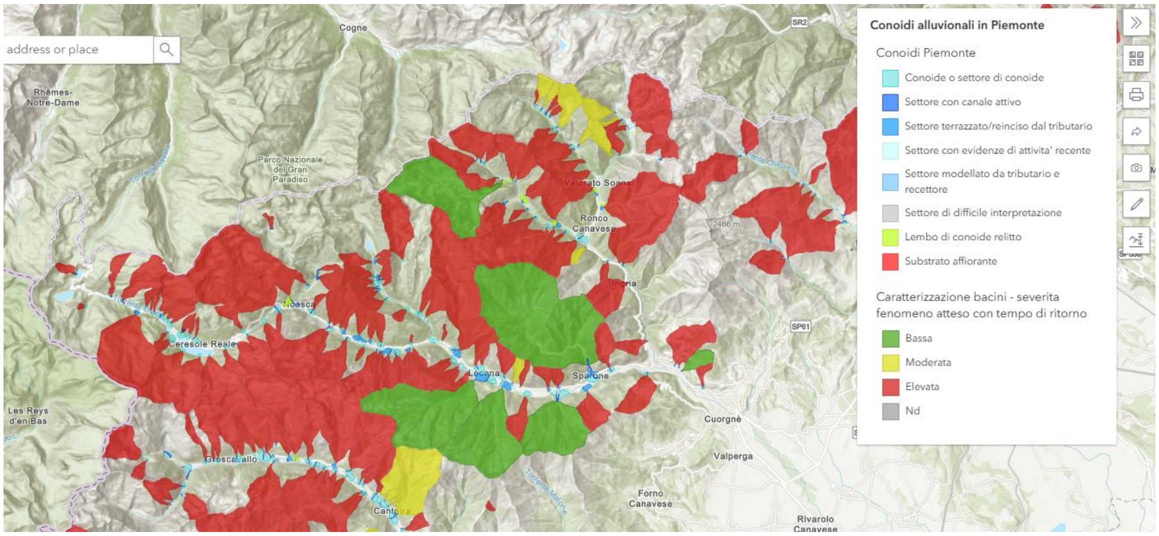


Figure 23. Alluvial Fans in Piedmont
Source: ARPA Piemonte

- Unstable Areas (Aree Instabili)

The Aree Instabili or Unstable Areas, it shows the information collected by the database for geological processes provided by the Piedmont region, which illustrates the sectors vulnerable to landslides. Meta documentation available on the ARPA Piemonte. Below is an image related to the information found.

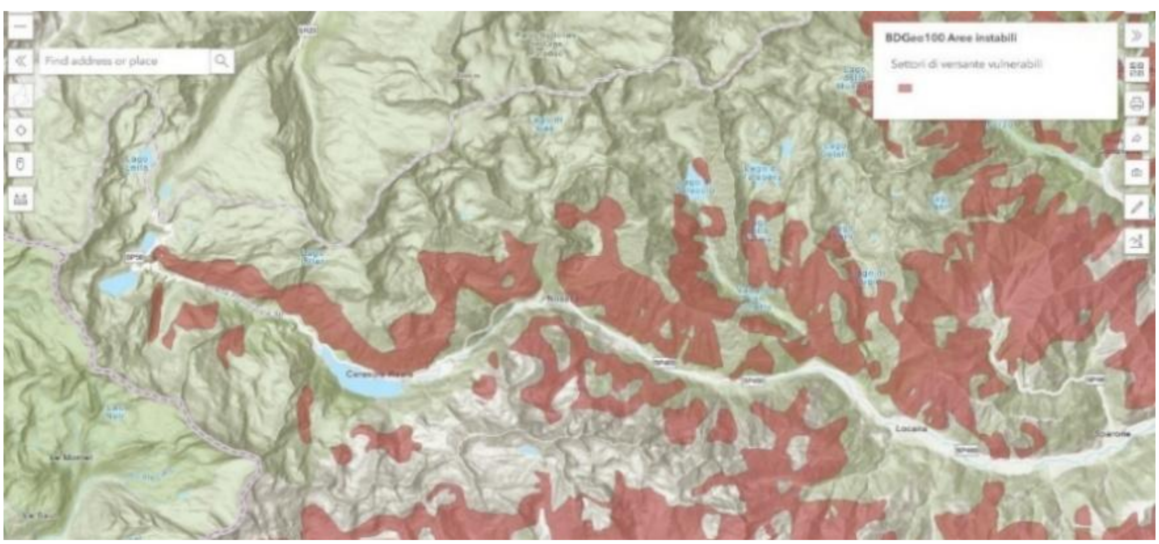


Figure 24. Unstable Areas
Source: ARPA Piemonte

The following table presents the prioritization of the samples (hazards). This prioritization ranges from 5 to 1, with 5 being the highest priority and 1 the lowest. This prioritization, performed using the AHP methodology, seeks to generate a weighted average of the hazard levels present in the area. In addition, the attributes (classes) were categorized using the information presented in ***Table 8. Verbal Description of Adapted Probabilities,*** for the information found.

Table 10. Landslides Categorization

Landslides Categorization				
Samples	Prioritization	Lai	Description (Attributes)	Deduced Probability
L1 = ARME	5	0.35	Area Rischio Molto Elevato	0.9
L2 = Info Frane	4	0.3	Frane Cartografabili	0.9
			Frane Antiche Possible Attiv	0.7
			Crolli delimitabile	0.5
L3 = Severita Fenomeno Atteso	3	0.2	Severita Elevata	0.7
			Severita Moderata	0.5
			Severita Bassa	0.4
L4 = Aree Instabili	2	0.14	Aree Instabili	0.5
LL = Land	1	0.01	Land with no hazard	0.1
		1.00		

5.2.1.3. Avalanche

- Avalanche Information System (SIVA)

Sistema Informativo Valanghe or Avalanche Information System for its acronym in the Italian language. It is constantly updated as seasonal avalanches occur and new historical data becomes available. Where you can find all the information related to this type of event, where you can find the areas defined as dangerous, the areas recorded in the archive and the photo interpretation obtained thanks to the advances in technology. Meta documentation available on the ARPA Piemonte. Below is an image related to the information found.

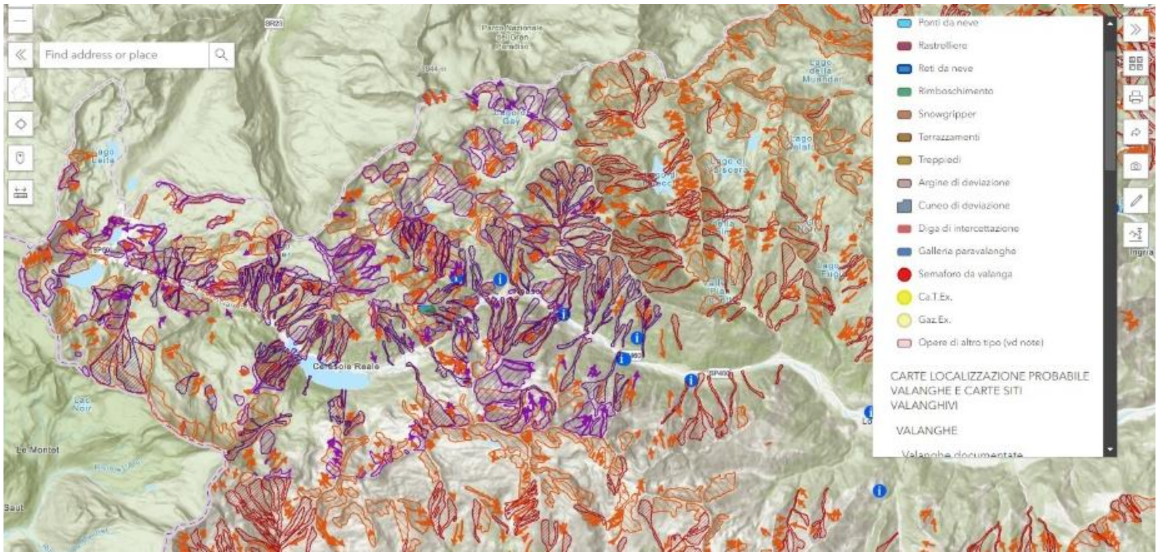


Figure 25. Avalanche Information System
Source: ARPA Piemonte

The following table presents the prioritization of the samples (hazards). This prioritization ranges from 5 to 1, with 5 being the highest priority and 1 the lowest. This prioritization, performed using the AHP methodology, seeks to generate a weighted average of the hazard levels present in the area. In addition, the attributes (classes) were categorized using the information presented in ***Table 8. Verbal Description of Adapted Probabilities,*** for the information found.

Table 11. Avalanche Categorization

Avalanche Categorization				
Samples	Prioritization	Aai	Description (Attributes)	Deduced Probability
A1 = SIVA	5	0.50	Zone Pericolose	0.9
			Foto Interpretazione	0.7
A2 = Archive	3	0.30	Zone Pericolose	0.9
			Terreno e Archivio	0.7
A3 = Photo Interpret	4	0.19	Terreno e Archivio	0.9
AL = Land	1	0.01	Land with no hazard	0.1
		1.00		

5.2.1.4. Wildfires

- Trigger Areas and Points

Aree e Punti di Innesco or Trigger Areas and Points, this dataset concerns forest fires affecting the territory of the Piedmont region, particularly the areas affected by large forest fires (greater than or equal to 10 ha) delimited by the State Forestry Corps and the related trigger points. As well as the trigger points of forest fires in a time range from 1997 to 2023. Meta documentation available on the Geoportale Piemonte. Below is an image related to the information found.

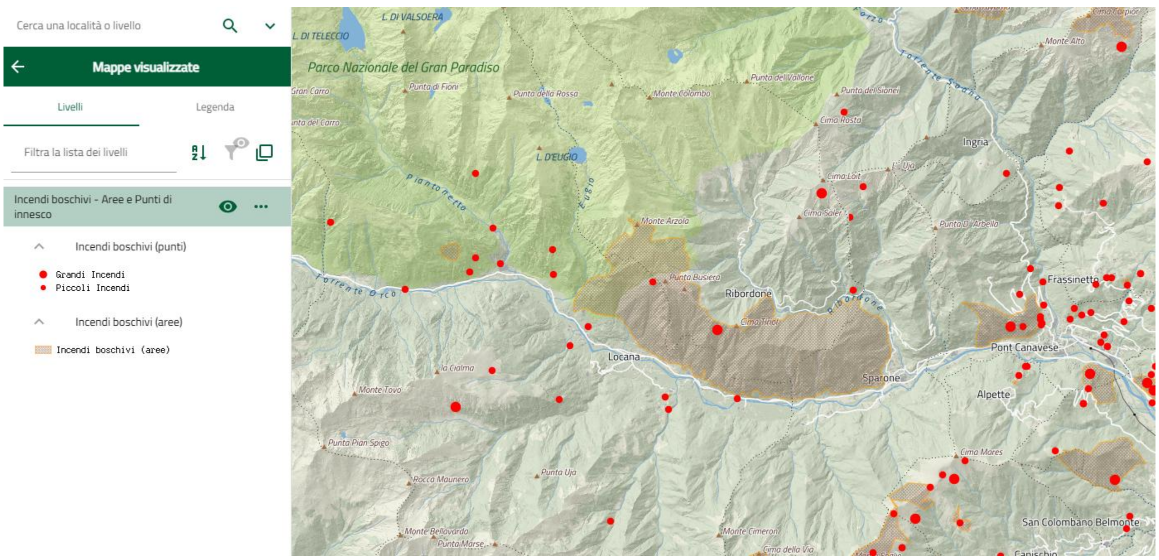


Figure 26. Aree e Punti di Innesco
Source: Geoportale Piemonte

The following table presents the prioritization of the samples (hazards). This prioritization ranges from 5 to 1, with 5 being the highest priority and 1 the lowest. This prioritization, performed using the AHP methodology, seeks to generate a weighted average of the hazard levels present in the area. In addition, the attributes (classes) were categorized using the information presented in ***Table 8. Verbal Description of Adapted Probabilities,*** for the information found.

Table 12. Wildfire Categorization

Wildfire Categorization				
Samples	Prioritization	Wai	Description (Attributes)	Deduced Probability
W1 = Fire Points	5	0.69	Zone Pericolose	0.9
W2 = Area Fires	4	0.30	Terreno e Archivio	0.7
WL = Land	1	0.01	Land with no hazard	0.1
		1.00		

5.2.2. Vulnerability Analysis

As mentioned throughout this thesis project, vulnerability analysis will be carried out by a multi-criteria assessment that considers the inherent vulnerabilities of each infrastructure element (POI) and the geomorphological vulnerabilities of the area (slope, land cover/use, height, etc.). For the analysis, the samples are POIs and the surrounding area. Each sample is characterized by its classes (attributes) and assigned to a vulnerability level. This approach is context-dependent, based on qualitative data and inferences drawn from factors such as capabilities, design, and literature reviews. While numerical values are assigned, there is inherent uncertainty. Confidence in these assessments is conveyed through descriptive information. However, by drawing on common knowledge and published information, these descriptions are translated into correct approximate vulnerability values.

This study initially relied on qualitative information, but significant progress was made through data interpretation, triangulation, and statistical techniques. By integrating intrinsic and geomorphological data and understanding their complex interplay with vulnerability, a more accurate and comprehensive assessment was achieved. The following tables present the data collected for each sample, including information about the physical environment and their assigned prioritization criteria. These values, reflecting the confidence in each contributing factor, were assigned based on expert judgment and analysis of each situation.

5.2.2.1. Inherent Vulnerabilities of POI's

Prioritization of the inherent vulnerabilities of the Poi's was carried out through rigorous data collection, triangulation, reflexivity, detailed description, and peer review as mentioned to avoid the limitations in this research and obtain better quality results. We must keep in mind that inherent vulnerabilities are those related to their design, construction or materials; these vulnerabilities can be physical, functional or social.

The following table presents the prioritization of the population (POI's). This prioritization ranges from 5 to 1, with 5 being the highest priority and 1 the lowest. This prioritization, performed using the AHP methodology, seeks to generate a weighted average of each infrastructure present in the area. In addition, the attributes (classes for inherent vulnerabilities) were categorized using a deduced probability according to the information found.

Table 13. Inherent Vulnerabilities of POI's

POI's Categorization				
Samples	Prioritization	V'ai	Description (Attributes)	Deduced Vulnerability
V1' = Dams	1	0.09	Very Low Vulnerability	0.1
V2' = Hydropower Plants	2	0.15	Low Vulnerability	0.4
V3' = Electrical Transformer Cabinets	3	0.20	Medium Vulnerability	0.5
V4' = Aqueduct	4	0.25	High Vulnerability	0.7
V5' = Electric Distribution Networks	5	0.30	Very High Vulnerability	0.9
VL = Vulnerability Land	1	0.01	Land with no POI's	0.1
		1.00		

5.2.2.2. Geomorphological Vulnerabilities

For the prioritization of geomorphological vulnerabilities (Slope, Land Cover/Use and Height), the same considerations were taken to avoid the limitations of the analysis, but in this case, the vulnerabilities can be quantified thanks to the evidence found in the literature. This allows us to prioritize the geomorphological vulnerabilities more objectively.

The following table presents the prioritization of the samples (geomorphological vulnerabilities). This prioritization ranges from 5 to 1, with 5 being the highest priority and 1 the lowest. This prioritization, performed using the AHP methodology, seeks to generate a weighted average of each vulnerability present in the area. In addition, the attributes (classes for geomorphological vulnerabilities) were categorized using a deduced probability according to the information found.

Table 14. Geomorphological Vulnerabilities

Geomorphological Categorization					
Samples / Prioritization	Slope [°]	LC/LU	Height [m.a.s.l.]	Description (Attributes)	Deduced Vulnerability
1	0 - 9	Urban	175 -700	Very Low Vulnerability	0.1
2	9 - 18	Lands, vegetation	700 - 1600	Low Vulnerability	0.4
3	18 - 27	Snow, Water	1600 - 2300	Medium Vulnerability	0.5
4	27 - 36	Rocks	2300 - 3000	High Vulnerability	0.7
5	> 36	Forest	> 3000	Very High Vulnerability	0.9
Gai	0.34	0.33	0.33		

5.2.3. Risk Analysis

Generally, risk is estimated by the product of the probability of occurrence of a natural hazard and the vulnerability that exists to said hazard materializing, represented by the following equation:

$$R = P(hazards) * Vulnerability$$

In this thesis project, the objective is to perform a comprehensive risk assessment using a multi-criteria analysis involving most of the factors that may cause an undesirable event; the factors that have been considered so far in the model are the Probability of occurrence of a natural hazard, and Vulnerability, either intrinsic or geomorphological (POIs and Terrain). In order to enrich this model and achieve the main objective of this thesis project, other definitive factors will be evaluated when performing a risk assessment. These factors are Exposure and Consequence to undesirable events; these factors will be developed below.

5.2.3.1. Exposure

Exposure is an important component of risk and defines proximity to the impact of an undesirable event. Without exposure, there is no risk. By defining the areas of greatest exposure, risk prevention and mitigation initiatives can be strategically targeted, determining whether they are affected by the hazardous event or whether other infrastructure is nearby. Exposure is measured differently depending on the risk and the elements at risk. In this case, it will be assessed and defined as the distance from every 100 m to 400 m from a point of interest.

The following table presents the prioritization of the population (POI's). This prioritization ranges from 5 to 1, with 5 being the highest priority and 1 the lowest. This prioritization, performed using the AHP methodology, seeks to generate a weighted average of each infrastructure present in the area. In addition, the attributes (classes for exposure) were categorized using a deduced probability according to the information found.

Table 15. Exposure

Exposure Categorization							
Eai	0.2	0.2	0.2	0.2	0.19	0.01	Deduced Exposure
Prioritization	E1 = Dams	E2 = Hydropower Plants	E3 = Electrical Transformer Cabinets	E4 = Aqueduct	E5 = Electric Distribution Networks	E5= Exposure Land	
5	100m	100m	100m	100m	100m	> 400m	0.9
4	200m	200m	200m	200m	200m		0.7
3	300m	300m	300m	300m	300m		0.5
2	400m	400m	400m	400m	400m		0.4
1	> 400m	> 400m	> 400m	> 400m	> 400m		0.1

5.2.3.2. Consequence

Consequence refers to the negative impact of an undesirable event, encompassing potential harm to people, property, the environment, and economic stability, generally derived from the literature review. These impacts can range from minor injuries and damage to catastrophic losses and long-term effects. When assessing risks, the severity of consequences is a crucial factor along with the probability of the event occurring. Typically, the most severe consequences are prioritized, even if they are less likely. This focus on severe consequences guides informed decision-making in risk prevention and mitigation initiatives.

The following table presents the prioritization of the population (POI's). This prioritization ranges from 5 to 1, with 5 being the highest priority and 1 the lowest. This prioritization, performed using the AHP methodology, seeks to generate a weighted average of each infrastructure present in the area. In addition, the attributes (classes for consequence) were categorized using a deduced probability according to the information found.

Table 16. Consequence

Consequence Categorization				
Samples	Prioritization	Cai	Description	Categorization
C1 = Dams	5	0.30	Very High Consequences	0.9
C2 = Hydropower Plants	4	0.25	High Consequences	0.7
C3 = Electrical Transformer Cabinets	3	0.20	Medium Consequences	0.5
C4 = Aqueduct	2	0.15	Low Consequences	0.4
C5 = Electric Distribution Networks	1	0.09	Very Low Consequences	0.4
CL = Consequence Land	1	0.01	Land with no Conseq.	0.1
		1.00		

5.3. Determine Areas of Interest and Risk Levels.

To effectively overlay georeferenced data and conduct spatial analysis, we will utilize GIS methodology. GIS processing revolutionizes map creation by integrating geographic data with alphanumeric data, traditionally presented in tables. This integration results in thematic maps that effectively combine multiple layers of information. This powerful tool enables mathematical operations between these layers, providing invaluable insights and deeper understanding of the spatial relationships within the data.

5.3.1. GIS Processing

GIS methodology stands out for its efficient management of data and projects at various stages, from site location and environmental analysis to construction, data collection, operations, and long-term maintenance. Defining a solid workflow is crucial for successful project execution. This analysis integrates multiple engineering disciplines, and ArcGIS Pro is the primary tool. The GIS design process involves defining key variables and creating diagrams to ensure efficient data management and reliable analysis, ultimately leading to informed decision making and effective solutions. (Paul A. Longley, 2010)

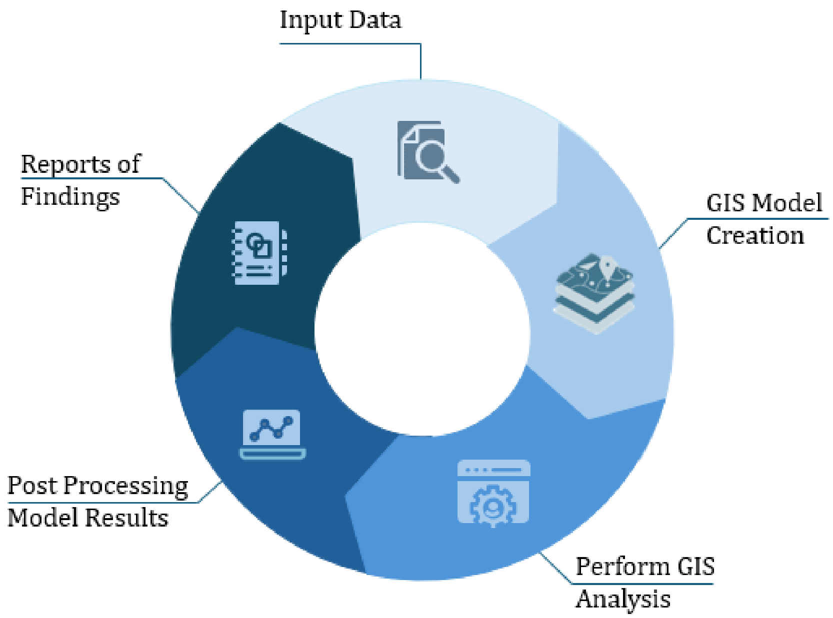


Figure 27. GIS Process

5.3.1.1. Input Data

Once the information is collected, the database can be created. A database is a whole of structured information, which is dependent on acquisition, management, and use. In GIS, the database is used to manage the connection between attribute and geometry; in other words, it is the link between the attribute of an entity and the entity itself. (Paul A. Longley, 2010)

As shown in ***Figure 14. GIS Process for Data Input***, the process for data input consists of Formulating Research Questions, Collecting Data, Creating the Data Model, and Entering the Data Into GIS. (Piras, 2020)

- Formulating Research Questions

The Formulating Research Questions will involve defining and developing three key models: external, conceptual, and logical. The External Model, representing reality within the GIS context, necessitates a simplified representation based on the specific goals and applications of the GIS database. The key entities considered were described in section ***4.2.1.1. Definition of the Criteria***, for data collection.

The Conceptual Model was established using an entity-relationship model, focusing on objects, their properties and their interconnections. Data definitions were derived from their source and categorized as vector or raster data, crucial for determining supported operations. The database was built by combining public data with software-generated information, ensuring a complete data set for the required analysis.

The Logical Model is used to define the structure of data elements and establish relationships between them. It adds more information to the elements of the conceptual model. The advantage of using a logical model is that it provides a basis for forming the foundation of the GIS model. The logical model adopted was the model with the implementation of the Analytic Hierarchy Process (AHP). This term is useful and mandatory to perform some operations and connections between external tables and the database we are creating. The implementation is shown in section ***5.2. Analysis and Prioritization of Potential Risk Factors***.

- Collecting Data

The GIS data environment is the foundation for all geographic analysis. It's how spatial data is organized and utilized, enabling automated tasks, improved efficiency, and collaborative workflows. Within this environment, GIS web services offer dynamic and flexible access to geographic data online. (Pyo, 2019)

For this specific project, WMS and WFS services were deemed most suitable for map visualization and spatial analysis. Since it was necessary to visualize the maps in an appropriate manner (WMS); as well as perform spatial analysis or create interactive applications (WFS). This selection of the services was made based on the considerations made of factors such as task complexity, data volume, technical expertise, service performance and data security. Thanks to the amount of information that we can find today, all the input needed for this project could be accessed from the same data source and official entities mentioned in the previous section.

- Creating Data Model

As we have already mentioned above, ArcGIS Pro software will be used to create Data Model, since this software provides the necessary tools to create the database structure and manage the geographic data. For this process, it is crucial to select the appropriate data type for each attribute, and most of the data was geometric, since for the geographic entities, the type of geometry must be defined. These geometries can be of the Point type, to represent point entities (infrastructure); of the Line type, to represent linear entities (roads, rivers); and finally of the Polygon type, to represent polygonal entities (Areas, bodies of water, etc.). Once the database structure has been created, geographic data can be entered. This can be done in several ways: by digitizing it, by drawing geographic entities in GIS software; and by importing, by converting data from other formats (WMS and WFS services).

GIS software offers a broad set of specialized tools for model development. These tools are organized into distinct categories, each with specific functions to carry out the different stages of the modeling process, like Map Visualization and Exploration Tools, Data Creation and Editing Tools, Spatial Analysis, Symbolization and Representation Tools, and Geographic Data Management Tools. (Bolstad, 2019)

Map Visualization and Exploration Tools offer essential functionality for analyzing geographic data. Layers allow different sets of spatial information to be organized and visualized independently, making it easier to identify patterns and relationships. The ability to zoom in, out, and pan the map, along with the ability to identify specific elements by clicking, allows for detailed exploration of the data. In addition, attribute tables provide detailed information about each geographic element, allowing for querying and editing. These tools are essential for effectively understanding and analyzing spatial data.

Data Creation and Editing Tools in a GIS allow for precise manipulation and generation of geographic information. These tools facilitate the construction of new geographic elements, such as points, lines, and polygons, directly on the map. They also allow existing features such as shape, location, and attributes to be modified. Georeferencing is essential for incorporating images or maps without geographic coordinates into the system, assigning them a precise position. Digitization transforms maps or raster images into vector format, allowing their editing and analysis. In short, these tools provide a set of essential functions for creating and maintaining accurate and detailed geographic databases. (Goodchild, 2007)

Spatial Analysis is performed using a set of tools that allow the manipulation and extraction of information from geographic data. These tools include geoprocessing, which allows operations such as overlaying maps or creating zones of influence; network analysis, which studies the connectivity of elements such as roads or rivers; raster analysis, which works with images and digital terrain models to obtain information about the Earth's surface; and spatial statistics, which identify patterns and relationships between geographic data. (Bolstad, 2019)

Symbolization and Representation Tools are essential for creating clear and understandable maps. Symbology assigns specific symbols and colors to different geographic features, helping to visualize their attributes. Labeling adds direct text to these features for quick identification. These tools, together with the design of custom maps, allow for the creation of clear and effective visual representations of geographic information, facilitating its interpretation and analysis. (Goodchild, 2007)

Geographic Data Management Tools are essential for organizing and managing spatial information efficiently. These tools, such as geographic databases, allow us to store large volumes of data in a structured and accessible way. In addition, they facilitate the transfer of data between different systems and formats thanks to import and export functions. To ensure the quality and understanding of this data, metadata is used, which are detailed descriptions that accompany geographic data and provide information about its origin, content, and structure. In short, these tools are essential for any analysis or project involving spatial data. (Bolstad, 2019)

- Entering Data Into a GIS

Validating a data model in a GIS is crucial to ensure its quality and reliability. This process involves a rigorous review of the database structure and the accuracy of the geographic data. The data is verified to be consistent, complete and reflective of reality. To do this, tests are carried out that assess the connection between spatial elements, the precision of locations and the accuracy of the information associated with each element. Any errors detected must be corrected before using the model in subsequent analyses. In essence, validation ensures that the data is reliable and useful for making informed decisions. (Piras, 2020)

5.3.1.2. GIS Model Creation

GIS models allow the real world to be represented and analysed digitally. These models, which can be simple or complex, simulate geographic processes and predict outcomes. From calculating areas to simulating water flows, GIS offers a powerful tool for decision-making. Once created, these models generate results that are visualised through maps, graphs and tables. Interpreting these results is essential to understanding their meaning in the context of the specific problem being studied. Below are the models of the potential risk factors analysed in section ***5.2. Analysis and Prioritization of Potential Risk Factors*.**

In order to maintain clarity and conciseness in the main body of this document, detailed information on the sources and descriptions of the infrastructure found in the Orco Valley has been comprehensively compiled and structured and is available for review in the section ***9 Appendix***.

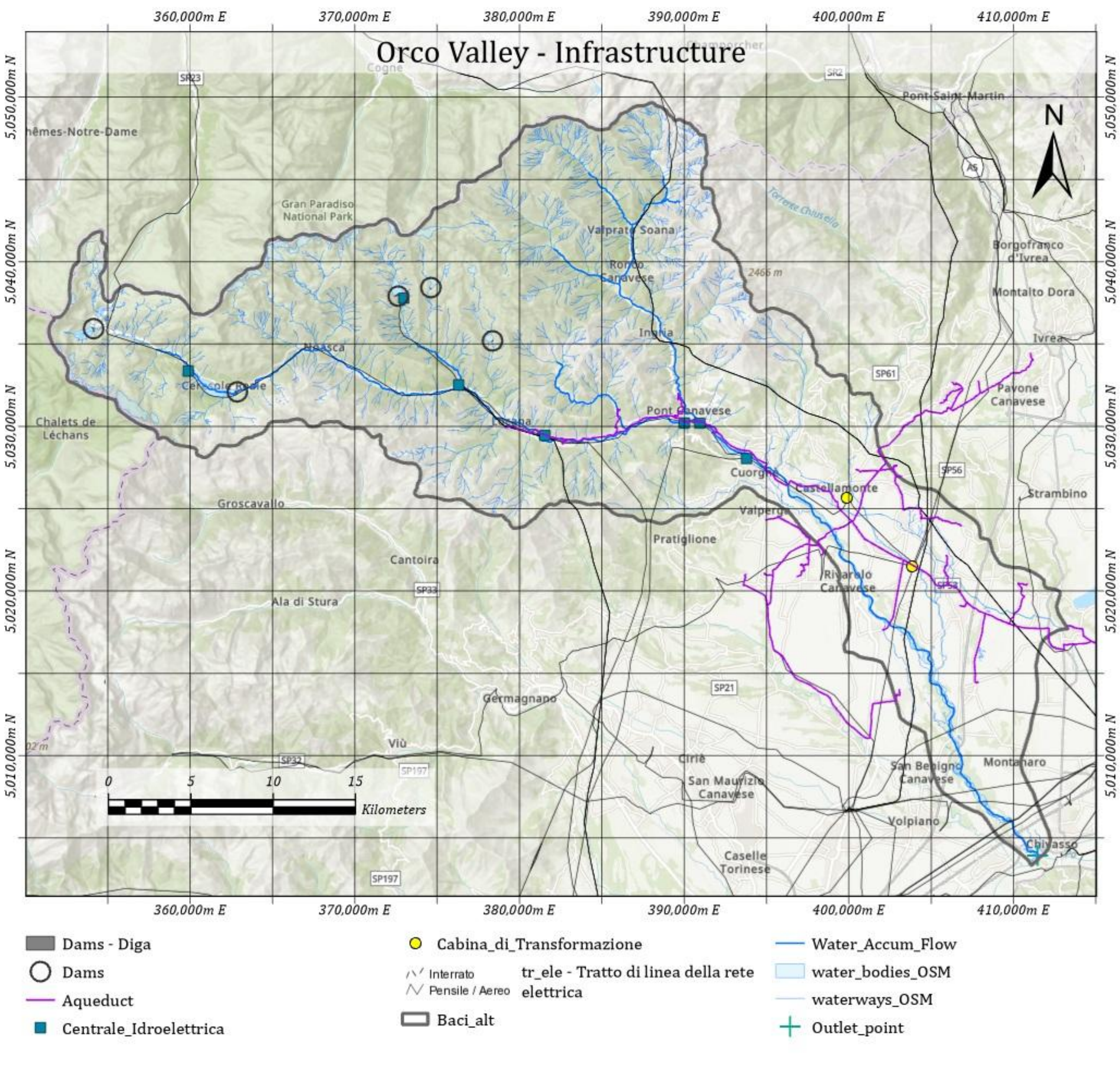


Figure 28. Input Data Model

In ***Figure 28*** we can see the GIS model representation of the Orco Valley infrastructure with its input data layers mentioned above (Dams, Aqueduct, Hydropower plants, Electrical transformer cabinets, Electric distribution networks, Water Bodies, Water ways). After having our model in ArcGIS Pro, we can integrate the geographic data with the numerical data of the attributes considered. This integration allows us to perform the corresponding mathematical operations, providing invaluable insights and deeper understanding of the relationships within the data.

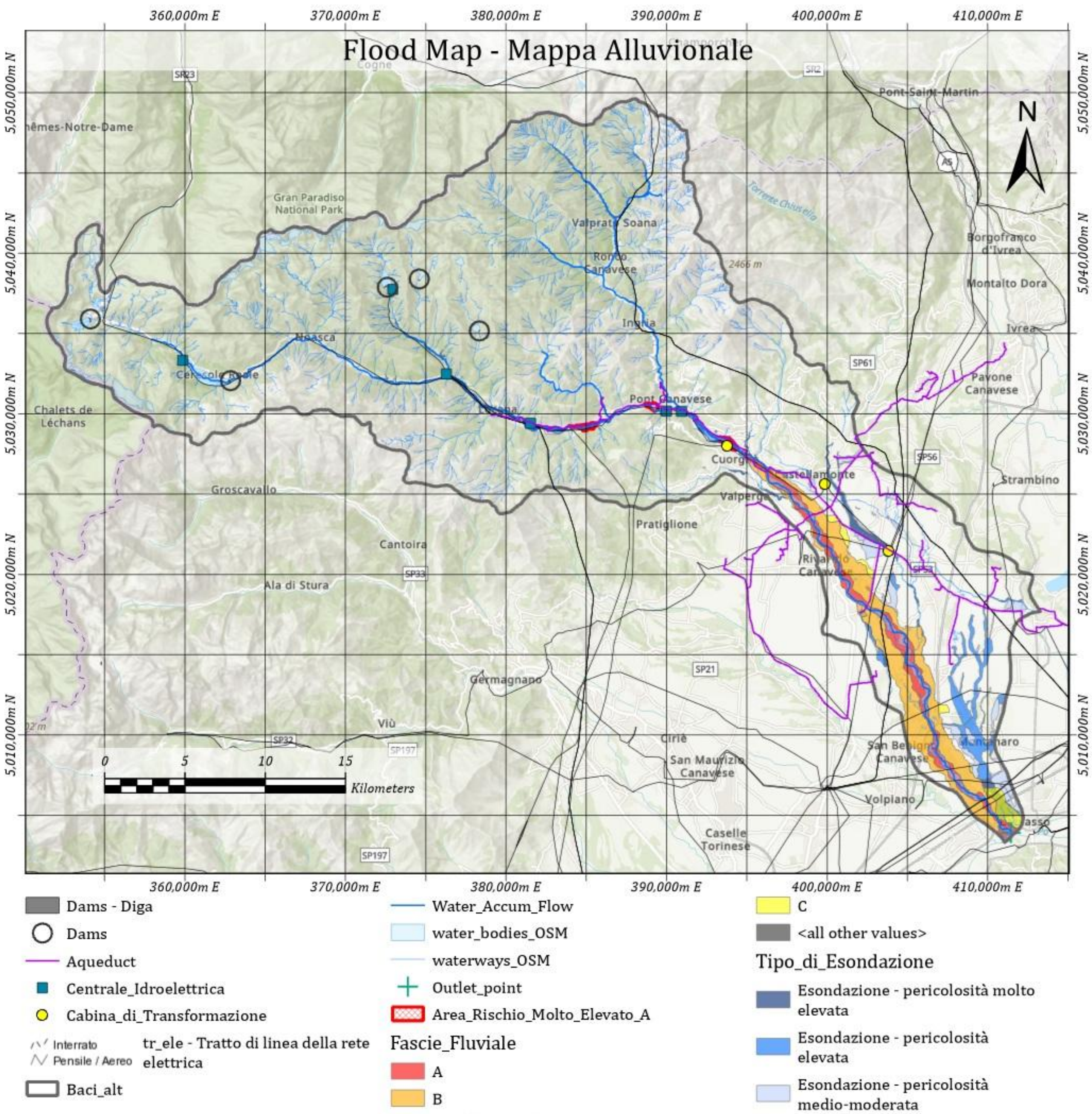


Figure 29. Flood Map

In ***Figure 29***, we can see the GIS model representation of the flood map with its three data layers mentioned above [Very High-Risk Area (ARME) – Floods (PAI), River Bands (Fascie Fluviali), Area Floods (Esondazioni Areali)]. After having our model in ArcGIS Pro, we can integrate the geographic data with the numerical data of the attributes considered in ***Table 9***. This integration allows us to join (Union command) different layers of information to perform the corresponding mathematical operations, providing invaluable insights and deeper understanding of the spatial relationships within the data.

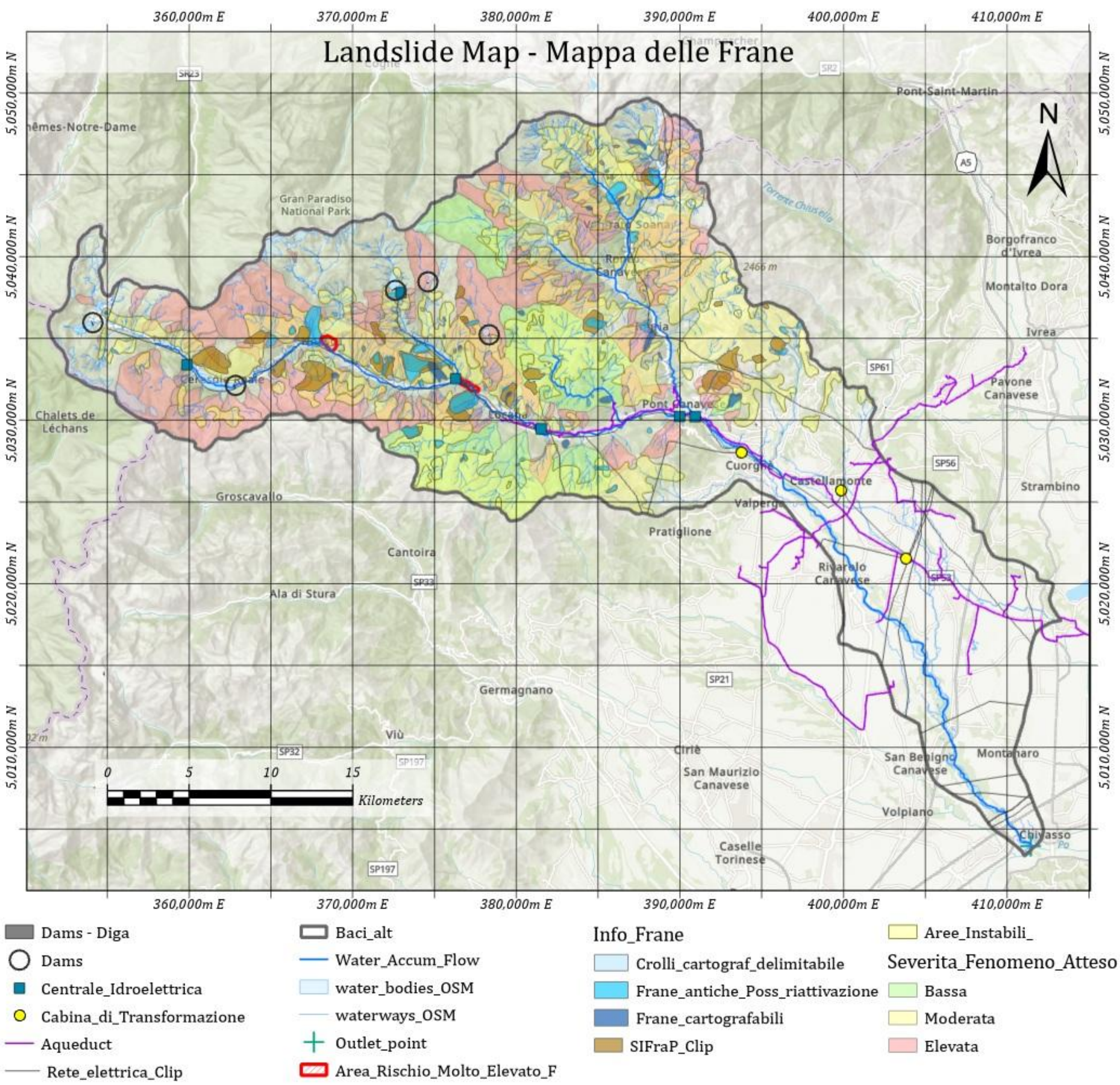


Figure 30. Landslide Map

In ***Figure 30***, we can see the GIS model representation of the landslide map with its four data layers mentioned above [Very High-Risk Area (ARME) – Landslides (PAI), Landslide Phenomena Information System in Piedmont (Info Frane), Alluvial Fans in Piedmont (Severita Fenomeno Atteso), Unstable Areas (Aree Instabili)]. After having our model in ArcGIS Pro, we can integrate the geographic data with the numerical data of the attributes considered in ***Table 10***. This integration allows us to join (Union command) different layers of information to perform the corresponding mathematical operations, providing invaluable insights and deeper understanding of the spatial relationships within the data.

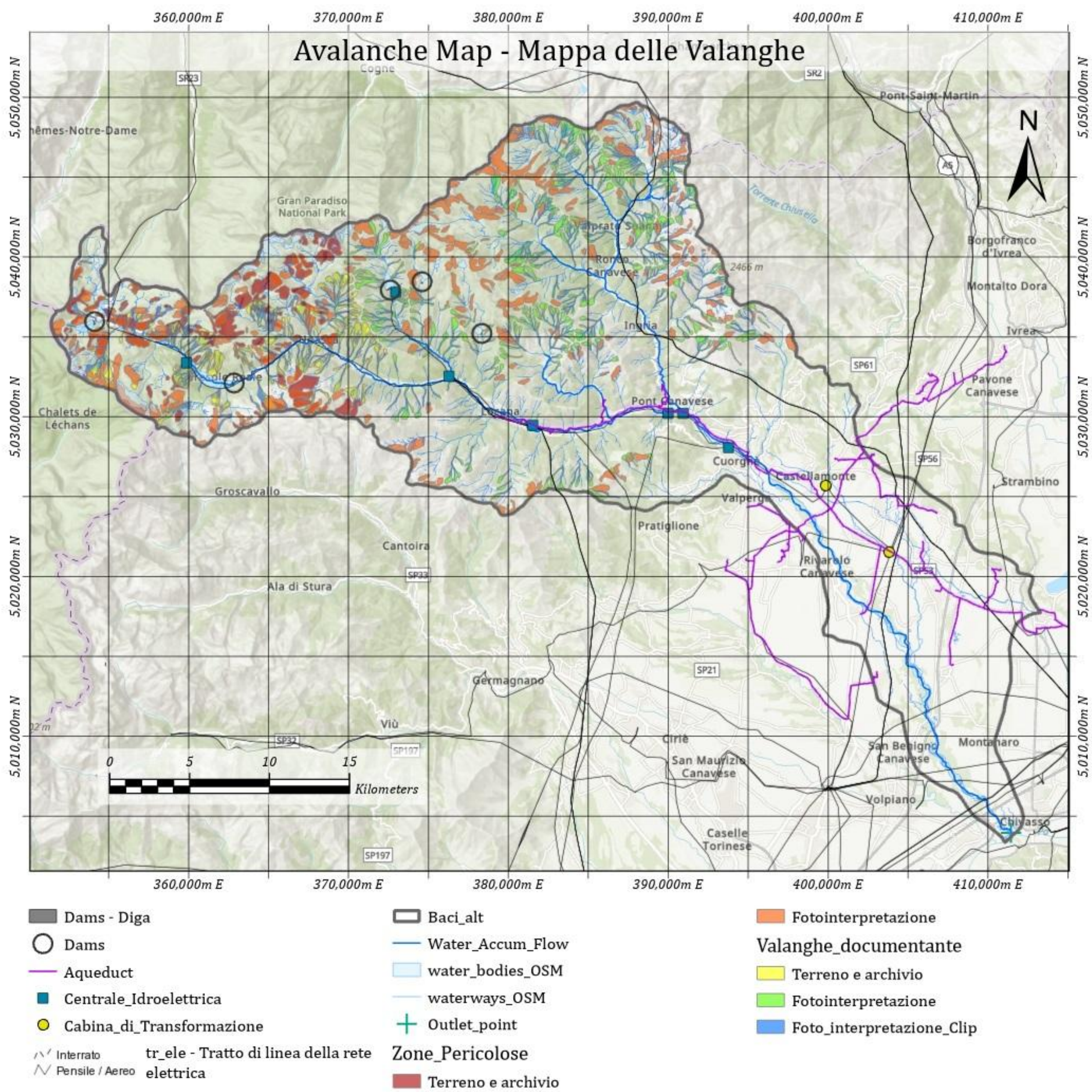


Figure 31. Avalanche Map

In ***Figure 31***, we can see the GIS model representation of the avalanche map with its data layers mentioned above [Avalanche Information System (SIVA), Archive, Photo Interpretation]. After having our model in ArcGIS Pro, we can integrate the geographic data with the numerical data of the attributes considered in ***Table 11***. This integration allows us to join (Union command) different layers of information to perform the corresponding mathematical operations, providing invaluable insights and deeper understanding of the spatial relationships within the data.

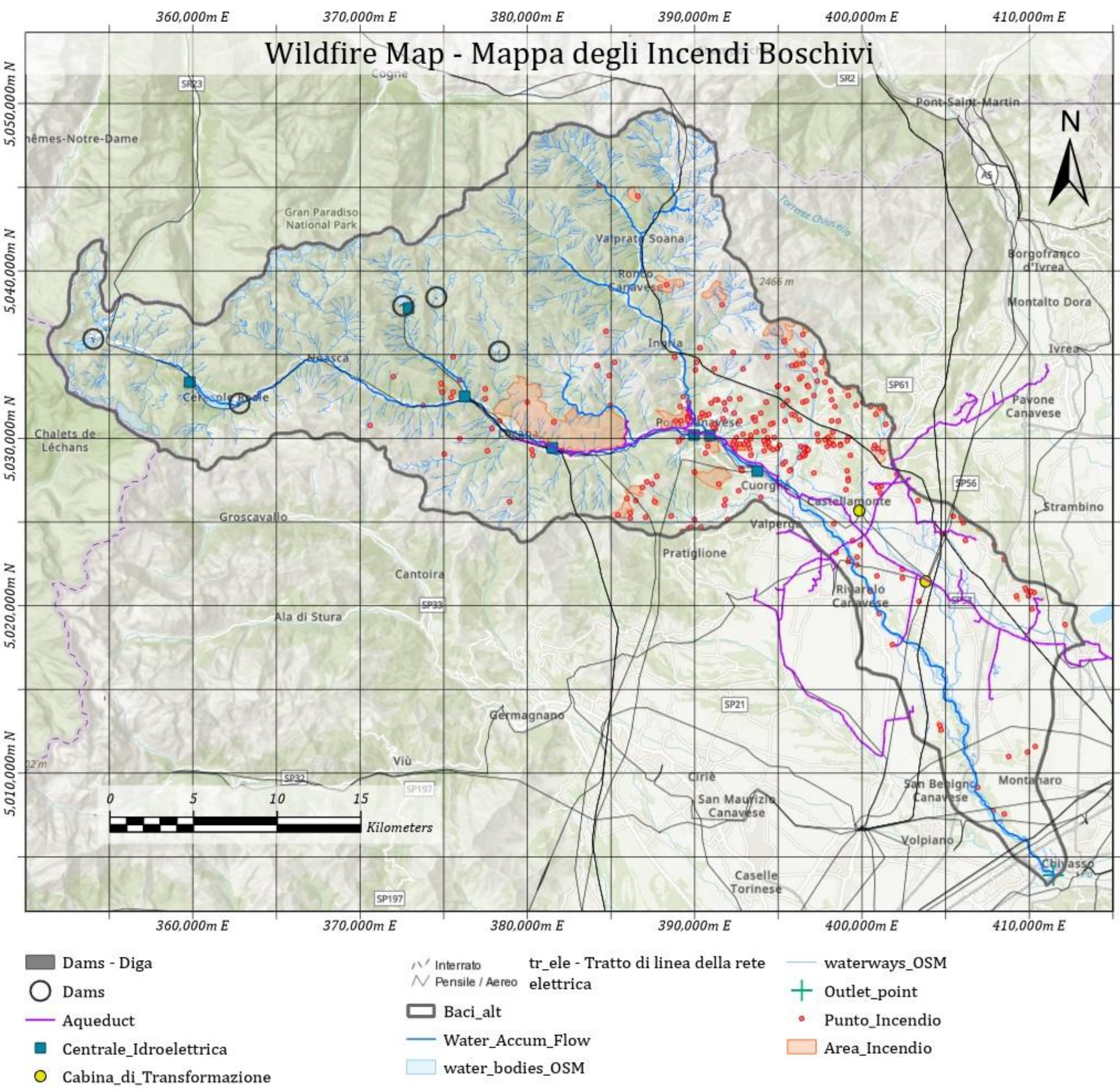


Figure 32. Wildfire Map

In ***Figure 32***, we can see the GIS model representation of the wildfire map with its data layers mentioned above [Fire Points, Area Fires]. After having our model in ArcGIS Pro, we can integrate the geographic data with the numerical data of the attributes considered in ***Table 12***. This integration allows us to join (Union command) different layers of information to perform the corresponding mathematical operations, providing invaluable insights and deeper understanding of the spatial relationships within the data.

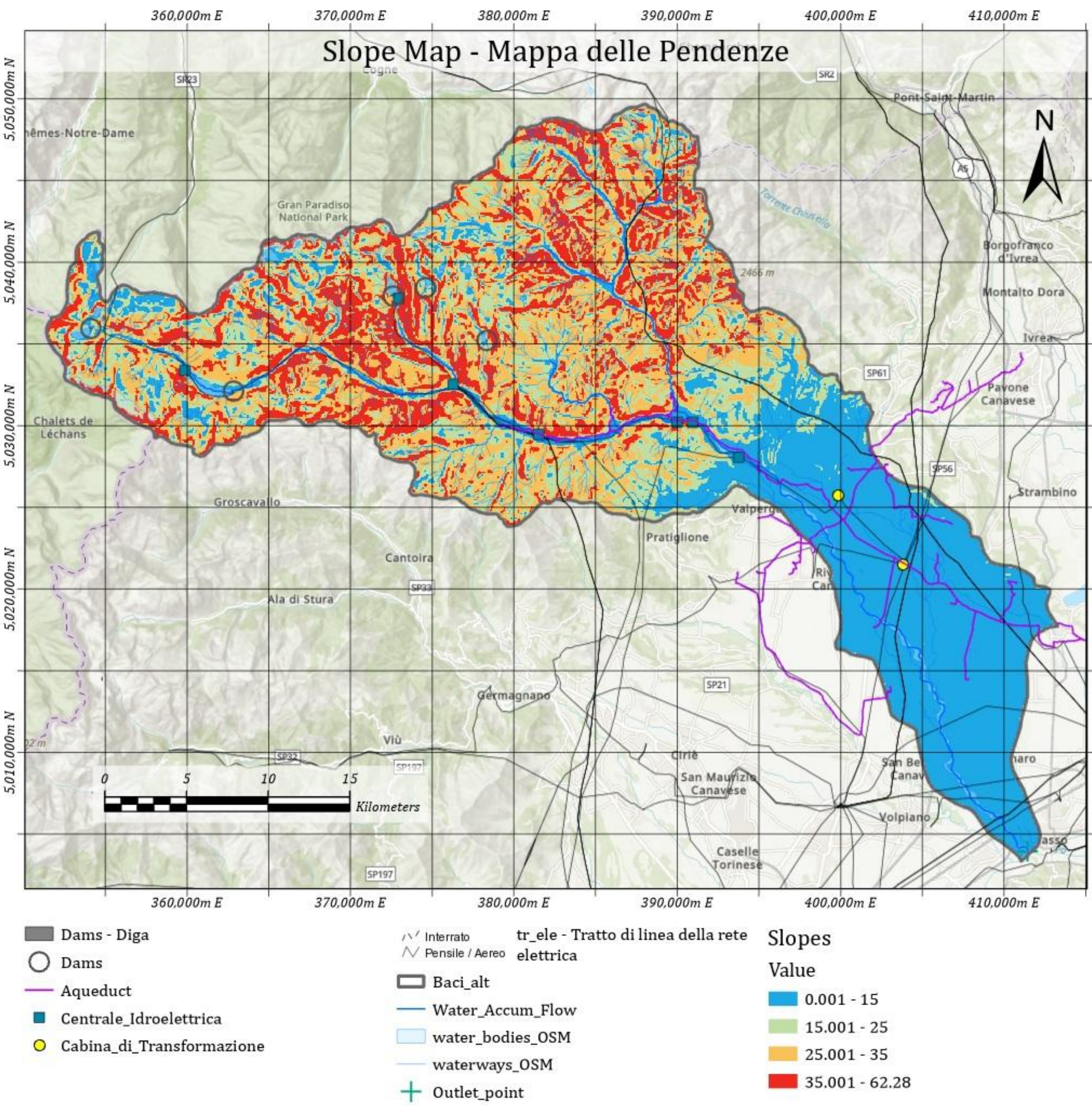


Figure 33. Slope Map

In ***Figure 33***, ***Figure 34***, and ***Figure 35***, we can see the GIS model representation of maps with its data layers mentioned above. After having our model in ArcGIS Pro, we can integrate the geographic data with the numerical data of the attributes considered in ***Table 14***. This integration allows us to join (Union command) different layers of information to perform the corresponding mathematical operations, providing invaluable insights and deeper understanding of the spatial relationships within the data.

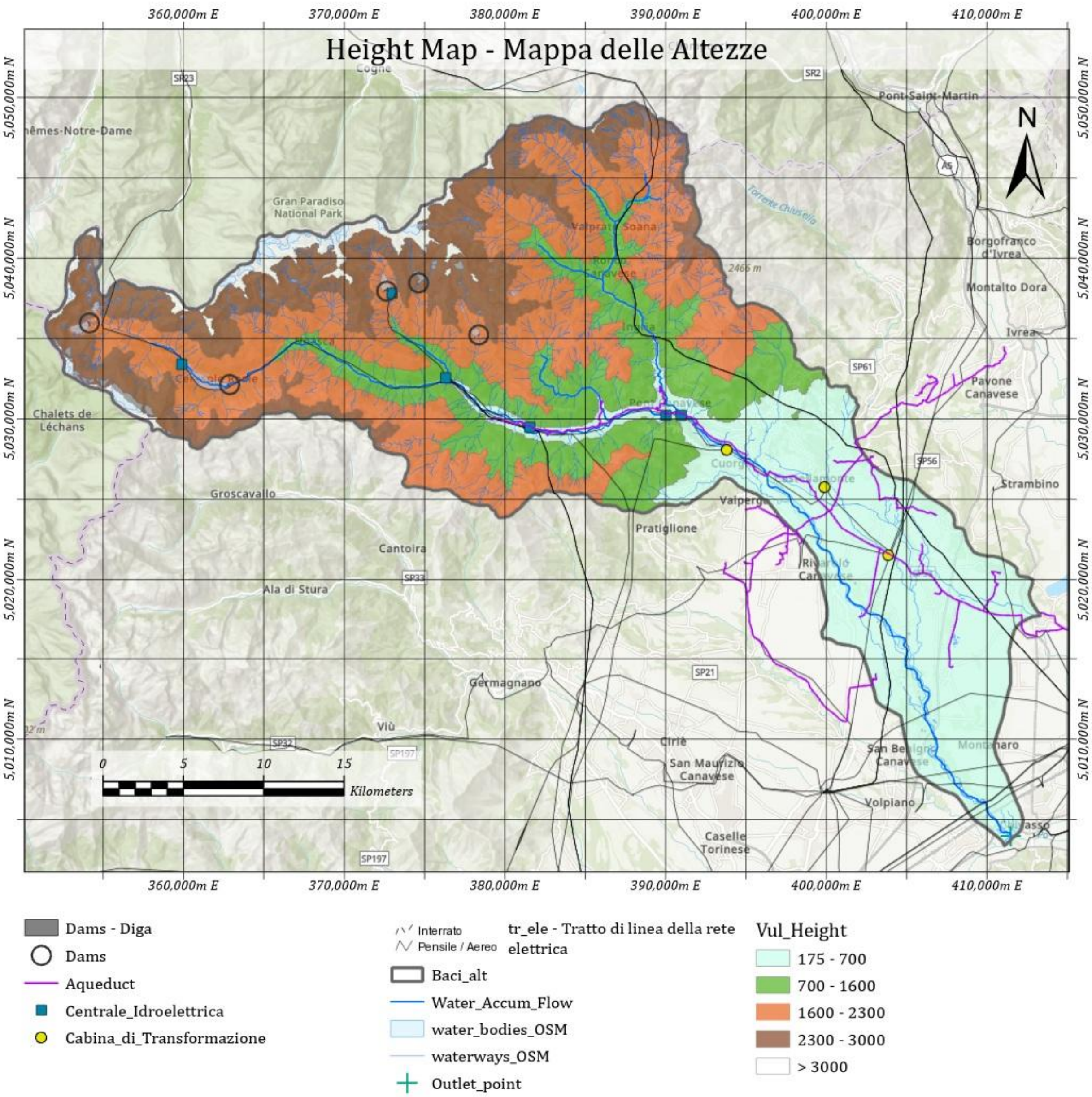


Figure 34. Height Map

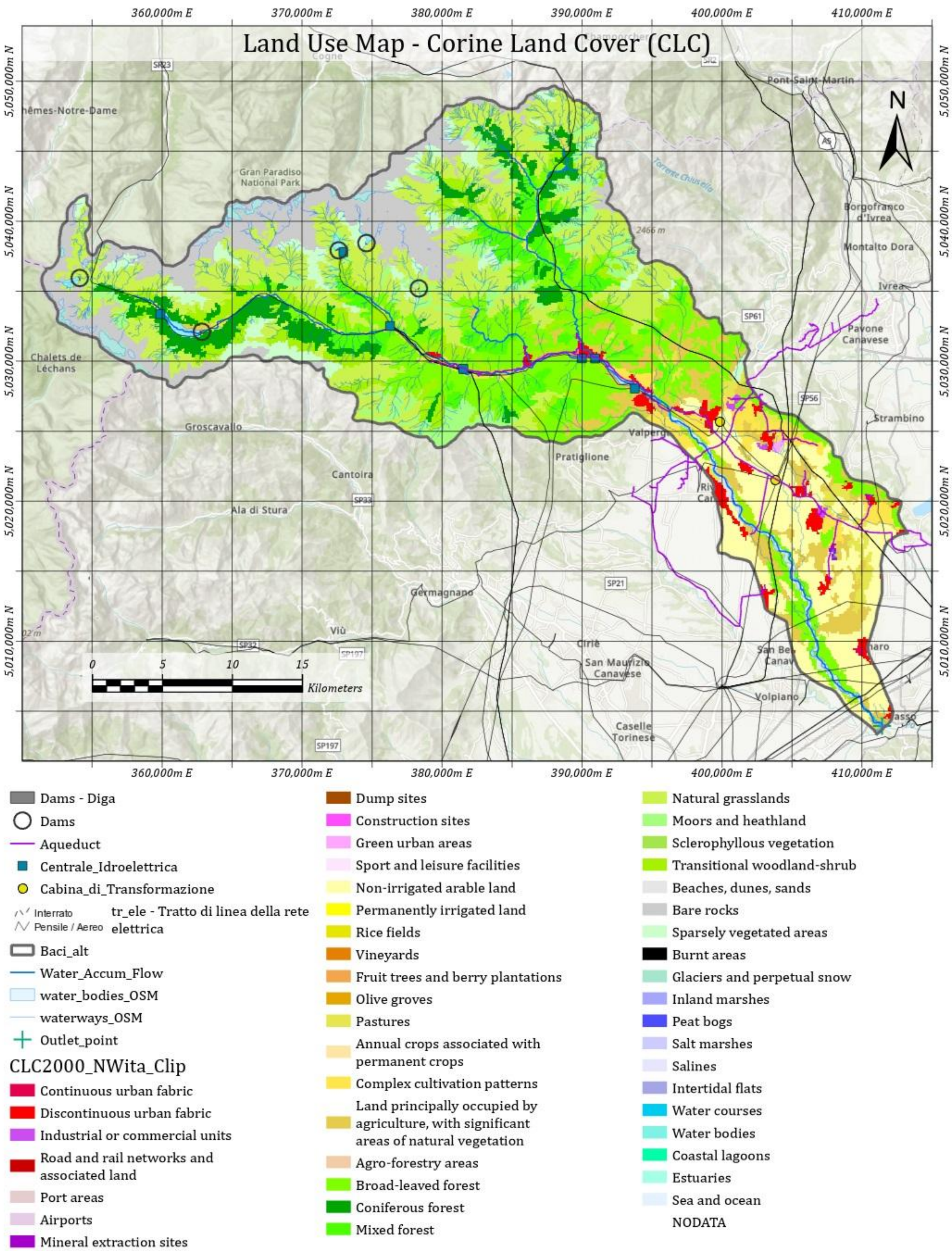


Figure 35. Land Use / Land Cover Map

5.3.1.3. Perform GIS Analysis

- GIS Analysis for Floods

To accurately reflect the importance of various factors, a GIS analysis was implemented using the Spatial Analyst map algebra tool in ArcGIS Pro, along with the AHP (prioritization framework) and the classification of the aforementioned attributes. This ensures a clear and accurate display of the susceptibility map, crucial for spatial analysis and understanding of the values. This refined probability will represent the potential occurrence of the hazard within the designated area.

$$F = \sum_{ai=1}^{n} (Fa_i * Deduced\ Probability_i)$$

- F is the probability of a natural hazard (Flood).
- Fai = is a weighted value of several events (representing the "influence" or "magnitude" of a set of events).
- Deduced Probability i = is the probability of event i occurring.

The formula calculates the aggregate probability of a natural hazard occurring (F) in a given area. In this context, the formula represents an aggregate or weighted probability, combining the contributions of different types of events or scenarios that could lead to the occurrence of that natural hazard. This method offers a more comprehensive assessment than treating the hazard as a singular event, but as the manifestation of multiple possible scenarios or event types, each with its own probability and its own "weight" or "influence" on the overall risk.

Table 17. Flood Categorization

Flood Categorization				
Samples	Prioritization	Fai	Description (Attributes)	Deduced Probability
F1 = ARME	5	0.40	Area Rischio Molto Elevato	0.9
F2 = Fascie Fluviali	4	0.40	Fascie Fluviali A	0.9
			Fascie Fluviali B	0.7
			Fascie Fluviali C	0.5
F3 = Esondazioni Areali	3	0.19	Esondazione Molto Elevata	0.9
			Esondazione Elevata	0.7
			Esondazione Media	0.5
FL = Land	1	0.01	Land with no hazard	0.1
		1.00		

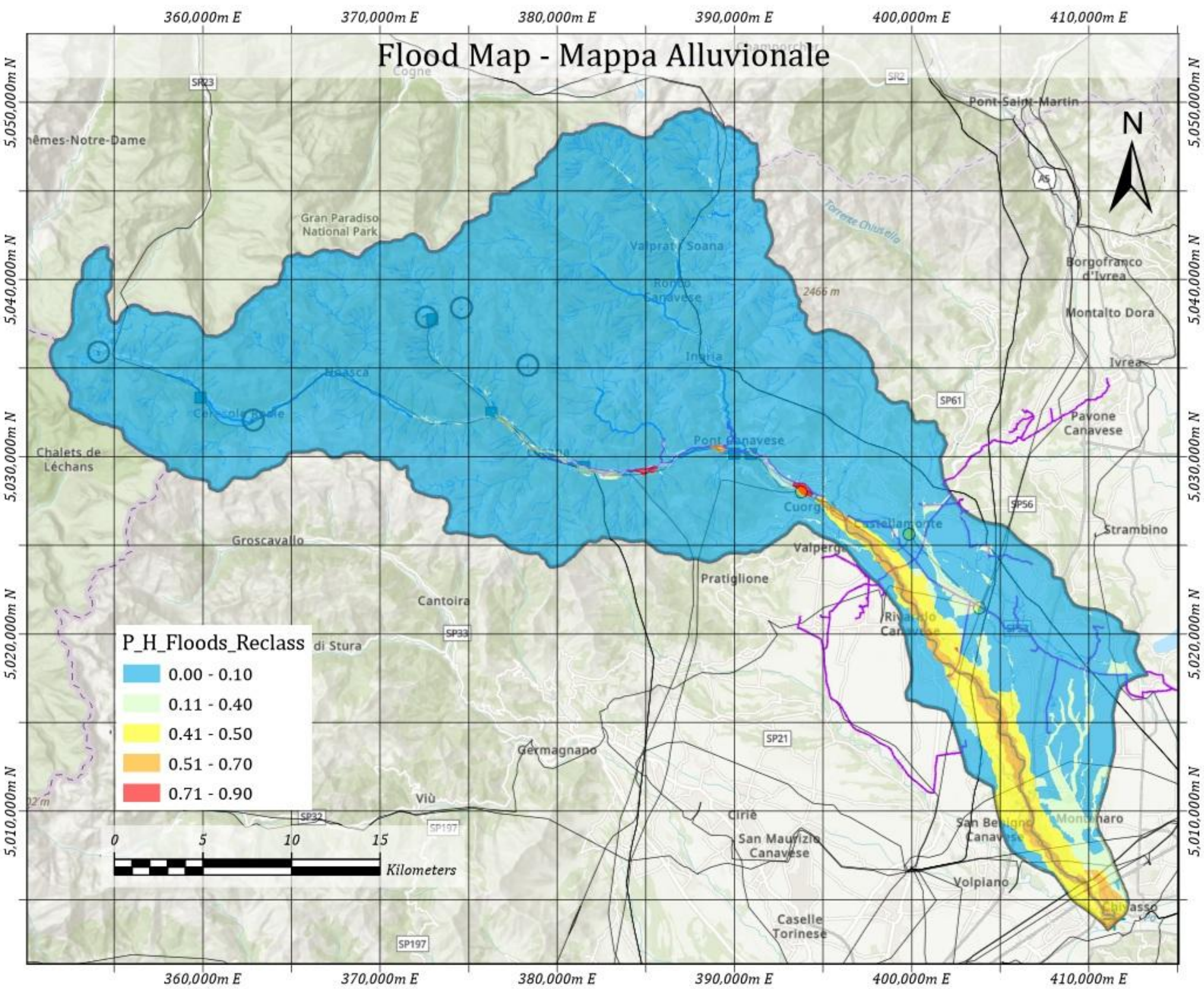


Figure 36. GIS Analysis for Floods

In ***Figure 36*** shows the results of the previous calculation, where we obtain the aggregate probability. The image shows the red areas with the highest probability and the blue areas with the lowest probability. It's worth noting that the results were reclassified to maintain the same data structure as the input data (from 0.1 – 0.9).

The same procedure is then followed for the other natural hazards, so the results will be displayed, and it will not be necessary to comment on each one.

- GIS Analysis for Landslides

$$L = \sum_{ai=1}^{n} (La_i * Deduced\ Probability_i)$$

Table 18. Landslides Categorization

Landslides Categorization				
Samples	Prioritization	Lai	Description (Attributes)	Deduced Probability
L1 = ARME	5	0.35	Area Rischio Molto Elevato	0.9
L2 = Info Frane	4	0.3	Frane Cartografabili	0.9
			Frane Antiche Possible Attiv	0.7
			Crolli delimitabile	0.5
L3 = Severita Fenomeno Atteso	3	0.2	Severita Elevata	0.7
			Severita Moderata	0.5
			Severita Bassa	0.4
L4 = Aree Instabili	2	0.14	Aree Instabili	0.5
LL = Land	1	0.01	Land with no hazard	0.1
		1.00		

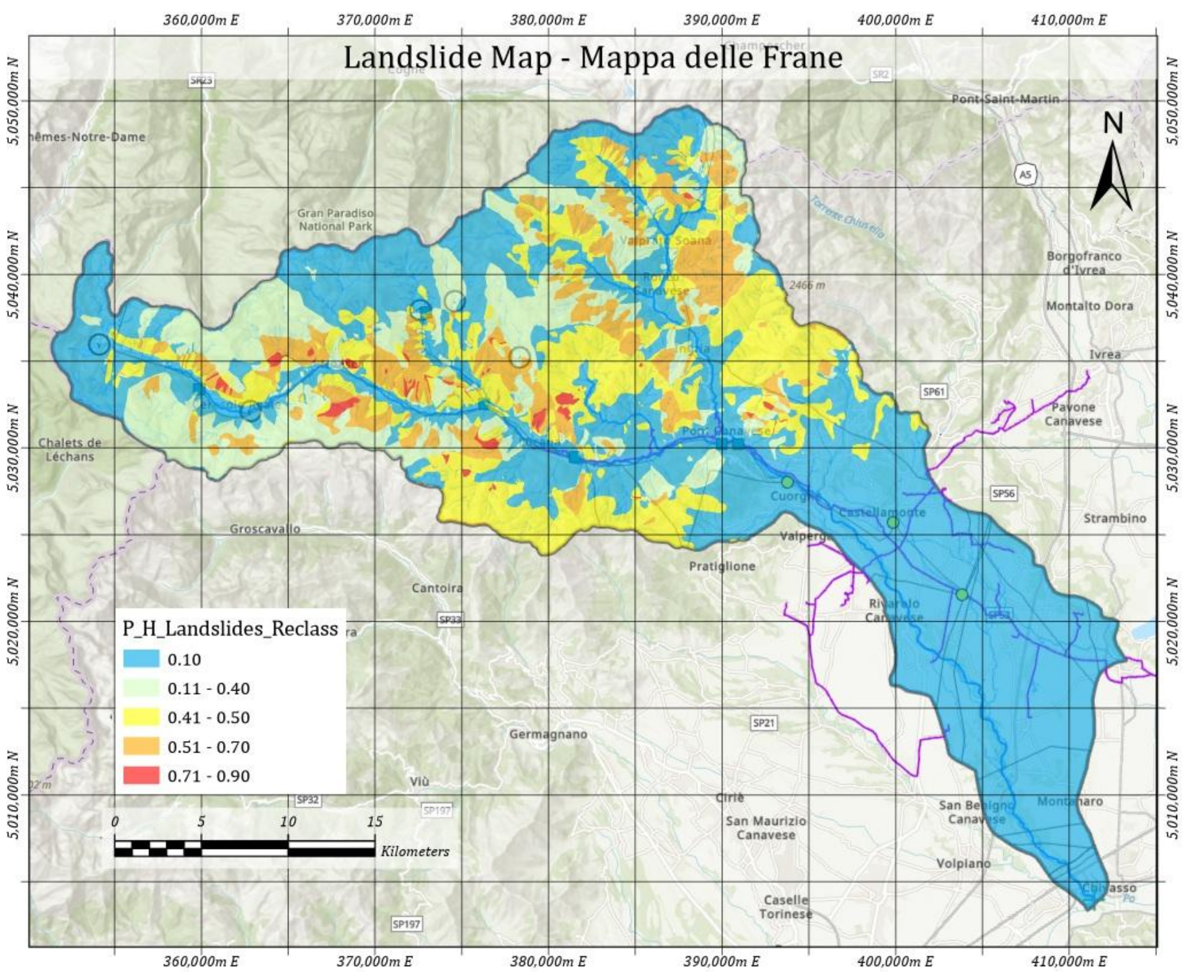


Figure 37. GIS Analysis for Landslides

- GIS Analysis for Avalanche

$$A = \sum_{ai=1}^{n} (Aa_i * Deduced\ Probability_i)$$

Table 19. Avalanche Categorization

Avalanche Categorization				
Samples	Prioritization	Aai	Description (Attributes)	Deduced Probability
A1 = SIVA	5	0.50	Zone Pericolose	0.9
			Foto Interpretazione	0.7
A2 = Archive	3	0.30	Zone Pericolose	0.9
			Terreno e Archivio	0.7
A3 = Photo Interpret	4	0.19	Terreno e Archivio	0.9
AL = Land	1	0.01	Land with no hazard	0.1
		1.00		

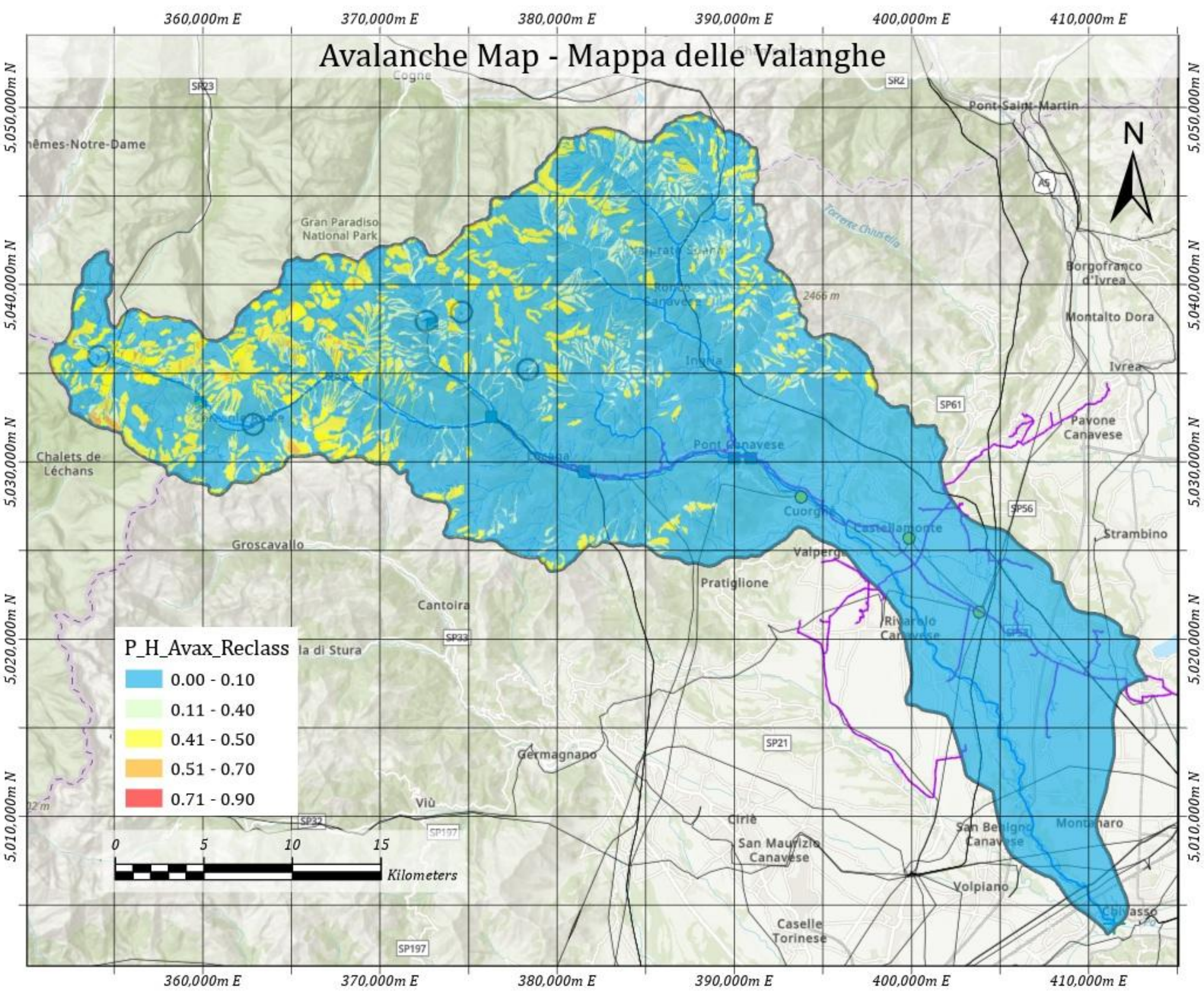


Figure 38. GIS Analysis for Avalanche

▪ GIS Analysis for Wildfires

For the analysis of the other hazards, a procedure similar to the previous one is carried out; the results obtained are shown below.

$$W = \sum_{ai=1}^{n} (Wa_i * Deduced\ Probability_i)$$

Table 20. Wildfire Categorization

Wildfire Categorization				
Samples	Prioritization	Wai	Description (Attributes)	Deduced Probability
W1 = Fire Points	5	0.69	Zone Pericolose	0.9
W2 = Area Fires	4	0.30	Terreno e Archivio	0.7
WL = Land	1	0.01	Land with no hazard	0.1
		1.00		

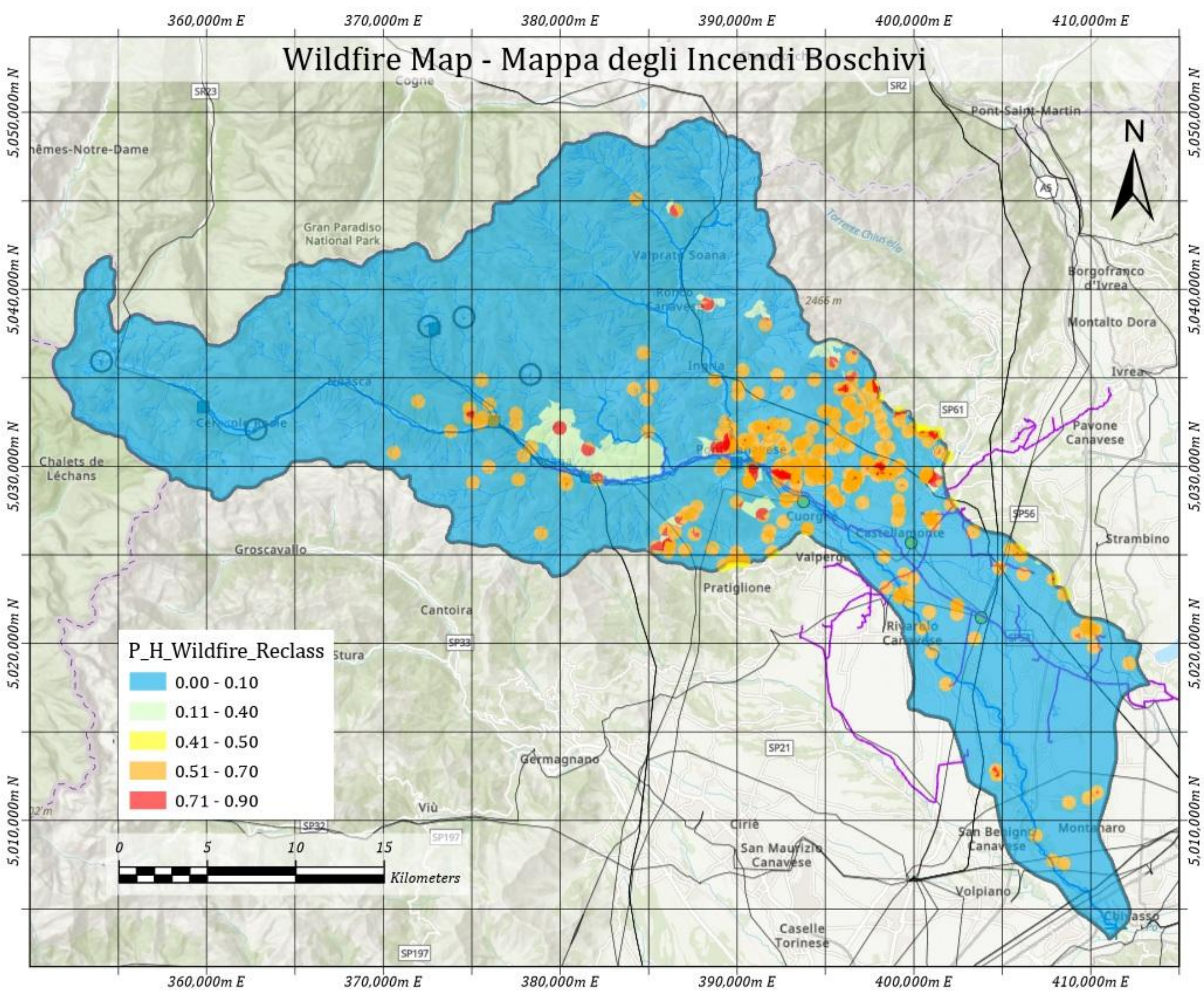


Figure 39. GIS Analysis for Wildfires

- GIS Analysis of Inherent Vulnerabilities of POI's

$$V_i = \sum_{ai=1}^{n} (Va_i * Deduced\ Vulnerability_i)$$

Table 21. Inherent Vulnerabilities of POI's

POI's Categorization				
Samples	Prioritization	V'ai	Description (Attributes)	Deduced Vulnerability
V1' = Dams	1	0.09	Very Low Vulnerability	0.1
V2' = Hydropower Plants	2	0.15	Low Vulnerability	0.4
V3' = Electrical Transformer Cabinets	3	0.20	Medium Vulnerability	0.5
V4' = Aqueduct	4	0.25	High Vulnerability	0.7
V5' = Electric Distribution Networks	5	0.30	Very High Vulnerability	0.9
VL = Vulnerability Land	1	0.01	Land with no POI's	0.1
		1.00		

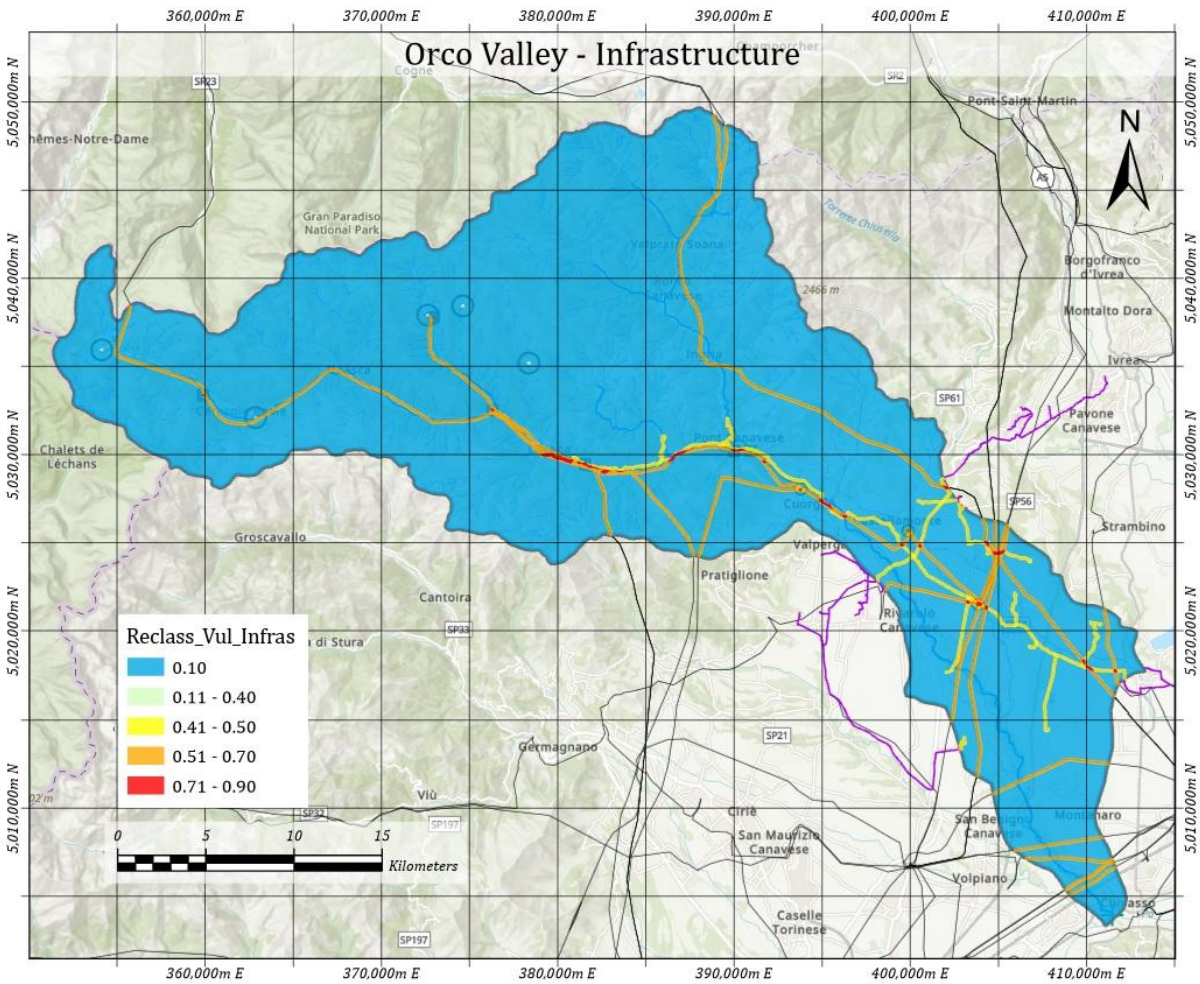


Figure 40. GIS Analysis of Inherent Vulnerabilities of POI's

- GIS Analysis for Geomorphological Vulnerabilities

$$V_g = \sum_{ai=1}^{n} (Ga_i * Deduced\ Vulnerability_i)$$

Table 22. Geomorphological Vulnerabilities

Geomorphological Categorization					
Samples / Prioritization	Slope [°]	LC/LU	Height [m.a.s.l.]	Description (Attributes)	Deduced Vulnerability
1	0 - 9	Urban	175 -700	Very Low Vulnerability	0.1
2	9 - 18	Lands, vegetation	700 - 1600	Low Vulnerability	0.4
3	18 - 27	Snow, Water	1600 - 2300	Medium Vulnerability	0.5
4	27 - 36	Rocks	2300 - 3000	High Vulnerability	0.7
5	> 36	Forest	> 3000	Very High Vulnerability	0.9
Gai	0.34	0.33	0.33		

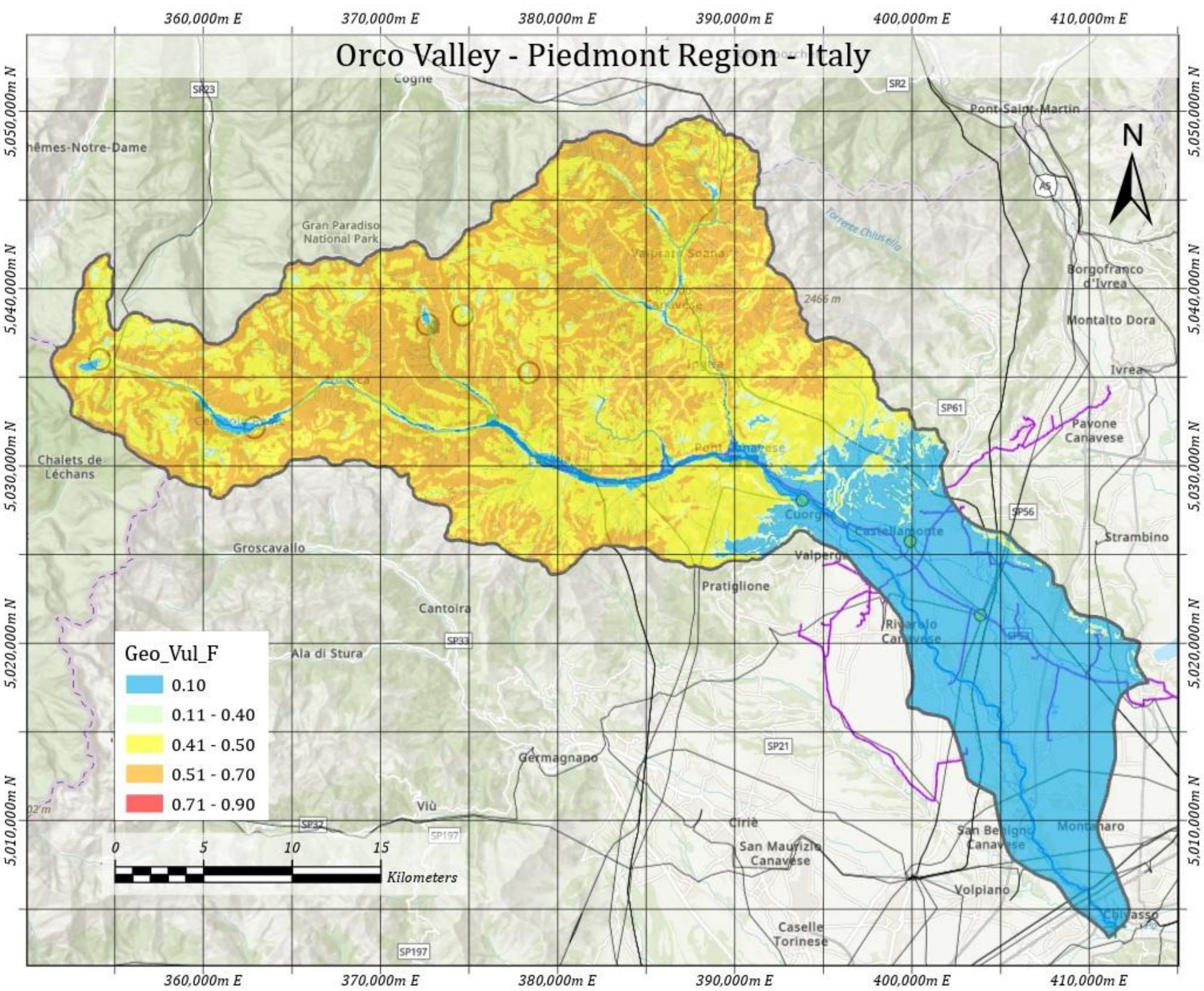


Figure 41. GIS Analysis for Geomorphological Vulnerabilities

- GIS Analysis for Exposure

$$E = \sum_{ai=1}^{n} (Ea_i * Deduced\ Exposure_i)$$

Table 23. Exposure

Exposure Categorization							
Eai	0.2	0.2	0.2	0.2	0.19	0.01	Deduced Exposure
Prioritization	E1 = Dams	E2 = Hydropower Plants	E3 = Electrical Transformer Cabinets	E4 = Aqueduct	E5 = Electric Distribution Networks	E5= Exposure Land	
5	100m	100m	100m	100m	100m		0.9
4	200m	200m	200m	200m	200m		0.7
3	300m	300m	300m	300m	300m	> 400m	0.5
2	400m	400m	400m	400m	400m		0.4
1	> 400m	> 400m	> 400m	> 400m	> 400m		0.1

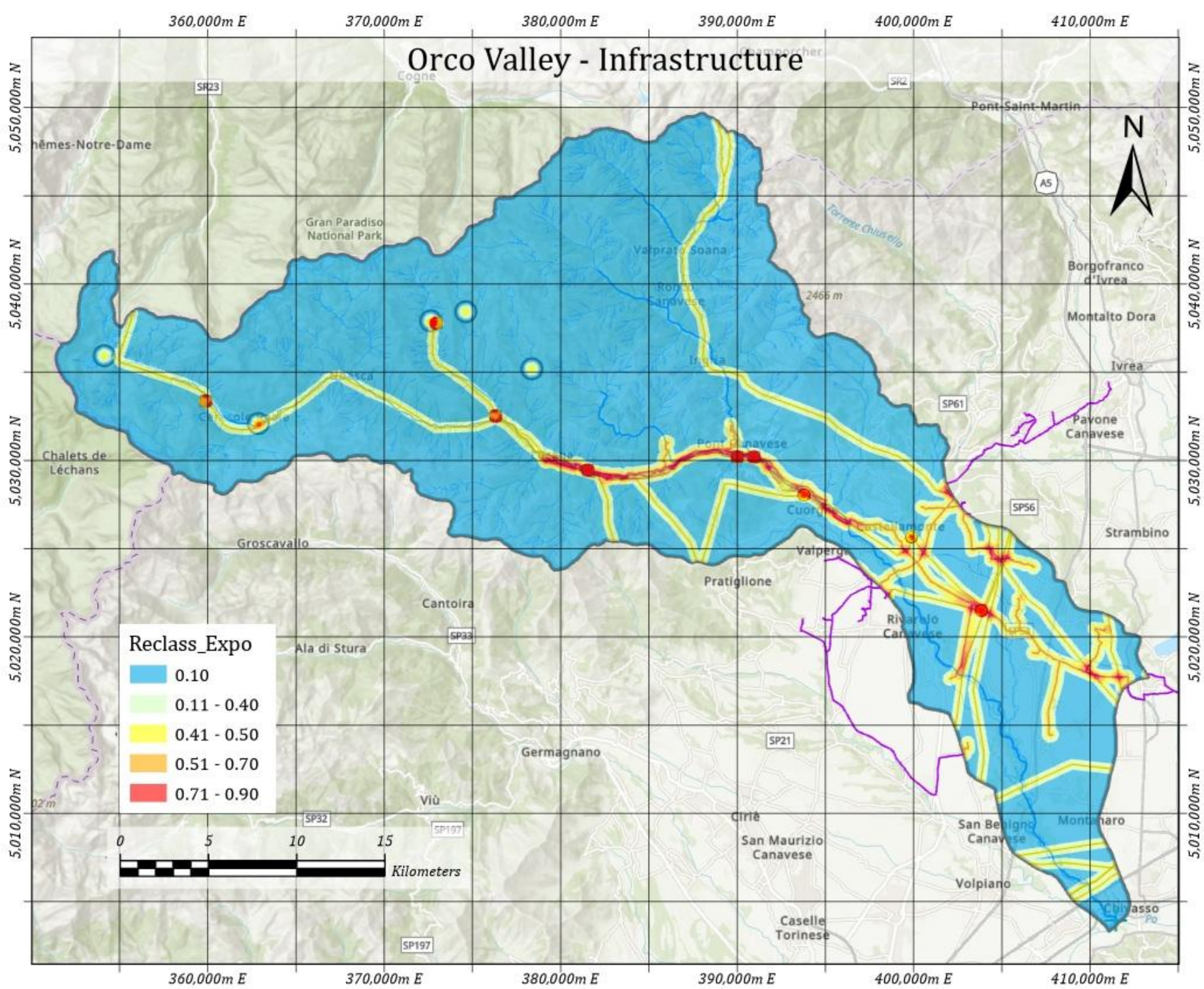


Figure 42. GIS Analysis for Exposure

- GIS Analysis for Consequence

$$C = \sum_{ai=1}^{n} (Ea_i * Deduced\ Consequence_i)$$

Table 24. Consequence

Consequence Categorization				
Samples	Prioritization	Cai	Description	Categorization
C1 = Dams	5	0.30	Very High Consequences	0.9
C2 = Hydropower Plants	4	0.25	High Consequences	0.7
C3 = Electrical Transformer Cabinets	3	0.20	Medium Consequences	0.5
C4 = Aqueduct	2	0.15	Low Consequences	0.4
C5 = Electric Distribution Networks	1	0.09	Very Low Consequences	0.4
CL = Consequence Land	1	0.01	Land with no Conseq.	0.1
		1.00		

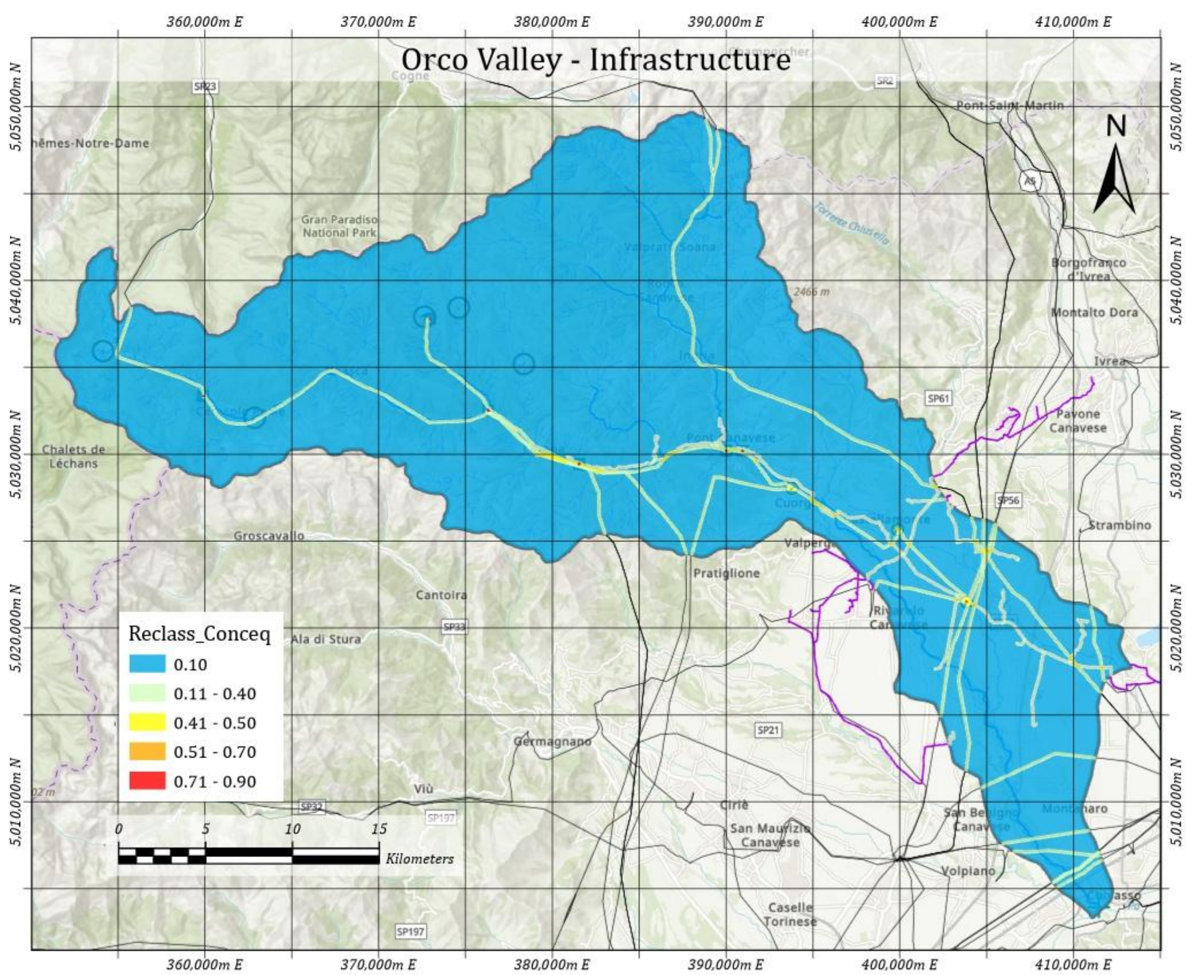


Figure 43. GIS Analysis for Consequence

5.3.1.4. Post Processing Model Results

After analyzing the data, we will use GIS tools to identify intervention areas and risk levels. By exploring spatial patterns and correlations, we will create maps to effectively visualize the model results.

The Risk Model has been finally developed according to the assessment provided in the section ***5.2.3 Risk Analysis***, i.e. variables such as hazard probability, vulnerability, exposure and consequence. Of course, this is a simplified model, if compared to existing rigorous assessments for risks to natural events. But even though it works well and delivers consistent and satisfactory results as will be shown later.

$$R = Ph_i * V_i * (E + C + V_g)$$

Phi = Probability of Hazard
Vi = Inherent Vulnerabilities of POI’s
E = Exposure (Distances between 100m,200m,300m,400m)
C = Consequence (Important, Value, Impact)
Vg = Geomorphological Vulnerabilities (Slope, Height, LC / LU)

First, to confirm the reliability of the risk model, the existing probability analyses were compared with the final risk model, superimposing the layers of the obtained results. This is done to demonstrate its accuracy and usefulness for informed decision-making, validating a strong correlation between the model's results and the actual distribution of the inventory data. Secondarily, since this thesis project aims to generate a multi-criteria risk assessment, a map will be generated with the combination of all the obtained risks.

5.3.1.5. Reports of Findings

The results of the models obtained for each type of hazard are presented below. After that the 3D Map tool can be used to delve deeper into the report of the results obtained.

The ArcGIS Pro 3D Maps application is a powerful tool that improves spatial understanding and communication by transforming geospatial data into immersive 3D visualizations. This capability enables realistic exploration of terrain, buildings, and infrastructure from any perspective, which is invaluable for tasks such as urban planning, asset management, complex simulations, 4D

BIM-based construction planning, and disaster response. Its powerful communication features make complex spatial data understandable to a wide range of professionals. (Esri, ArcGIS Pro Help: Create 3D maps., 2025)

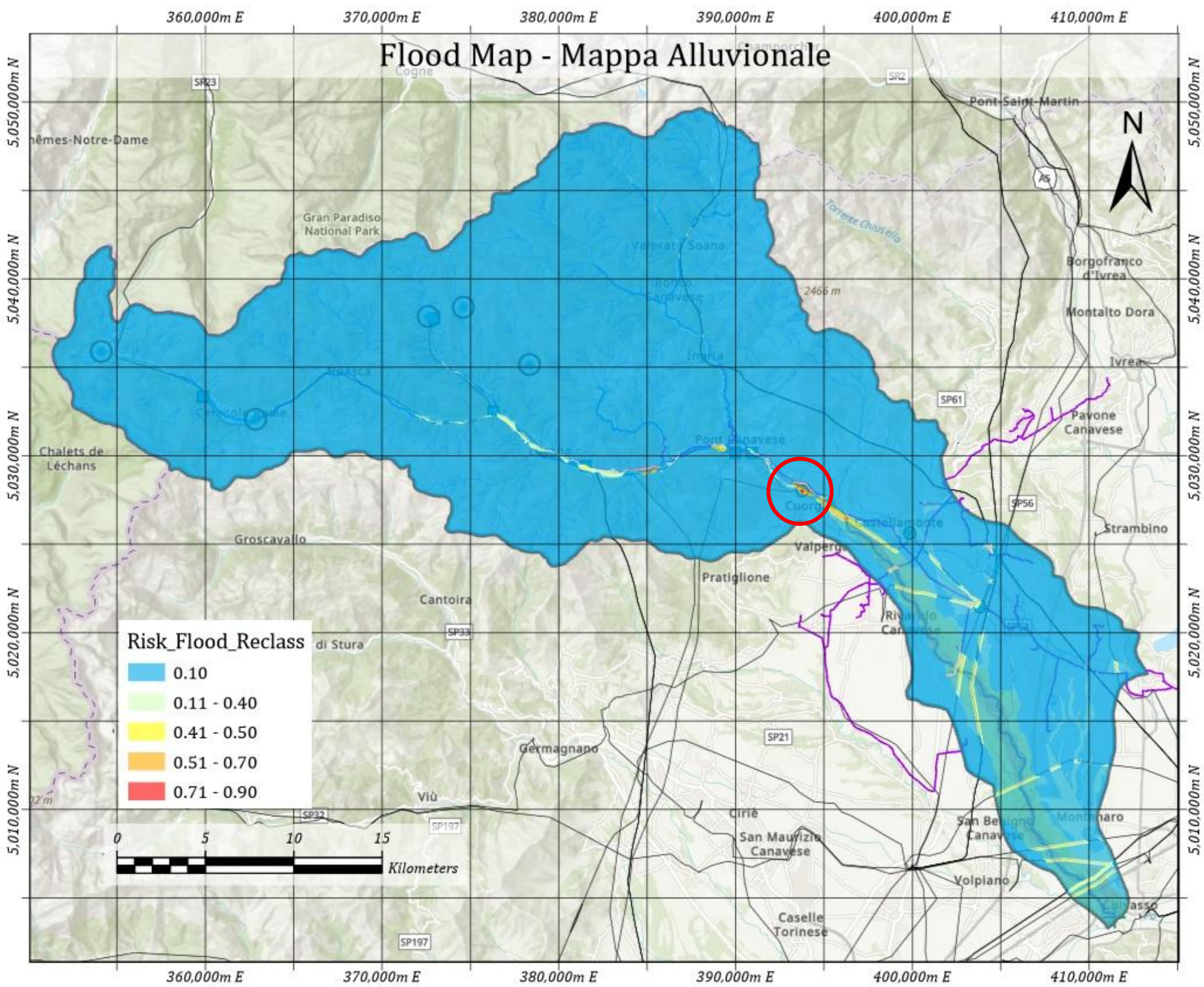


Figure 44. Areas of Interest and Risk Levels - Floods

The results in ***Figure 44***, for flood risk assessment in the Orco Valley revealed that some electricity distribution networks could be affected, but the area most at risk is specifically in the town of Goritti, in the commune of Courgne. This critical area directly affects two major POI's, a small hydroelectric plant and an electrical transformer station, making them more vital than the general distribution networks.

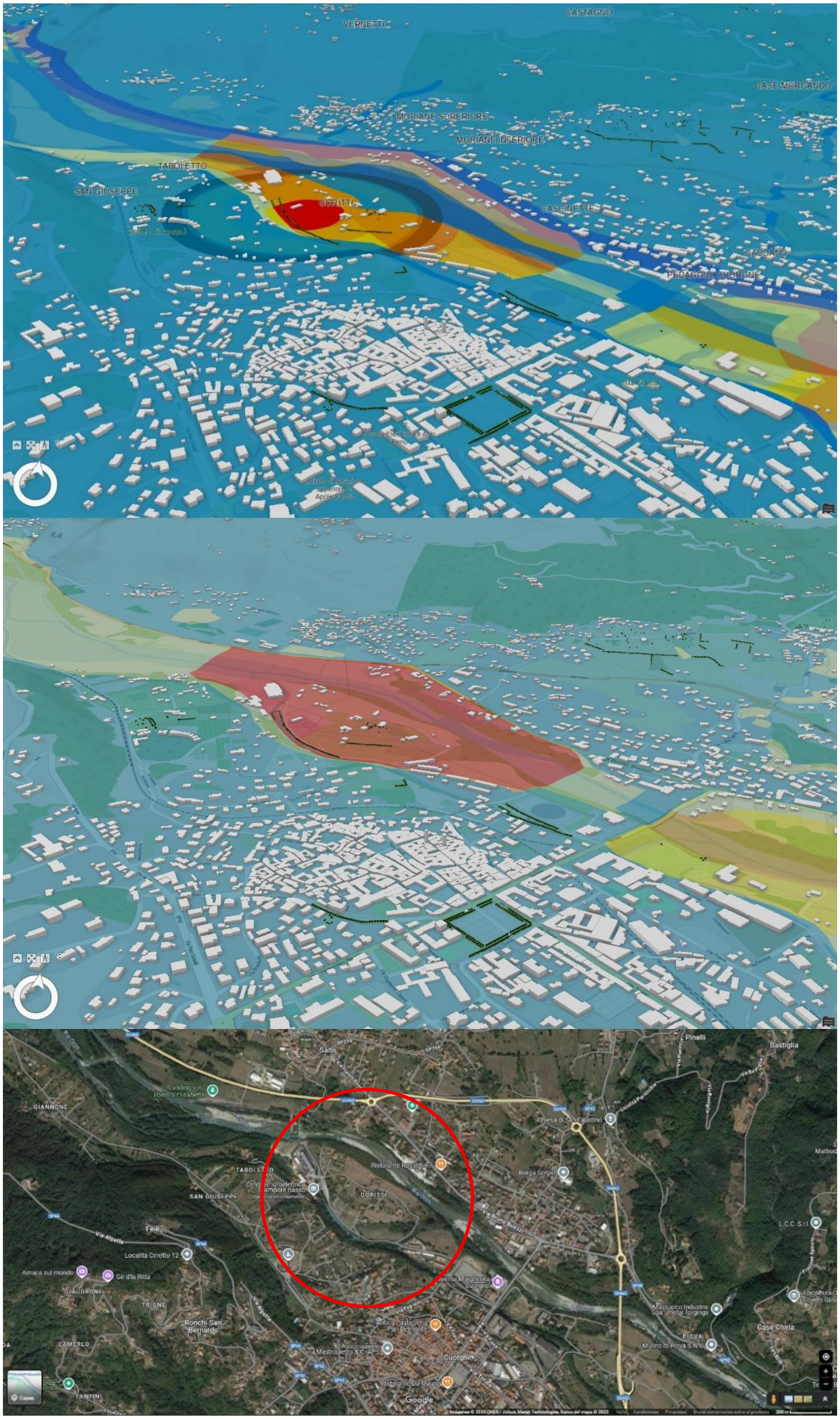


Figure 45. Critical Point for Flood Assessment

The same procedure is then followed for the other natural hazards, so the results will be displayed, and it will not be necessary to comment on each one.

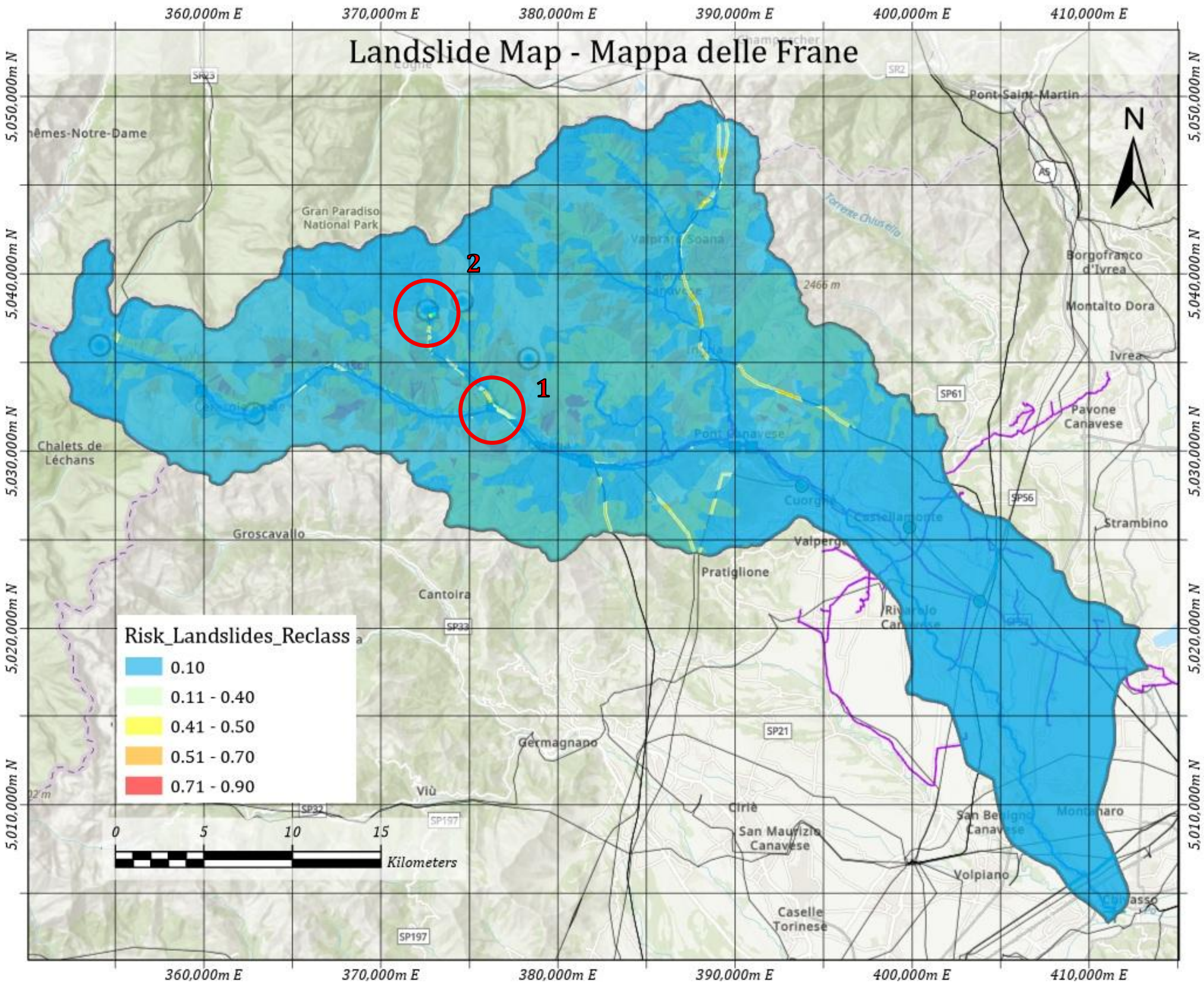


Figure 46. Areas of Interest and Risk Levels - Landslides

The results in ***Figure 46,*** for landslide risk assessment in the Orco Valley revealed that some electricity distribution networks could be affected, but two areas of greatest risk have been identified: the first critical point (1) is located in Rosone, directly affecting a small hydroelectric power plant and its surrounding electricity distribution networks. The second critical point (2) is located on Lake Telesio, where it impacts a hydroelectric power plant and its electricity distribution networks, the latter being considered of vital importance over the general distribution networks.

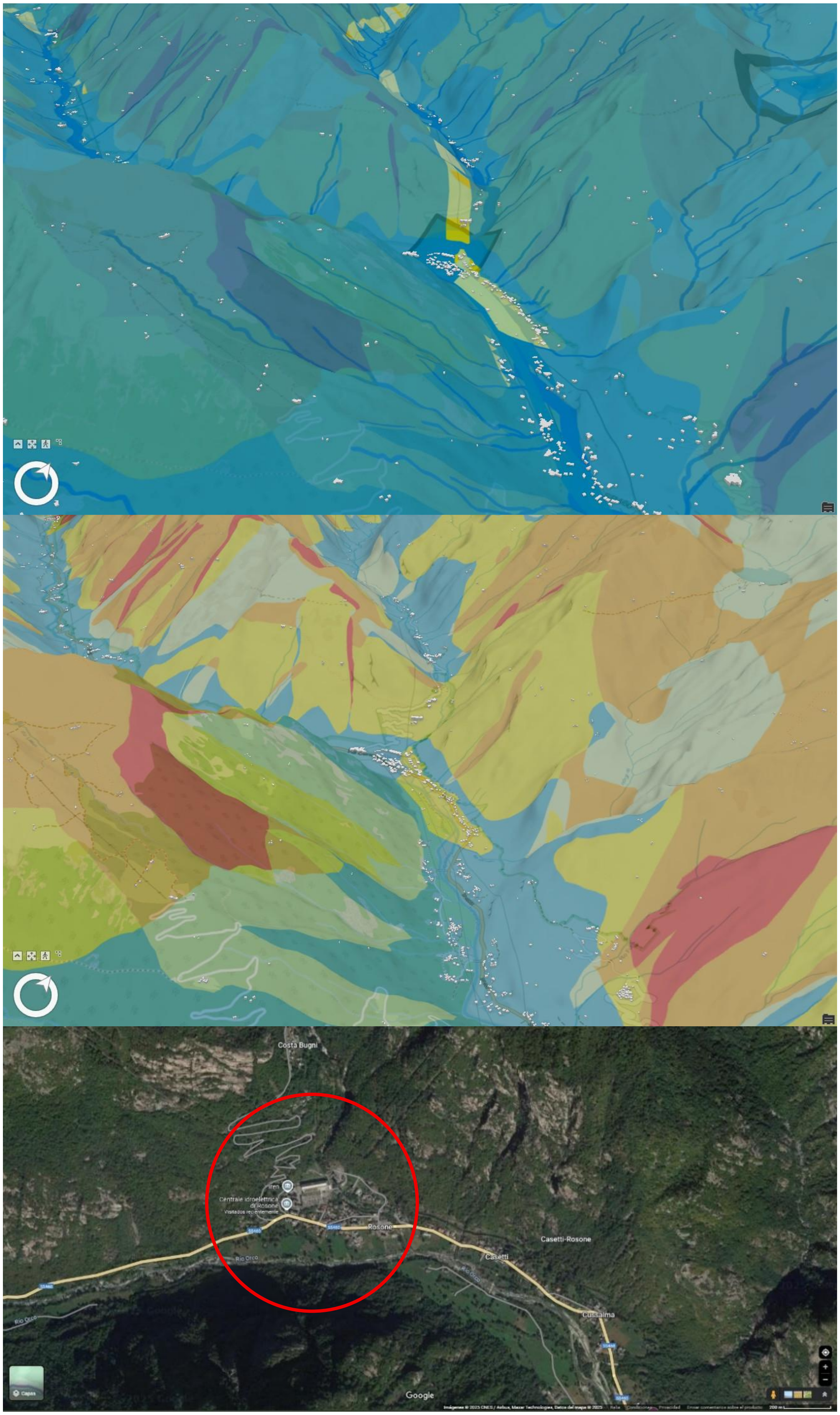


Figure 47. Critical Point 1 for Landslides Assessment

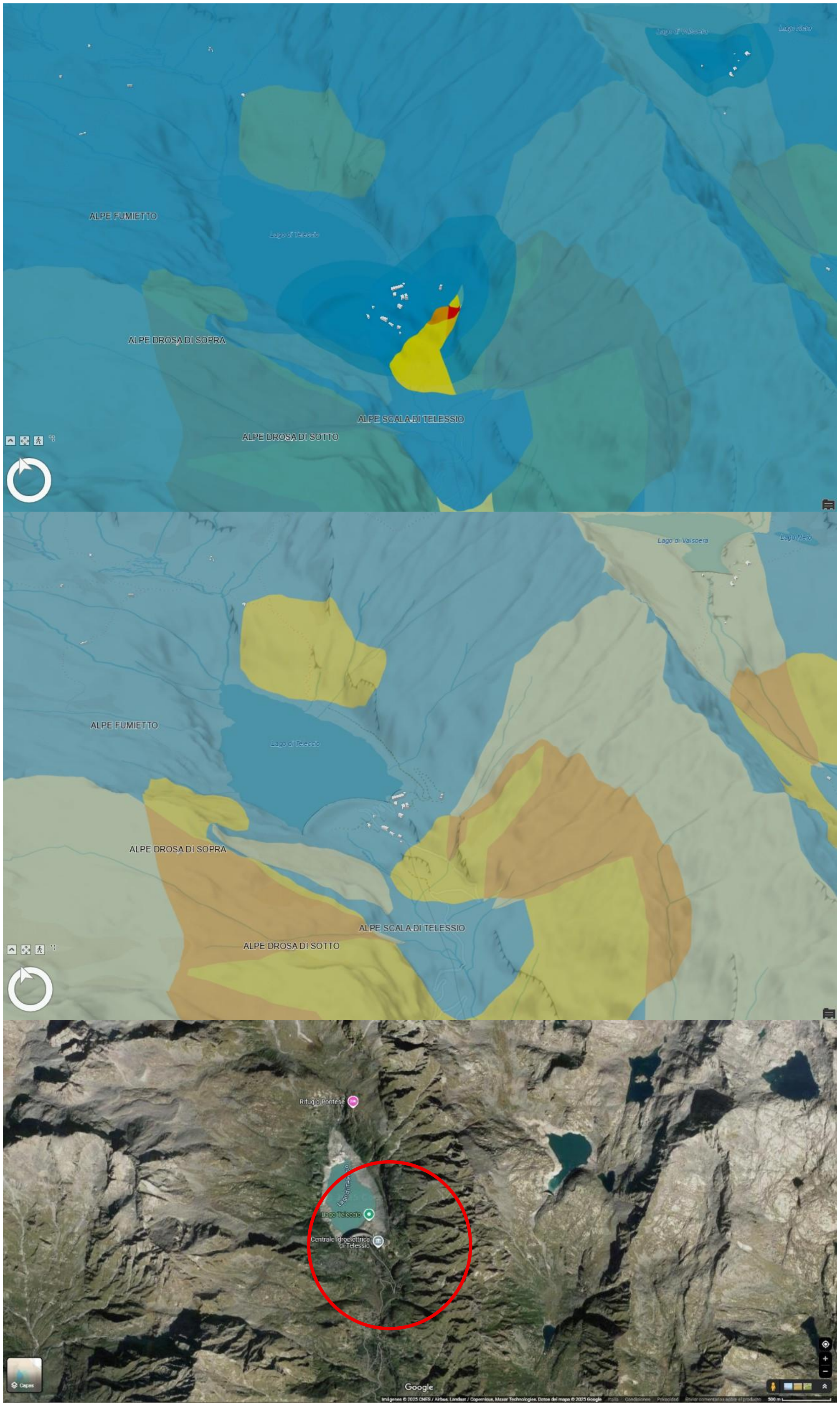


Figure 48. Critical Point 2 for Landslides Assessment

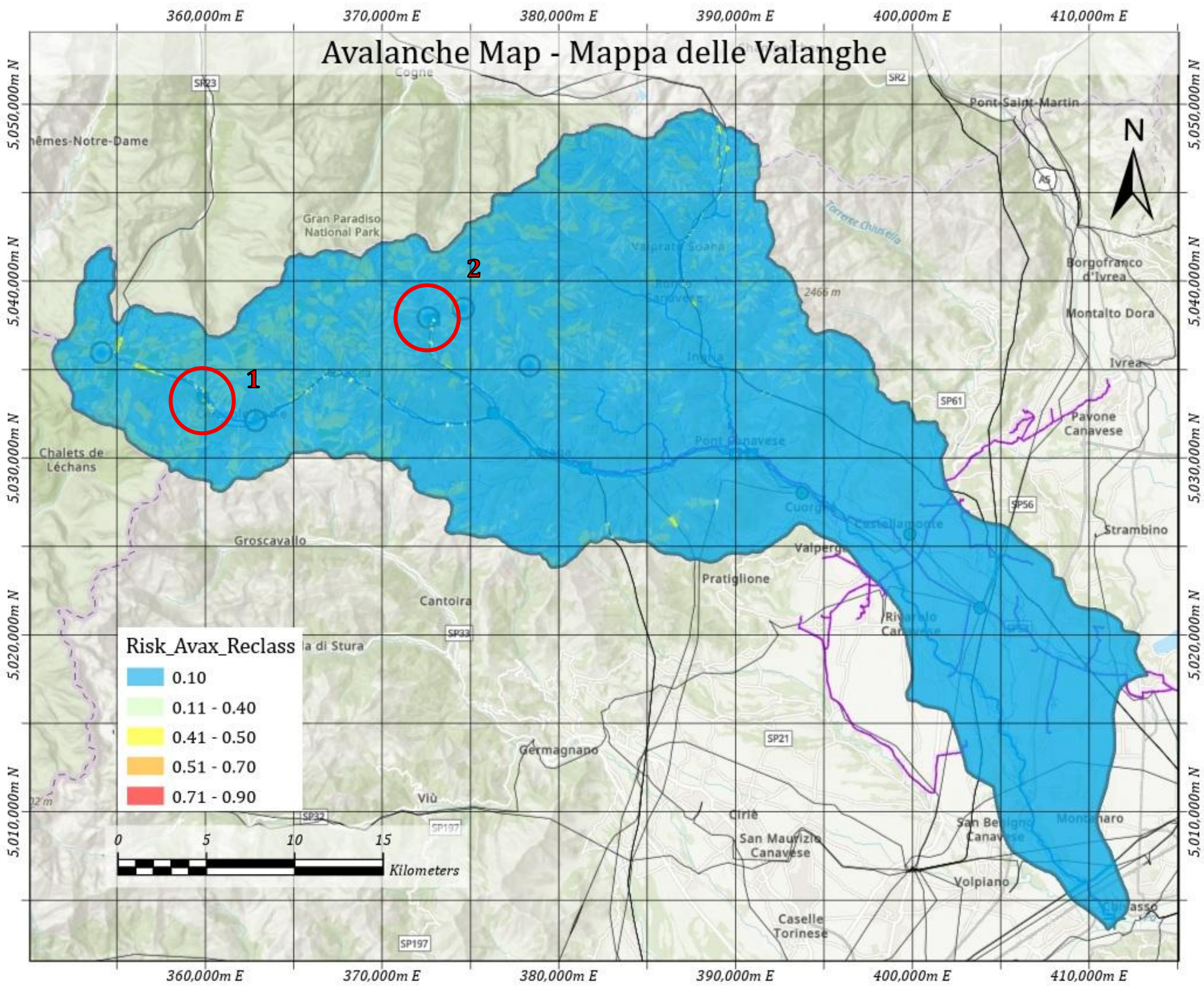


Figure 49. Areas of Interest and Risk Levels - Avalanche

The results in ***Figure 49,*** for avalanche risk assessment in the Orco Valley revealed that some power distribution networks could be affected, but two areas of greatest risk have been identified: the first critical point (1) is located in the town of Villa, directly affecting a small hydroelectric power plant and its surrounding electricity distribution networks. The second critical point (2) is located on Lake Telesio, where it impacts a hydroelectric power plant and its electricity distribution networks, the latter being considered of vital importance over the general distribution networks.

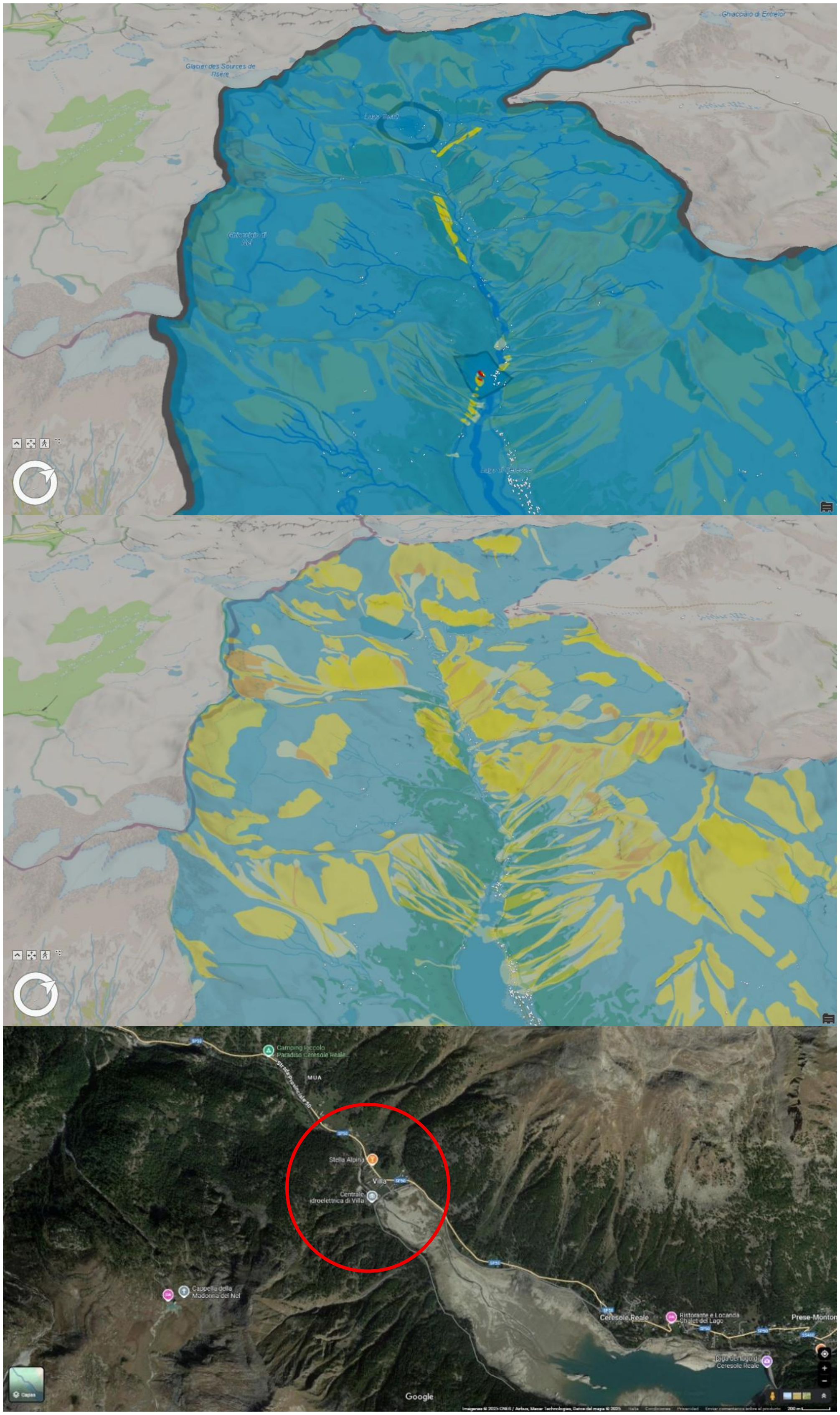


Figure 50. Critical Point 1 for Avalanche Assessment

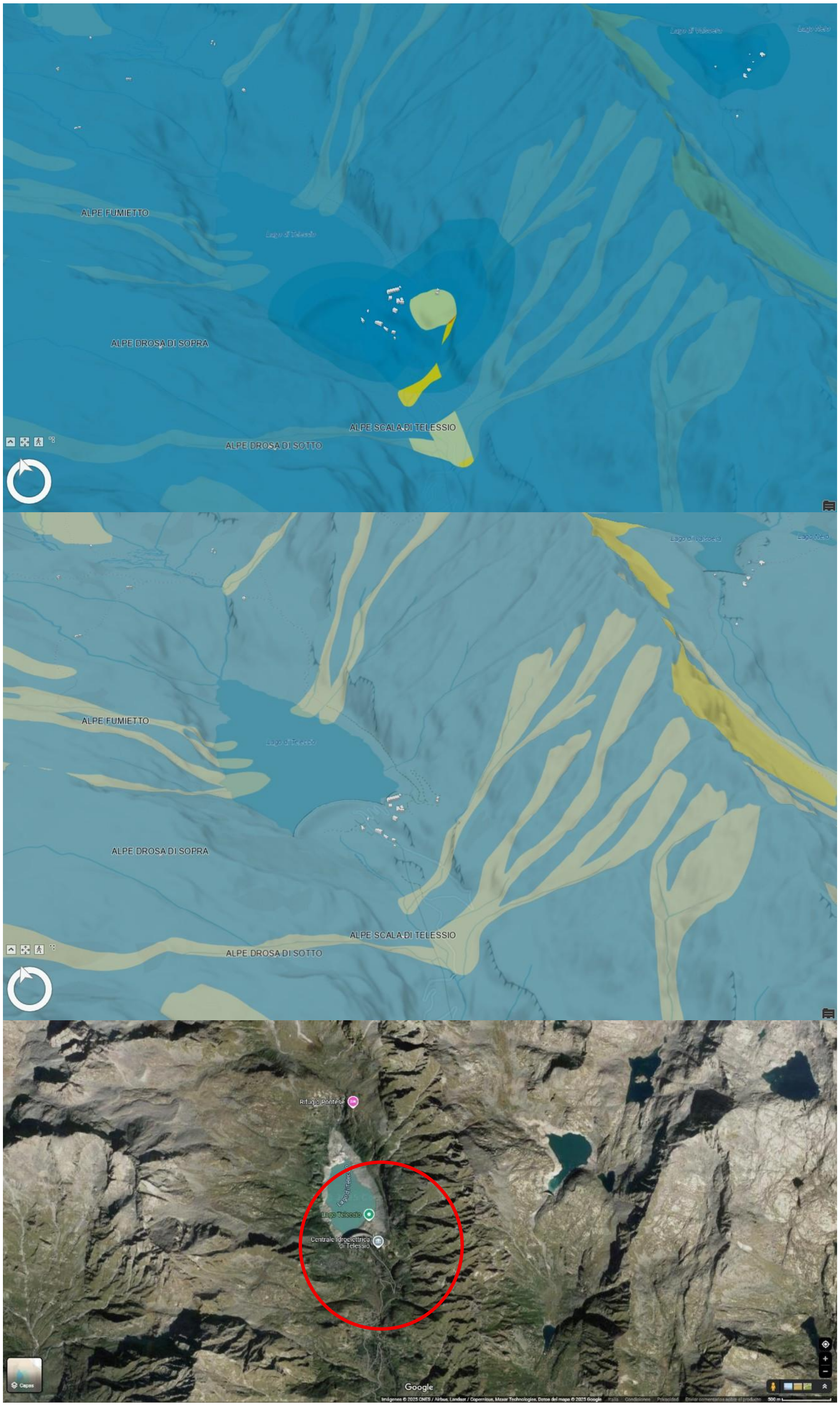


Figure 51. Critical Point21 for Avalanche Assessment

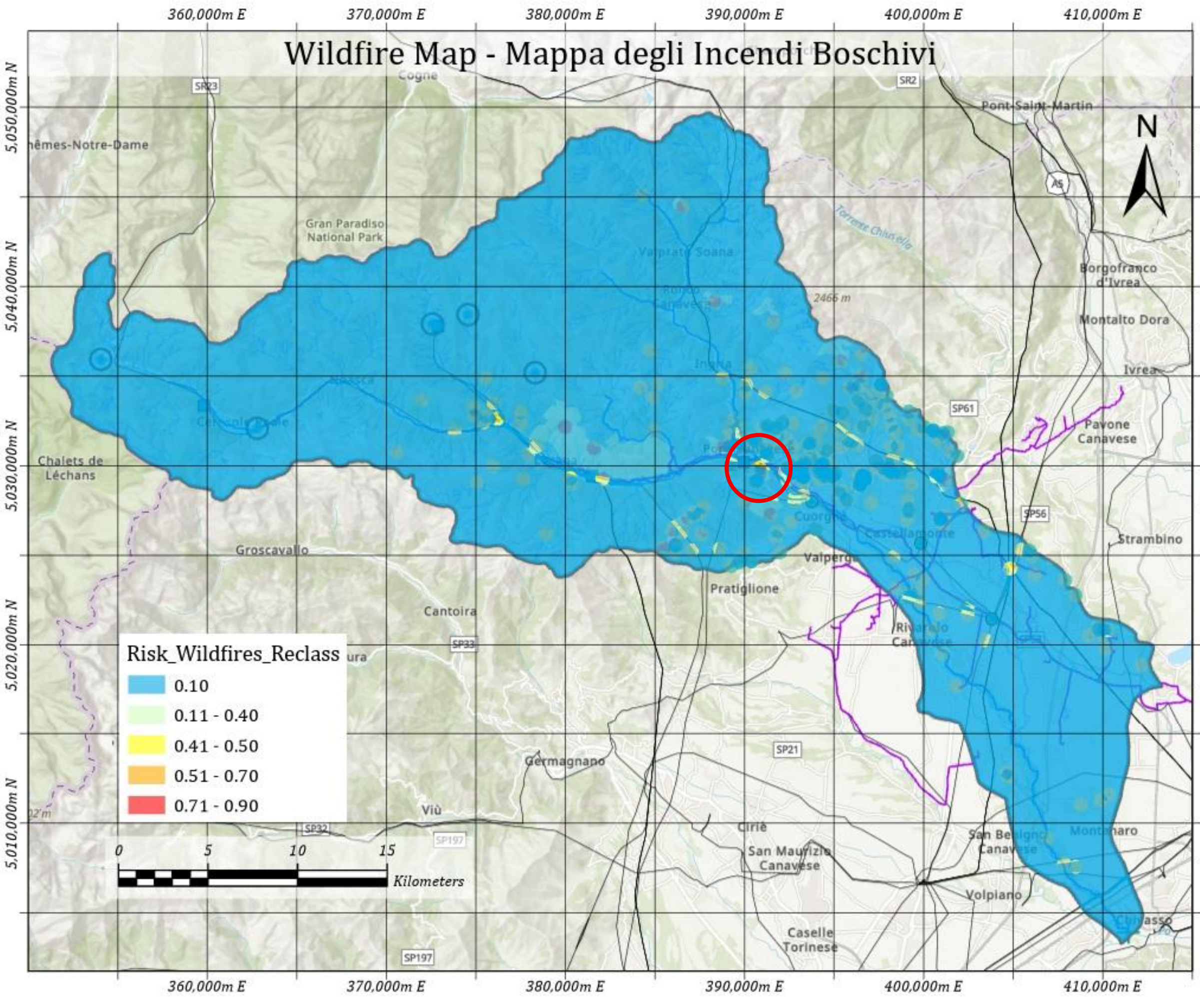


Figure 52. Areas of Interest and Risk Levels - Wildfire

The results in ***Figure 52,*** for wildfire risk assessment in the Orco Valley revealed that some electricity distribution networks could be affected, but the area most at risk is the commune of Pont-Canavese. This critical area directly affects two important points of interest: a small hydroelectric power plant and the surrounding electricity distribution networks, making them more vital than the general distribution networks.

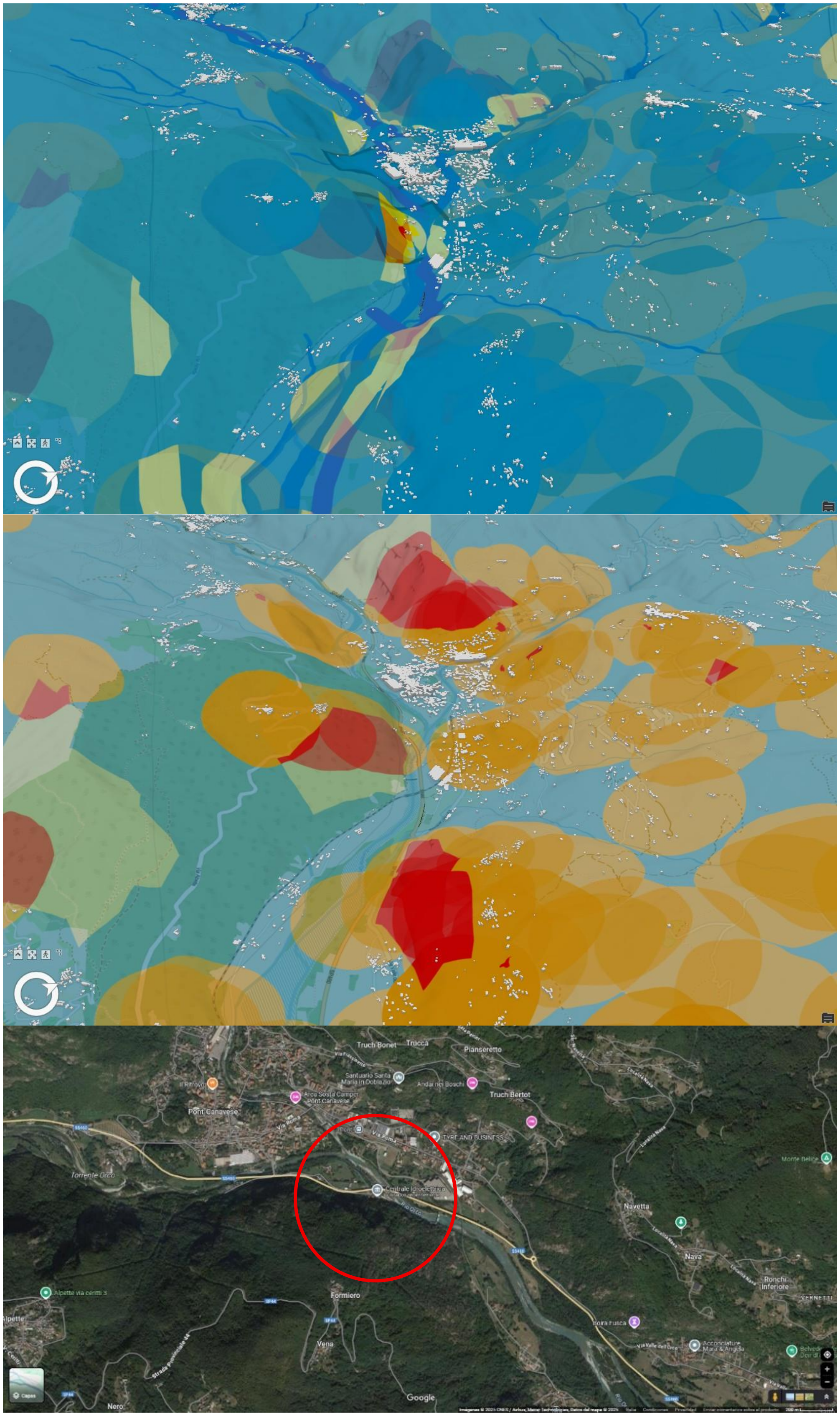


Figure 53. Critical Point for Wildfire Assessment

5.4. Suggestions for Implementation, Monitoring and Updates of Mitigation Strategies

To effectively manage potential risks, mitigation strategies are crucial, aiming to reduce the probability or severity of hazards and implementing contingency plans for consequences. The Orco Valley currently employs various measures to combat natural hazards, including dams and flood walls for water management and flood prevention, along with walls, barriers, reforestation, and sustainable forestry to address landslides and wildfires. Government agencies also operate electronic monitoring systems that provide early warnings of various potential hazards.

For mitigation strategies to be effective, they must be integrated throughout the entire project lifecycle, from initial design through construction and into the safety protocols in place. Constant monitoring is essential to confirm the success of protective measures, and trend analysis helps evaluate the effectiveness of initiatives, identify areas for improvement, predict potential disaster impacts, and refine strategies accordingly. To maintain robust risk management, the BIM methodology is particularly well-suited to this type of work, as it emphasizes the importance of regularly reviewing and updating risk analysis, ensuring its relevance to changing project conditions and ultimately leading to optimal risk management. (Skibniewski, 2014) This dynamic with BIM is addressed below.

5.4.1. Suggestions for Implementation of Mitigation Strategies

To ensure the safety and longevity of critical Points of Interest (POI's) and improve infrastructure resilience, it is crucial to take a proactive approach to managing their inherent vulnerabilities. This involves a continuous cycle of periodic inspections, ongoing monitoring, rigorous maintenance, and frequent updates to risk models. These measures are vital to preventing disasters and prolonging the lifespan of these structures, ultimately enabling them to better withstand adverse events. When necessary, this should be supported by regulations and standards requiring vulnerability analysis. Furthermore, establishing early warning systems and developing robust emergency response protocols are general mitigation strategies that further strengthen preparedness.

Effective mitigation strategies must be tailored to each region and community, considering factors such as population density, economic development, and specific local characteristics. Successful implementation depends critically on strong coordination between authorities and the community. Other hazard-specific mitigation strategies are described below.

5.4.1.1. Mitigation Strategies for Floods

Suggested structural measures for flood mitigation include the construction and maintenance of levees and retaining walls to protect defined risk areas. If necessary, urban drainage systems should be improved to channel rainwater efficiently. Reservoirs and dams should be maintained to regulate river flow and prevent flash floods. Storm sewer systems should also be inspected to reduce water accumulation in the risk area. (Zanchetta, 2021)

To mitigate flood risks without disrupting existing structures, a multifaceted approach is recommended. This includes establishing restricted and buffer zones in high-risk areas, implementing land-use regulations to prevent construction in floodplains, developing early warning systems with effective communication technologies, promoting reforestation and wetland restoration to improve water retention, adopting sustainable agricultural practices to reduce erosion, conducting public education campaigns to raise awareness, and developing comprehensive family and community emergency plans. (Leopold, 1994)

In the case of using emerging technologies for mitigation measures, the suggestion is the implementation of artificial intelligence and machine learning systems, to improve the accuracy of flood forecasts; the deployment of sensor networks to monitor water levels in rivers and reservoirs in real time; and the use of satellite imagery and drones to obtain detailed information on the extent and magnitude of flooding. (Shen, 2018)

5.4.1.2. Mitigation Strategies for Landslides

Suggested corrective measures for landslides mitigation include stabilizing slopes with retaining walls and gabions, anchoring the soil, enhancing ground stability through geotechnical techniques, constructing terraces and barriers to minimize erosion, revegetating to secure the surface, diverting rainwater with channels and ditches, draining groundwater with pipes. (Coduto, Yeung, & Kitch, 2011)

To prevent landslides, implementing soil stabilization measures in at-risk areas is crucial. Key strategies include effective water management through drainage and runoff control, along with preventing deforestation to preserve soil-stabilizing vegetation. Furthermore, deploying sensor networks for soil and hydrological monitoring, establishing early warning systems for timely evacuations, and planting deep-rooted vegetation to reinforce the soil are vital components of a robust landslide mitigation plan. (Brunsden & Brundsden, 2004)

In the case of landslides, preparation is essential. Emergency evacuation plans must be created and practiced, the population must be educated about risks and prevention, and drills must be conducted to train residents on how to respond safely to an event. (Pradhan, 2019)

5.4.1.3. Mitigation Strategies for Avalanches

Safety in mountain areas requires engineering solutions for adapting the landscape and constructing protective structures against natural hazards such as avalanches and rockfalls; this includes building retaining walls and barriers to redirect or stop debris, installing snow barriers to manage snow accumulation, and using controlled detonations to safely trigger smaller avalanches. (Dominijanni, 2020)

Effective land planning is also crucial, using hazard zoning to restrict development in high-risk areas, establishing safe corridors, regulating activities during critical periods, and implementing permits to ensure responsible conduct in mountain environments. Furthermore, continuous monitoring using sensors and weather stations can detect changes in conditions that could trigger avalanches or rockfalls. (Petley, 2012)

Educating the public about the risks of avalanches and rockfalls through information campaigns and practical training in rescue techniques is crucial for preparedness. Clear signage in danger areas reinforces safety measures. To minimize the impact of these events, community-specific evacuation plans must be thoroughly rehearsed, and specialized rescue teams must be equipped and prepared for rapid response. (William & Waugh, 2013)

5.4.1.4. Mitigation Strategies for Wildfires

Effective wildfire mitigation involves a multifaceted approach that combines established methods with modern technology. Predictive modelling and simulations help plan suppression, while fuel reduction through controlled burns and clearing minimizes fire intensity. Creating firebreaks and promoting plant diversity further limit fire spread. Public education campaigns are essential to instil responsible fire practices, raise awareness of the risks, and promote preventive measures. (Cleaves & Steiguer, 2009)

Rapid fire detection is essential for an effective response, which is achieved through aerial and ground surveillance, sensor networks, and camera systems that monitor weather and fire behaviour. Drones and satellites provide real-time data for informed decisions, while strict laws and regulations regarding fire use and fuel management are crucial to safeguarding forest areas. (Arvanitis, 2012)

Effective fire suppression depends on well-equipped and trained firefighters, supported by heavy equipment for firebreak construction and aerial resources such as airplanes, helicopters, and drones for the targeted application of water and retardant. After a fire, ecosystem restoration is crucial, requiring reforestation, natural vegetation regeneration, and erosion control to ensure long-term recovery. (NWCG, 2018)

5.4.2. Suggestions for Monitoring and Updates of Mitigation Strategies / BIM Methodology

Using a GIS methodology combined with 3D BIM, detailed visualization of potential damage caused by natural hazards is possible, allowing stakeholders to identify critical structural assets and understand areas requiring review. This facilitates informed decision-making for mitigation strategies, leveraging GIS-BIM modelling representations and simulations to identify hazards and develop effective countermeasures, thereby ensuring environmental protection against future natural events in the region.

As mentioned above, effective GIS-BIM implementation requires a lifecycle approach that prioritizes the interdependence of project participants and relies heavily on interoperability. Since no single software can manage an entire construction project, seamless data exchange between the various programs used by architects, engineers, and constructors is crucial. This is achieved by integrating internal data structures into a universal model. While complete data exchange between programs remains a challenge, choosing compatible platforms is essential for data integrity. Collaborative work using work sets, a centralized database

(Common Data Environment), and the exchange of linked data further optimize the flow of information, reducing the need for constant updates to a single central file. (MacLeamy, 2015)

Despite the importance of collaboration in AEC projects (Architectural, Engineering, Construction), this thesis study is managed by a single person, which limits the full use of BIM modelling and makes a Common Data Environment (CDE) unnecessary. Therefore, all files will be centralized in a personal database. However, for proper tracking and updating of the suggested mitigation measures, appropriate information sharing across various platforms is recommended.

ArcGIS Pro has significantly improved its interoperability with 3D modeling and BIM platforms, strengthening its role in integrating geospatial data with design and construction models. This demonstrates Esri's commitment to the AEC sector and the growing importance of BIM. Successful import of BIM data into ArcGIS Pro, which creates useful feature layers with attributes, depends on the quality of the IFC export from the source BIM software. While ArcGIS Pro automatically positions Revit models with shared base points and defined geographic coordinate systems, manual georeferencing is required otherwise.

6. Results

This thesis project seeks to implement the procedure proposed in section ***5.4 Suggestions for Implementation, Monitoring and Updates of Mitigation Strategies,*** aiming to offer natural hazard mitigation solutions by integrating diverse sources of information. The objective is to effectively visualize the behavior of built and natural environments, thus facilitating a comprehensive connection between hazard maps and digital representations of Points of Interest (POIs) and the territory in general.

As mentioned above, since this thesis project aims to generate a multi-criteria risk assessment, with different types of hazards, a map will be generated with the combination of all the obtained risks, where the different critical points found in all risk analyses are indicated. It's important to highlight that one of the critical points found is repeated for two different types of natural hazards, making it even more relevant than the others. This critical point is located on Lake Telesio, where it is exposed to landslides and avalanches.

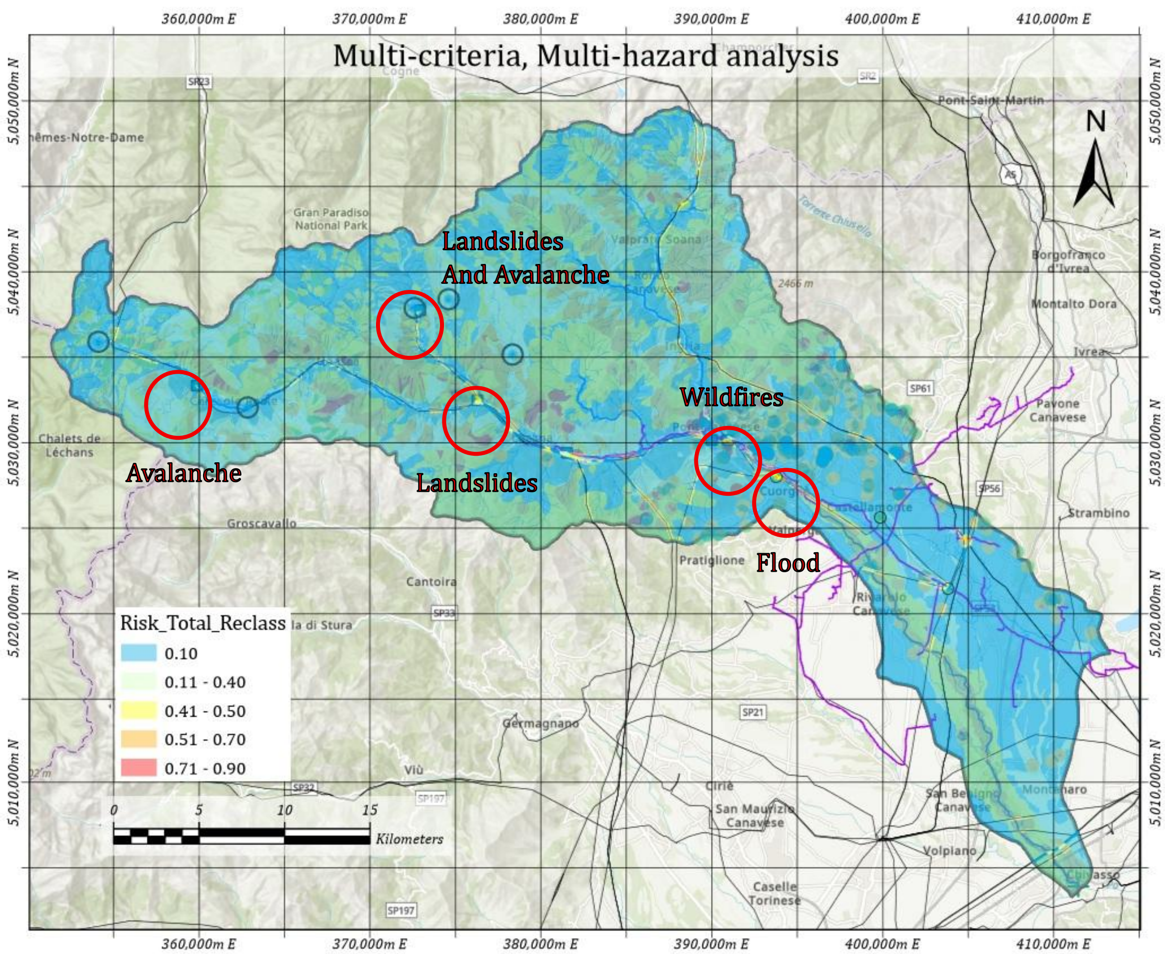


Figure 54. Multi-criteria, Multi-hazard Analysis

6.1. Interoperability between software

The integration of BIM and GIS systems is vital to several key workflows, as it geographically contextualizes BIM models, enables comprehensive data analysis, and optimizes infrastructure management. This interoperability improves communication through high-quality 3D visualizations and interactive web maps, ultimately enabling the creation of "digital twins" for urban environments and buildings. ArcGIS Pro specifically facilitates this by converting BIM files (such as Revit or IFC) into GIS feature classes using tools such as "BIM File to Geodatabase," which transfers BIM element attributes, enabling advanced GIS analysis and management based on these properties.

Other ways ArcGIS Pro achieves interoperability with BIM and 3D platforms are through services like ArcGIS Online, direct connections via APIs and third-party plugins for seamless integration, and web services. Esri specifically promotes web services like Scene Layers to enable the online sharing and visualization of large 3D and BIM models, which fosters collaboration without requiring all users to have specialized BIM or GIS software. (Liu, Tang, & Li, 2018)

6.1.1. Analysis of Interoperability

The level of interoperability in a BIM project depends largely on its specific design and the software used at various stages, such as architecture, structure, construction management, and detailing. Since different software packages are often used for each design process, the ease and efficiency of data exchange between them can vary. Furthermore, interoperability is often related to software developers; typically, programs from the same company (e.g., Autodesk products) offer superior seamless integration.

Interoperability analysis at this stage requires a list of software solutions capable of addressing all risk analysis outcomes for the Orco Valley. Given ArcGIS Pro's ability to share data via CDE/IFC files and web applications, Revit, Infraworks, and Navisworks are recommended for file exchange, while Cesium is recommended for integration with third-party APIs and add-ins. These options are based on their known advantages in design accuracy, implementation, and overall workflow efficiency.

Table 25. List of software – Interoperability

Software's proposed	Connection	Function
ArcGIS Online	Web / APIs	SaaS - Software as a Service based on cloud
Cesium	Web / APIs	interaction with real-world 3D models on a global scale
Revit	CDE/IFC	Architectural, Engineering and executive design
Infraworks	CDE/IFC	Conceptual Design and Infrastructure Planning
Navisworks	CDE/IFC	Time depending modelling and simulation

Once the software to be analyzed has been specified, the interoperability analysis process between the different programs is described. This analysis is performed using the methodology Open-Source Intelligence (OSINT) analysis. This process consists of collecting, evaluating, and analyzing data from openly accessible public sources to generate practical information or knowledge. To assess software interoperability, each program is compared with the others, describing the BIM methodology steps involved in the analysis. (Bazzell, 2023)

6.1.2. Evaluation of Interoperability

This evaluation seeks to evaluate the interaction between various platforms, such as ArcGIS, Autodesk products (Revit, Infraworks, Navisworks), and Cesium tools (CesiumJS, Cesium for Unreal, Cesium for Unity), to facilitate workflows in infrastructure and building projects, from initial design to asset management, including geospatial visualization and analysis. Evaluation criteria include direct import/export formats, compliance with open standards (CDE/IFC, GeoJSON), dependency on third-party plugins, potential information loss, georeferencing capabilities, 3D and web visualization support, bidirectional workflows, and community support and documentation. Information will be collected through open-source intelligence (OSINT) from official websites, technical documentation, user forums, technical articles, case studies, video tutorials, and open-source repositories, followed by peer-to-peer analysis and synthesis.

- **ArcGIS Online & Cesium:**

Cesium is a web 3D rendering engine that often consumes data hosted on ArcGIS Online, especially Scene Layers (3D) and Feature Layers (2D). Esri and Cesium have actively partnered, offering high native interoperability. The workflow typically involves creating scene layers in ArcGIS Pro (creates Scene Layers) -> hosting them on ArcGIS Online (hosts Scene Layers) -> then visualizing them using CesiumJS (visualizes Scene Layers). Its strengths lie in open standards (3D Tiles), excellent web performance, and accurate georeferencing. However, CesiumJS is not a full-fledged GIS, but primarily functions as a 3D viewer, which means that complex analysis still needs to be performed in ArcGIS Pro or the backend. (Esri D. R., Continuosly Updated) (Cesium O. G., Continuosly Updated)

- **ArcGIS Online & Revit:**

Interoperability between Revit and ArcGIS Online is indirect but robust and requires ArcGIS Pro as an intermediary. The workflow involves processing Revit models (either .rvt or imported IFC) -> ArcGIS Pro, publishing them as scene layers for hosting and viewing -> ArcGIS Online (hosting and displaying the scene layer). This method effectively preserves BIM attributes and enables georeferencing, integrating BIM models into a web geospatial context. However, one limitation is the lack of bidirectional editing from ArcGIS Online to Revit, meaning that any updates to the BIM model require republishing it from ArcGIS Pro. (Esri R. U., Regularly Updated) (Liu, Tang, & Li, 2018)

- **ArcGIS Online & Infraworks:**

InfraWorks demonstrates excellent and continuous improvement in GIS interoperability, particularly through its compatibility. The workflow typically involves creating a conceptual model in InfraWorks -> exporting it to GIS/3D formats (such as FBX, SHP, or, preferably, ArcGIS Pro) -> publishing it as a scene layer in ArcGIS Pro -> using it in ArcGIS Online. InfraWorks, on the other hand, can import data directly from ArcGIS Online and ArcGIS Enterprise. Its strength lies in establishing the initial geospatial context for infrastructure projects and facilitating seamless workflows between GIS and civil engineering during the conceptual stages. However, one limitation is that transferring all of InfraWorks' parametric intelligence into a traditional GIS (such as feature layers) may require some data transformation. (Esri, Autodesk Knowledge Network/Help Documentation for InfraWorks:, Continually Updated) (Autodesk, Enhancing BIM-GIS Integration through InfraWorks A Comprehensive Application, 2023)

- **ArcGIS Online & Navisworks:**

Navisworks provides indirect interoperability with ArcGIS Online, primarily for the visualization of federated models. While it excels as a platform for aggregating various engineering models (such as Revit and Civil 3D) into NWC/NWD formats, it lacks a direct native web connector to ArcGIS Online. The typical workflow is to export from Navisworks to generic 3D formats (e.g., FBX/OBJ) -> ArcGIS Pro processes into a scene layer -> hosts them on ArcGIS Online. While ArcGIS Pro Online can effectively display the consolidated model in a geospatial context, a major limitation is the loss of crucial BIM information when converting from native Navisworks formats to these generic 3D formats, as there is no optimized workflow to preserve semantic properties in the web environment. (Esri, BIM data as ArcGIS Pro layers—ArcGIS Pro | Documentation, Continuously Updated) (Erfanian, Ebrahimi, & Delavar, 2025)

- **Revit & Infraworks / Navisworks:**

Within the Autodesk ecosystem, Revit, Infraworks, and Navisworks offer robust native interoperability, enabling seamless workflows across civil and building projects. Revit and Infraworks facilitate direct model exchange, allowing architectural designs to be easily contextualized within larger infrastructure projects and detailed. Revit and Navisworks also provide a standard workflow for BIM model coordination, clash detection, and 4D simulations, typically through direct file opening or export to NWC. Infraworks also features robust native interoperability with Navisworks, enabling the transfer of conceptual infrastructure models for detailed review and coordination, streamlining processes at all stages of the project. (Autodesk, BIM and Infrastructure Design: A Guide to Using Autodesk, 2018) (Kreider & Messner, 2013)

- **Cesium & Revit/Infraworks/Navisworks:**

  Interoperability between BIM/3D software and Cesium is mostly indirect, typically based on intermediate formats such as glTF, FBX, or 3D Tiles, or through ArcGIS Pro. The general workflow involves exporting models from tools such as Revit, Infraworks, or Navisworks -> an intermediate format (FBX/glTF/IFC) -> Processing to 3D Tiles (using tools such as FME, or specific converters) -> using ArcGIS Pro to create and publish scene layers to ArcGIS Online -> visualization in CesiumJS (visualize Scene Layer). This approach excels at bringing highly complex BIM/3D models to the web for large-scale visualization and digital twin applications. However, one limitation is the often-required conversion and processing step to optimize data for Cesium, which can sometimes result in the loss of BIM attributes if the conversion to 3D Tiles is not meticulously managed. (Cesium, Ongoing) (Isikdag & Zlatanova, 2019)

Once the different levels of interoperability of the software analysed have been evaluated, they can be rated by assigning a value to each case. To do this, three different ratings will be considered, as shown in the following table.

Table 26. Interoperability Assessment Ratings

80 – 100%	*30 – 79%*	*0 – 29 %*

As can be seen in the ***Table 26***, interoperability will be assessed in three different ways. First, good interoperability between two software programs will be marked with a green colour. Then, a medium level of interoperability will be marked with a yellow colour. Finally, software with no or very low interoperability will be graded with a red colour. The interoperability of the software programs It was carried out based on the evaluation raised above and it will now be represented in the table below, which visualizes each relationship between the different programs.

Table 27. Visualization of Software Interoperability

	ArcGIS Pro	ESRI ArcGIS Online	CESIUM	AUTODESK REVIT	AUTODESK INFRAWORKS	AUTODESK NAVISWORKS
ArcGIS Pro	✓	✓	–	✓	✓	✓
ESRI ArcGIS Online	✓	✓	✓	–	–	–
CESIUM	–	✓	✓	✗	✗	✗
AUTODESK REVIT	✓	–	✗	✓	✓	✓
AUTODESK INFRAWORKS	✓	–	✗	✓	✓	✓
AUTODESK NAVISWORKS	✓	–	✗	✓	✓	✓

The ***Table 27***, graphically represents the previous description of the relationship between the programs. The Autodesk ecosystem, which includes Revit, Infraworks, and Navisworks, offers robust interoperability for integrated BIM/3D design, modelling, coordination, and simulation. It serves as the backbone for creating detailed BIM/3D models. Meanwhile, the Esri ecosystem (ArcGIS Pro, ArcGIS Online) is highly interoperable and excels at managing BIM/3D data for georeferencing, spatial analysis, and web publishing. It serves as the bridge between BIM and the broader GIS context. Finally, Cesium stands out as the leading solution for web-based 3D geospatial visualization, facilitating the online consumption and presentation of comprehensive BIM/GIS models, making it crucial for developing web-accessible digital twins.

The most effective interoperability strategy today typically involves a multi-step approach: initially, detailed model creation in software such as Revit (for buildings) and Infraworks (for conceptual infrastructure), with Navisworks for coordination; then import into ArcGIS Pro for geospatial contextualization, georeferencing, and spatial analysis; and finally, publishing and web visualization for digital twins, on platforms such as ArcGIS Pro. Pro publishes to ArcGIS Online (as scene layers) and Cesium (which often uses ArcGIS Online scene layers or its own 3D tiles) manages high-performance web visualization. This process highlights that true interoperability is not always straightforward and simple, often requiring intermediate formats (such as IFC and 3D tiles) and specialized tools (such as ArcGIS Pro) to transform and optimize the data for final use (GIS analysis, web visualization).

However, the trend is toward greater integration and automation of these workflows. (Biljecki, Heuvelink, & Stoter, 2022)

6.2. Indications and Considerations

In order to provide a deeper understanding of this thesis project within the academic context, this section will explain some of the key variables considered during its development. This serves to connect the research conducted with the broader field of study, while also describing the limitations and implications of the results. The study leverages officially published GIS data to create a digital twin framework for risk assessment, integrating multi-criteria analysis. This study proposes an innovative and simple assessment, which is the primary objective of the project. However, the simultaneous analysis of numerous natural hazards, while positively expanding the scope of the study, inherently limited its profound analysis and posed a challenge for generating results.

It is important to highlight that the natural hazard probability maps obtained are based on a historical analysis of natural disasters, as they are a tool that offers a deep understanding of the past behaviour of phenomena, which serves as a basis for predicting future scenarios and developing more effective preventive measures. They allow for the identification of the recurrence and frequency of events, delimit high-risk areas by mapping past impacts in relation to geographic conditions, and help assess the magnitude and intensity of events, estimate trigger thresholds, and identify recurring vulnerabilities in infrastructure. They are also crucial for validating and calibrating predictive models, thus improving the reliability of future projections.

Another important point to note is that 3D models were not available for any of the POI's. Therefore, to address this shortcoming, the project undertook an interoperability analysis and assessment using the Open-Source Intelligence (OSINT) methodology. This approach made it possible to leverage data collected from public and open-access sources to generate practical and valid results (Bazzell, 2023).

Finally, another important consideration relates to the proposed mitigation works. While they are general in nature, addressing multiple natural hazards and critical POI's, they are crucial to strengthening preparedness and enabling these assets to better withstand adverse events, ensuring the safety and longevity of critical POI's and improving the overall resilience of the infrastructure and surrounding terrain.

6.2.1. Limitations of the Study

The most significant limitation encountered was the difficulty in establishing causality using qualitative data alone. While qualitative research offers valuable insights into natural hazards, it faces limitations such as subjectivity, potential researcher bias, and the excessive amount of time required to analyse large data sets. To counteract these limitations, strategies such as rigorous data collection, triangulation of multiple sources, researcher reflexivity, detailed data descriptions, and peer review are employed. Furthermore, due to the difficulty in establishing definitive causal relationships, this thesis project integrated qualitative findings with quantitative analysis using GIS.

The Analytic Hierarchy Process (AHP) enables multi-criteria decision-making by weighing different factors and making informed decisions. This is ideal for problem decomposition, especially in geomorphological vulnerability assessments. However, for this very reason, it can generate variable results due to the subjective prioritization of factors, which can differ significantly between analyses and areas. This means that the impact of a single factor, and its subsequent ranking, can vary depending on the type of hazard and the specific area analysed, ultimately influencing the overall risk assessment. For example, variables such as slope versus flood risk, among others, can be problematic.

Another limitation of the study is that despite significant progress, BIM and GIS integration still faces several challenges. These include ensuring accurate georeferencing by aligning local BIM coordinates with global GIS systems and avoiding the loss of complex parametric intelligence from BIM models during GIS transfer. Furthermore, maintaining model synchronization as designs evolve remains difficult, as current tools are more effective at one-way imports than at two-way updates. Managing the high level of detail of BIM models in GIS environments can also impact performance, especially on large-scale projects. Finally, the lack of a universally adopted industry standard for BIM-GIS interoperability further complicates the entire process.

6.2.2. Implications of the Findings

The results of this research, by integrating an initial qualitative analysis of risk factors with a quantitative experimental design based on GIS models for the Digital Twin, not only confirm the importance of considering the interrelationship between the nature of the risk and the intrinsic characteristics of the infrastructure, but also expand existing theories on risk assessment by proposing an innovative and simplified perspective through modelling and information provided by public entities. This suggests a new line of thinking where the efficiency of resource allocation can be optimized from earlier phases of risk analysis.

One of the most important implications would be at the public level, as it could propose improvements in how public entities, such as those in the Piedmont Region, provide GIS information. By demonstrating how a more detailed, standardized, and organized qualitative description of geographic data (beyond simple layers) improves its understanding and application, this research offers a practical model for institutions to increase the usefulness of their data, foster interoperability and collaboration, and improve evidence-based decision-making. In short, this thesis project not only proposes innovation in risk assessment but also drives a cultural shift toward more useful and interoperable GIS data publication for the benefit of society.

From a practical perspective, this study provides a robust and simplified methodology that can be adopted by civil engineers, infrastructure managers, and civil protection authorities for risk assessment on vulnerable areas. The approach, which combines qualitative factor prioritization analysis with a quantitative GIS model, especially when integrated with the modelling concept and information provided by public entities, allows for more efficient resource allocation in the initial stages of the assessment. This translates into the ability to quickly identify critical weaknesses and inform investment decisions based on preventive and mitigation measures, reducing costs and time compared to traditional methods and providing a clearer and more manageable view of the infrastructure and its risks.

Finally, at the social and political level, the results of this thesis can serve as a valuable tool for local and regional authorities (e.g., the Piedmont Region and Civil Protection) in formulating more effective risk management and sustainable territorial development policies. By more accurately and efficiently identifying risks associated with key infrastructure in vulnerable areas such as the Orco Valley, community safety and resilience can be improved, enabling better urban and emergency planning. Furthermore, the clarity and visualization offered by this approach could foster greater citizen participation and public understanding of risks and the measures needed to mitigate them, fostering a culture of prevention.

6.3. Future Developments and Recommendations

Building information modelling (BIM) is not limited to the creation of a 3D model for a project and its management; it also involves incorporating information related to sustainability and maintenance. Up to this point, the first dimensions of a BIM model have been addressed. In this chapter, some considerations for the future of risk mitigation solutions in Orco Valley will be presented, which can be considered when developing a complete BIM cycle. These considerations are dimension 6D, which corresponds to the project's sustainability; dimension 7D, which covers lifecycle and maintenance aspects; and dimension 8D, Health and Safety in construction.

6.3.1. 6D BIM: Sustainability

One of the primary goals of this thesis is to propose natural hazard mitigation measures that also add value to the Orco Valley region. To achieve this, the project advocates for implementing BIM's 6D dimension (Sustainability) in the design, construction, and management of mitigation infrastructure. This approach focuses on integrating environmental performance, energy efficiency, and Life Cycle Analysis (LCA), ensuring that proposed solutions not only protect against disasters but also minimize environmental impact and foster the valley's ecological resilience.

The 6D BIM model enables detailed Environmental Impact Assessment and Carbon Footprint calculations for construction materials and methods. By integrating data on materials used for mitigation works like retaining walls or drainage systems, the model can calculate the associated carbon footprint from production to installation. This allows for direct comparisons, for instance, between traditional concrete and more sustainable alternatives like local stone gabions or bioengineered solutions. This capability promotes the selection of low impact, recycled, or locally sourced materials, thereby reducing the project's greenhouse gas emissions. (Soustou, Cherif, & El Hajjaji, 2020)

Furthermore, 6D BIM optimizes resource use during both construction and operation. It facilitates planning and simulating water and energy consumption on-site, including efficient water sourcing and fuel-saving machinery routes. For operational elements like pumping stations or monitoring systems, the model optimizes their energy use throughout their lifespan, promoting renewable energy or passive designs. This dimension is also crucial for integrating nature-based and bioengineering solutions, allowing for the modelling and evaluation of Sustainable

Urban Drainage Systems (SUDS) and bioengineering techniques. Beyond simple risk reduction, BIM assesses how these natural approaches contribute to biodiversity, improve soil and water quality, and enhance overall ecosystem resilience, also facilitating comprehensive landscape and biodiversity impact assessments to ensure environmentally responsible designs. (CIRIA, 2024)

Finally, the 6D dimension is instrumental for conducting a complete Life Cycle Assessment (LCA) of mitigation infrastructures, analysing their total environmental impact from raw material extraction to disposal. By modelling these aspects within BIM, informed design and material choices can be made to minimize environmental impact across the entire lifespan of the structure, rather than just during construction. In essence, implementing BIM's 6D dimension transforms natural hazard mitigation in a mountain valley from merely building to building sustainably, ensuring decisions are guided by environmental impact and ecological resilience alongside engineering and economic effectiveness.

6.3.2. 7D BIM: Facility Management

Implementing 7D BIM for Facilities Management in the Orco Valley's natural hazard mitigation project offers an advanced strategy for maximizing the efficiency and longevity of mitigation infrastructure. While other BIM dimensions (3D to 6D) concentrate on the design and construction of protective measures like retaining walls, barriers, and drainage systems, 7D BIM extends its focus to encompass the entire lifecycle and ongoing maintenance of these crucial structures beyond their initial construction. (Tao & Zhang, 2019)

To optimize maintenance processes, each individual mitigation structure or system, such as landslide nets or monitoring stations, is meticulously modeled as a distinct asset within the BIM environment, complete with specific properties. This includes integrating vital maintenance attributes directly into the 3D model for every component. Such attributes comprise technical specifications, manufacturer information (contacts, warranties, manuals), detailed maintenance instructions (frequency, procedures, replacement schedules), expected lifespan, historical maintenance costs, and even real-time data streaming from IoT sensors monitoring conditions like water levels or ground deformation. (RICS, 2025)

Connecting a Computer-Assisted Facilities Management System (CAFM/CMMS) with a 7D BIM model significantly enhances facility management. This integration allows for the automated scheduling of preventive maintenance tasks, like routine inspections and sensor calibration, based on the specific attributes embedded within the BIM model. Furthermore, when issues or failures occur, the system can meticulously record them, with the BIM model providing essential visual context and detailed information to streamline the planning and efficient execution of necessary corrective maintenance actions. (Patacas, Dawood, & Kassem, 2020)

The integration of 6D and 7D BIM with IoT technology is pivotal for real-time monitoring and data utilization. Sensors designed to monitor earthworks, water levels, or vibrations can be directly linked to their corresponding elements within the BIM model. This linkage enables operators to visualize anomalies instantly within the comprehensive 3D context of the infrastructure. Moreover, the system can automatically generate alerts when predefined thresholds are exceeded, ensuring that maintenance personnel are immediately notified of potential issues, allowing for rapid intervention.

6.3.3. 8D BIM: Health and Safety in Construction

The implementation of the 8D BIM (Safety in Construction) dimension in a natural hazard mitigation project in a mountain valley is crucial to ensuring the safety of workers, the public, and the infrastructure itself throughout all phases of the project. 8D BIM focuses on the identification, analysis, and mitigation of safety and health risks on the construction site and during operation. In an environment as challenging as a mountain valley prone to natural hazards (landslides, rockfalls, flooding), the application of 8D BIM goes beyond standard occupational safety and integrates with the management of the natural hazards the project seeks to mitigate. (Monteiro, 2022)

The 3D/BIM model of the mitigation measures is integrated with surrounding terrain data and critical GIS layers, showing high-risk areas, including rockfalls, potential landslides, historical debris flows, and flood zones. This 3D visualization allows safety teams and planners to clearly identify where personnel or machinery could be exposed to existing natural hazards, as well as construction-related risks, such as slope instability due to excavations. This facilitates the detection of temporary risks, such as exposure to unstable areas during specific project phases, and is crucial for planning safe access routes for equipment and personnel, as well as emergency evacuation routes, especially in mountain valleys with limited access, where the topography is complex and construction progress is constant.

Within a 3D model, safety and exclusion zones, such as rockfall protection areas, temporary blasting exclusion zones, and material storage areas, can be defined and virtually visualized. This information can be linked to on-site digital access control systems, restricting access to authorized personnel only. Direct integration of Health and Safety (H&S) information into the model allows detailed safety attributes, such as high-risk zone labelling, to be assigned to specific elements. This functionality makes it possible to visualize specific safety needs and directly link crucial safety data sheets, rescue plans, or emergency procedures to relevant objects or locations within the model. (Adeleke, 2024)

For safer construction in mountainous terrain, BIM 8D facilitates "Design for Safety" by evaluating mitigation measures not only in terms of effectiveness and cost, but also ease and safety of construction, prioritizing solutions that minimize exposure to high-altitude work or unstable areas. Implementing BIM 8D in these mitigation projects improves on-site health and safety, increases project efficiency, reduces incident-related costs, and demonstrates proactive risk management, crucial for sensitive mountain valley environments.

7. Conclusions

This thesis developed an innovative and simplified risk assessment for the Orco Valley infrastructure by integrating a multi-criteria analysis and using information published by official entities, complemented by GIS and BIM methodologies, focusing on the effective management of natural hazards. To this end, a robust methodology was implemented that combined an initial qualitative analysis of risk factors with a quantitative experimental design based on GIS models. The study generated natural hazard probability maps from historical data, which allowed for understanding past phenomena, predicting future scenarios, delimiting high-risk zones and estimating trigger thresholds, validating predictive models, and identifying vulnerabilities.

The primary objective was to provide a comprehensive assessment of natural hazards and suggest mitigation measures for undesired events, using multi-criteria decision-making techniques to weigh various factors and inform decisions. To achieve this, the research identified and prioritized the natural hazards of the Orco Valley, assessed the specific characteristics of Points of Interest (POIs), and analysed the valley's geomorphological features to determine their vulnerability. The areas and POIs most at risk were identified, and mitigation solutions were proposed. The integration of qualitative analysis with quantitative experimental design based on GIS models was key to efficient resource allocation and the establishment of cause-effect relationships.

Despite the lack of pre-existing 3D models for Points of Interest (POIs), open-source intelligence (OSINT) was successfully used to facilitate an interoperability analysis. This demonstrated that mitigation works are critical to strengthening the preparedness and resilience of critical infrastructure. The ultimate goal of this research was to ensure the safety of these vital POIs, as well as improve the region's overall resilience to future events.

The central innovation of this work lies in the way that the integration of a qualitative analysis of risk factors with quantitative GIS models were done, using public data for a risk assessment that is not only innovative but also simplified. This represents a significant theoretical contribution, as it expands existing theories on risk assessment by highlighting the interrelationship between the nature of the hazard and the intrinsic characteristics of the infrastructure, optimizing resource allocation from the initial stages of the process. In practical terms, this methodology presents a robust and simplified tool for civil engineers, infrastructure managers, and civil protection authorities, facilitating faster identification of weaknesses and informed investment in preventive measures, resulting in reduced costs and time.

At the level of public and policy implications, this thesis proposes significant improvements in the way public entities, such as the Piedmont Region and Civil Protection, provide GIS information. By advocating for more detailed, standardized, and organized qualitative descriptions, it seeks to enhance usability, interoperability, and evidence-based decision-making, which in turn strengthens citizen empowerment. This offers a valuable tool for local and regional authorities in formulating more effective risk management and sustainable territorial development policies, positively impacting community safety and resilience, urban and emergency planning, and fostering a culture of prevention thanks to improved citizen understanding through the modelling.

It is important to acknowledge that the study faced limitations inherent to qualitative data collection and analysis, including subjectivity, researcher bias, and the time-intensive nature of the analysis. However, these were effectively mitigated through triangulation techniques and integration with quantitative GIS analysis. While prioritizing factors in the AHP can be subjective, the GIS- BIM integration cloud presents some challenges related to accurate georeferencing, model synchronization, and the lack of a universal interoperability standard. These do not detract from the validity of the findings. On the contrary, they underscore the continued importance of research in these areas for future improvements.

Finally, as mentioned during the development of this thesis project, this is a simplified model compared to existing rigorous natural event risk assessments, but it nonetheless works well and delivers consistent and satisfactory results. This innovative approach not only provides valuable information and promotes data-driven decision-making but ultimately delivers value and contributes to safeguarding communities.

8. References

Adeleke, O. T. (2024). *BIM in Construction Safety and Risk Management.* Hilaris Publisher.

Arno, S. F., & Brown, S. M. (2014). *Wildland Fire Management: Principles and Practices.* John Wiley & Sons.

Arno, S. F., & Fiedler, B. F. (2006). *Fire Ecology: United States and Canada.* Island Press.

Arvanitis, D. G. (2012). *Forest Fire Monitoring and Modeling.* CRC Press.

ASCE. (2017). *Civil Engineering Handbook, Sixth Edition.* American Society of Civil Engineers (ASCE).

Autodesk. (2018). *BIM and Infrastructure Design: A Guide to Using Autodesk.* Autodesk .

Autodesk. (2023). *Enhancing BIM-GIS Integration through InfraWorks A Comprehensive Application.* GeoTerrace.

Bamford & New, J. a. (2012). *Transport Infrastructure and Climate Change: A Global Perspective.* Routledge.

Bazzell, M. (2023). *Open Source Intelligence Techniques: Resources for Uncovering Online Information (10th Edition).* Self-published.

Bell, R. G. (2014). *Geotechnical Engineering Handbook, 4th Edition".* CRC Press.

Belton V., & Thomas L. (2001). *Decision Making with the Analytic Hierarchy Process: An Interactive Approach.* Springer.

Biljecki, F., Heuvelink, G. B., & Stoter, J. (2022). *3D City Models: Development, Georeferencing, and Applications.* CRC Press.

Biswas, A. K. (2010). *Drought and Water Crises: Science, Technology, and Management.* Springer.

Blakemore, E. (2023). AI tool will make landslide prediction easier, researchers say. *The Washington Post*.

Bolstad, P. A. (2019). *GIS Fundamentals: A First Text on Geographic Information Systems.* Eider Press.

Borrelli, R. L. (2018). *The Future of Energy Infrastructure .* Springer.

Bowles. (2008). *Foundation Engineering.* McGraw-Hill.

Brebbia. Adeli & Butz, C. ,. (2010). *Vulnerability and Risk Assessment for Critical Infrastructure.* WIT Press.

Brunsden, D. H., & Brundsden, D. B. (2004). *Landslide Hazard and Risk Assessment.* Wiley-Blackwell.

Bruthans, C. (2009). *Rockfall Hazard Rating.* Springer. Retrieved from Canadian Avalanche Association: https://cdn.ymaws.com/www.avalancheassociation.ca/resource/resmgr/standards_docs/tasarm_english.pdf

Busico, G., Giuditta, E., Kazakis, N., Colombani, & A., N. (2019). Hybrid GIS and AHP Approach for Modelling Actual and Future Forest Fire Risk under Climate Change Accounting Water Resources Attenuation Role. *Sustainability, 11*, Article No. 7166.

C.G. Knight. (2017). *Natural Hazards and Disaster Response.* Routledge.

C.Guillén, & F.Techel. (2022). *Data-driven automated predictions of the avalanche danger level for dry-snow conditions in Switzerland.* Retrieved from Natural Hazards and Earth System Sciences: https://nhess.copernicus.org/articles/22/2031/2022/

Cesium. (Ongoing). *Open Geospatial Consortium (OGC). OGC 3D Tiles Specification.* Cesium.

Cesium, O. G. (Continuosly Updated). *CesiumJS and 3D Tiles (Open Standards for Web 3D Geospatial Data).* Cesium.

CIRIA. (2024). *Sustainable Drainage Systems (SuDS) Manual (C753).* Construction Industry Research and Information Association (CIRIA).

Cleaves, D. A., & Steiguer, J. E. (2009). *Wildland Fire Management: A Systems Approach.* Island Press.

Coduto, D. P., Yeung, R., & Kitch, W. A. (2011). *Geotechnical Engineering: Principles and Practices.* Pearson.

Congjian, H. (2013). *Introduction to Geographic Information Systems.* CRC Press.

Cornell & Chopra, C. A. (2014). *Infrastructure Resilience: A Handbook for Building More Resilient Communities.* Springer.

Creswell J.W. (2014). *Qualitative Inquiry & Research Design.* Sage Publications.

D.Bryde, & M.Broquets. (2017). *The project benefits of Building Information Modelling (BIM).* Retrieved from ELSEVIER: https://www.sciencedirect.com/science/article/abs/pii/S0263786312001779

D.Han, & B.Chae. (2017). *Landslide prediction, monitoring and early warning: a concise review of state-of-the-art.* Retrieved from Research Gate: https://www.researchgate.net/publication/321654509_Landslide_prediction_monitoring_and_early_warning_a_concise_review_of_state-of-the-art

D.McClung, & P.Schaerer. (2015). *Climate Change and Avalanches.* Retrieved from WSL Institute for Snow and Avalanche Research SLF: https://www.wsl.ch/en/about-wsl/locations/slf-davos/

David W. Metcalf & Eddy. (2014). *Environmental Engineering: Fundamentals, Sustainability, and Design.* McGraw-Hill Education.

Dominijanni, A. (2020). *Landslides and Engineered Slopes: From Research to Practice.* CRC Press.

Donald D. Evans & L.F. Thomas. (2013). *Landslides: Investigation and Mitigation.* John Wiley & Sons.

Erfanian, E., Ebrahimi, N. J., & Delavar, M. R. (2025). *Georeferencing Building Information Models for BIM/GIS Integration: A Review of Methods and Tools.*

Esri. (2025). *ArcGIS Pro Help: Create 3D maps.* Retrieved from Esri. ArcGIS Pro: https://pro.arcgis.com/en/pro-app/latest/help/mapping/map-basics/create-3d-maps.htm

Esri. (Continually Updated). *Autodesk Knowledge Network/Help Documentation for InfraWorks:.* Esri.

Esri. (Continuously Updated). *BIM data as ArcGIS Pro layers—ArcGIS Pro | Documentation.* Esri .

Esri, D. R. (Continuosly Updated). *Esri-Cesium Partnership and Interoperability.* Esri.

Esri, R. U. (Regularly Updated). *Georeference BIM data—ArcGIS Pro.* Esri.

Fell, R., & Hartford, D. (1997). *Risk Management.* Honolulu: Proceedings of the International Workshop on the Risk Assessment.

FEMA. (2004). *Dam Safety Inspection and Evaluation.* Federal Emergency Management Agency.

FEMA. (2012). *Guideline for Evaluating the Vulnerability of Buildings and Other Structures.* Washington, DC: Federal Emergency Management Agency.

Fink & Beaty, D. G. (2017). *Standard Handbook for Electrical Engineers, 17th Edition".* McGraw-Hill Education.

Flannigan, M. (2013). *Global Wildfire Hazards in a Changing Climate.* International Journal of Wildland Fire, 22(1), 1-14.

Forouzan, B. (2018). *Communication Networks: Fundamental Concepts and Key Architectures.* McGraw-Hill Education.

Fowkes, D. (2013). *Earthworks: A Guide to Planning, Design, and Construction.* ICE Publishing.

Géron, A. (2019). *Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow.* O'Reilly Media.

Goodchild, M. F. (2007). *GIS for the 21st Century.* Taylor & Francis.

Goodchild, M. F. (2007). *GIS for the 21st Century.* Taylor & Francis.

Hambley, A. R. (2014). *Electrical Engineering Principles and Applications.* Pearson.

Hibbeler, R. (2010). *Building Structures.* Pearson Prentice Hall.

I.Kim, & K.Jung. (2018). *BIM and Its Integration with Emerging Technologies.* Retrieved from MDPI Journals: https://www.mdpi.com/journal/applsci/special_issues/building_information_modeling

ICE & Institute Faculty of Actuaries. (2021). *Success by risk management: A risk glossary in the context of civil engineering projects.* England, Wales, and Scotland.

ICOLD. (2010). *Dam Safety: A Global Perspective.* International Commission on Large Dams.

Isikdag, U., & Zlatanova, S. (2019). *BIM and GIS Integration for Smart Cities.* Springer.

J.Bazargani, & M.Zafari. (2022). *A Survey of GIS and AR Integration: Applications.* Retrieved from MDPI Journals: https://www.mdpi.com/2071-1050/14/16/10134

J.W.Creswell. (2014). *Qualitative Inquiry & Research Design: Choosing Among Five Approaches.* Sage Publications.

J.Winczek. (2016). *BIM and LCA Integration: A Systematic Literature Review.* Retrieved from MDPI Journals: https://www.mdpi.com/2076-3417/7/1/6

Jain, S. (2012). *Early Warning Systems for Natural Disasters.* Springer.

Kreider, R. G., & Messner, J. I. (2013). *BIM Project Execution Planning Guide.* The Pennsylvania State University.

L.Wang, & D.Chan. (2024). *A-state-of-the-art review of risk management process of green building projects.* Retrieved from Research Gate: https://www.researchgate.net/publication/378397739_A-state-of-the-art_review_of_risk_management_process_of_green_building_projects

Lee, K.-P. (2010). *Web and Internet GIS: Principles and Applications.* ESRI Press.
Leopold, L. (1994). Floodplain Management: Ecologic, Economic, and Social Dimensions. *Island Press*.
Lichtenstein, S., & Newman, J. (1967). *Empirical Scaling of Common Verbal Phrases Associated with Numerical Probabilities.* Psychonometric Science.
Liu, Y., Tang, X., & Li, X. (2018). A Critical Review of the Integration of Geographic Information System and Building Information Modelling at the Data Level. *Journal of Geomatics and Information Science of Wuhan University*.
M. Halpern, S. (2018). *Hazard Analysis and Risk Assessment.* CRC Press.
M.Ashford, & R.Wiley. (2019). *Hazard Identification, Assessment, and Control in Chemical Plants.*
M.Coleman, & H.Marks. (2019). *A State-of-the-Art Review on Quantitative Risk Assessment Techniques for Engineering Systems.* Retrieved from ELSEVIER: https://www.sciencedirect.com/science/article/abs/pii/S0956713599000523
M.Hammond, & A.Chen. (2013). *Urban flood impact assessment: A state-of-the-art review.* Retrieved from Taylor and Francis, Urban Water Journal: https://www.tandfonline.com/doi/abs/10.1080/1573062X.2013.857421
M.Kannan. (2023). *Review of Landslide Research.* Retrieved from Research Gate: https://www.researchgate.net/publication/373020098_Review_of_Landslide_Research
M.Reza, & D.Ryu. (2020). *Enabled Flood Severity Prediction via Ensemble Machine Learning Models.* Retrieved from Research Gate: https://www.researchgate.net/publication/362431899_Flood_Prediction_Using_Machine_Learning_Models
M.Waleed, & S.Muhammad. (2023). *Cloud Computing for Geographic Information Science.* Retrieved from ELSEVIER: https://www.sciencedirect.com/science/article/abs/pii/S2212420923005368
Mª. Martínez, d. C. (2015). *Fenómenos naturales: origen, evolución y prevención.* Research Gate.
MacLeamy, P. (2015). *Interoperability in the Built Environment: Information Delivery in the Digital Age.* Routledge.
Mahler, C. F., & Varanda, E. (2012). *Analytical Model of Landslide Risk Using GIS.* Rio de Janeiro: Scientific Research.
Mays, L. W. (2010). *Water Supply Engineering: Design, Construction, and Operation".* John Wiley & Sons.
Mays, L. W. (2010). *Water Supply Engineering: Planning, Design, and Management.* John Wiley & Sons.
Mercalli & Cat Berro, L. &. (2005). *Climi, acque e ghiacciai tra Gran Paradiso e Canavese.* Collana.
Metcalf & Eddy. (2014). *Water Treatment Engineering.* McGraw-Hill Education.

Monteiro, N. P. (2022). *8D BIM Model in Urban Rehabilitation Projects: Enhanced Occupational Safety for Temporary Construction Works.* Multidisciplinary Digital Publishing Institute (MDPI).

Muller, R. A. (2016). *Natural Hazards and Disasters: An Introduction .* Springer.

N.Denzin, & Y.Lincoln. (2018). *The SAGE Handbook of Qualitative Research.* Sage Publications.

NWCG. (2018). *Wildland Fire Suppression: Principles and Practices.* National Wildfire Coordinating Group.

O.Inabi, & M.Attou. (2023). *GeoHazards | Special Issue : Landslide Research: State of the Art and Innovations.* Retrieved from mdpi: https://www.mdpi.com/2073-4441/15/13/2423

O.Madubuike, & C.Anunba. (2022). *Digital Twins for Life Cycle Management of Constructed Assets.* Retrieved from Research Gate: https://www.researchgate.net/publication/358805731_A_review_of_digital_twin_applications_in_construction

O'Brien, J. W., Fischer, M., & Sahraei, A. (2010). *Integrating Project Delivery.* John Wiley & Sons.

Osello, A. (2021). BIM and InfraBIM for built heritage. Torino: PoliTO.

P.Lagasse. (2023). *Here's how businesses can adapt to a changing risk landscape.* Retrieved from World Economic Forum: https://www.weforum.org/agenda/2023/01/the-holistic-approach-to-confronting-an-evolving-risk-landscape-a-case-study/

P.Pengju, & H.Jianjun. (2023). *Digital Design and Data Management System for Network APP Based on GIS Technology.* Retrieved from ELSEVIER: https://www.sciencedirect.com/science/article/pii/S1877050923019762

Patacas, J., Dawood, N., & Kassem, M. (2020). *Challenges in Implementation of 7D-BIM for Infrastructure Asset Management: A Systematic Review.* Australian Journal of Construction Economics and Building.

Paul A. Longley, M. F. (2010). *GIS Fundamentals: A First Text on Geographic Information Systems.* John Wiley & Sons.

Pellow, D. J. (2014). *Environmental Management: A Global Perspective.* Routledge.

Petley, D. (2012). *Geomorphological Hazards and Disaster Risk Reduction.* Wiley-Blackwell.

Piras, M. (2020). Laboratory of GIS and Geospatial Service for engineering Applications. Torino: PoliTO.

Pradhan, B. B. (2019). *Disaster Management: From Risk to Resilience.* Springer.

Pyo, K. (2019). *Web and Internet GIS: Principles and Applications .* ESRI Press.

Rajput, R. (2014). *Power Plant Engineering.* Laxmi Publications.

RICS. (2025). *BIM and the power of data in construction.* Royal Institution of Chartered Surveyors website.

Rogers, J. D. (2012). *Risk Assessment in Civil Engineering: A Practical Guide.* CRC Press.

Rossiter, C. A. (2014). *Resilient Infrastructure: A Guide to Post-Disaster Recovery and Reconstruction.* Routledge.

Russell, K. N. (2014). *Dam Failure: Lessons from History.* CRC Press.

S. Pahwa - S. Doolla & N. Amjady. (2010). *Assessing the Vulnerability of Electric Power Grids.* IEEE Transactions on Power Systems.
Saadat, H. (2010). *Electrical Power Systems.* McGraw-Hill Education.
Saunders & Fallon, D. A. (2019). *Environmental Impact Assessment: A Practical Guide.* Routledge.
Shen, C. (2018). *Machine Learning for Flood Forecasting.* Elsevier.
Skibniewski, M. J. (2014). *BIM and Integrated Design: Strategies for Achieving Design and Construction Integration.*
Smith & Pinto, R. C. (2018). *Construction Project Management.* McGraw-Hill.
Soustou, Y., Cherif, M., & El Hajjaji, A. (2020). *BIM and Life Cycle Assessment Integration for Sustainable Buildings: A Review.* Journal of Building Engineering.
T.Dev, & I.Yang. (2015). *Landslide hazard zonation using GIS: A case study from Sindhupalchowk, Nepal.* Retrieved from Research Gate: https://www.researchgate.net/publication/281687568_Landslide_hazard_zonation_using_GIS_A_case_study_from_Sindhupalchowk_Nepal
Tamea, S. (2021). *Laboratory of GIS and Geospatial Service for engineering Applications.* Torino: PoliTO.
Tao, F., & Zhang, M. (2019). *Digital Twin Driven Smart Manufacturing.* Academic Press.
Turconi, L. e. (2015). *Landscape analysis for multi-hazard prevention in Orco and Soana valleys, North-Western Italy.* Torino: Copernicus Publications.
V.Kumar, & H.Azamathulla. (2020). *The State of the Art in Deep Learning Applications, Challenges, and Future Prospects*. Retrieved from https://www.mdpi.com/2071-1050/15/13/10543
V.Sharma, & S.Kumar. (2019). *A neural network model for automated prediction of avalanche danger level.* Retrieved from Natural Hazards and Earth Systems Sciencies: https://nhess.copernicus.org/articles/23/2523/2023/nhess-23-2523-2023.pdf
Van der Tak & Aerts, J. &. (2013). *Flood Risk Management: Challenges and Opportunities.* Springer.
Wiesner, W. J. (2014). *Construction Safety and Health.* McGraw-Hill Education.
William, L., & Waugh, J. (2013). *Emergency Management: Principles and Practice for Local Governments.* ICMA.
Zanchetta, G. (2021). Urban Stormwater Management. *CRC Press*.

9. Appendix

- Dams

BDTRE (Base Dati Territoriale di Riferimento degli Enti piemontesi) - Diga (Dams) or The Territorial Reference Database of Piedmontese Institutions for its acronym in the Italian language, to identify the dams present in the Orco Valley, which describes the hydraulic works that have a water defense function and the hydraulic regulation structures. Meta documentation available on the Geoportale Piemonte. Below is an image related to the information found.

Figure 55. Infrastructure – Dams
Source: Geoportale Piemonte

- Aqueduct

The Metropolitan Water Company of Turin proposes the aqueduct in the orco valley, approximately 150 km long that carry water from the Bardoneto hydroelectric power plant to the water purification plant in the municipality of Locana and will feed the municipal aqueducts of the Orco Valley and the Medio-Alto Canavese. Meta documentation available on Ministry of Environment and Energy Security.

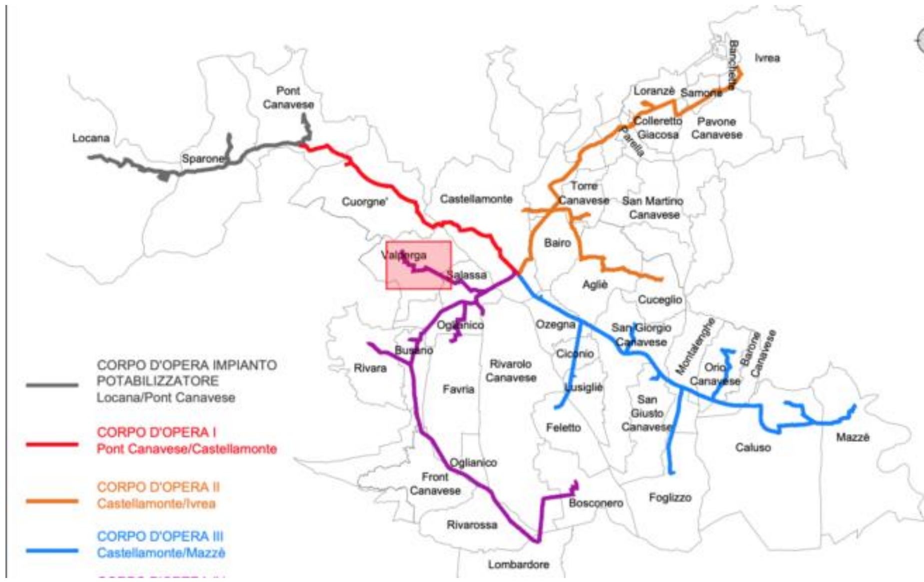


Figure 56. Infrastructure - Aqueduct
Source: https://va.mite.gov.it/it-IT/Oggetti/Info/1732

- Hydropower plants

The data, which is precise, includes the hubs and systems of proto-industry, the industrial production systems of the nineteenth and twentieth centuries, the mining areas of ancient and medieval times, the mining areas of modern and contemporary times, the infrastructures for the production of hydroelectric energy of historical and documentary value. Meta documentation available on the Geoportale Piemonte. Below is an image related to the information found.

Figure 57. Infrastructure - Hydropower Plants
Source: Geoportale Piemonte

- Electrical transformer cabinets

BDTRE (Base Dati Territoriale di Riferimento degli Enti piemontesi) - Nodo della rete elettrica (ND_ELE) or The Territorial Reference Database of Piedmontese Institutions for its acronym in the Italian language, to identify the Electrical transformer cabinets present in the Orco Valley, which includes both the electricity distribution network, made up of power lines at various voltages, and the electricity services network, relating to all those elements that are normally part of urbanized areas that allow public lighting and other similar services, functioning by means of electricity and therefore connected to the corresponding network. Meta documentation available on the Geoportale Piemonte. Below is an image related to the information found.

Figure 58. Infrastructure - Electrical transformer cabinets
Source: Geoportale Piemonte

- Electric distribution networks

BDTRE (Base Dati Territoriale di Riferimento degli Enti piemontesi) – Reti di sottoservizi, or The Territorial Reference Database of Piedmontese Institutions for its acronym in the Italian language, to identify the Electric distribution networks present in the Orco Valley, which groups together all the technological networks properly speaking, while the related artefacts, belong to the Artefacts layer. Meta documentation available on the Geoportale Piemonte. Below is an image related to the information found.

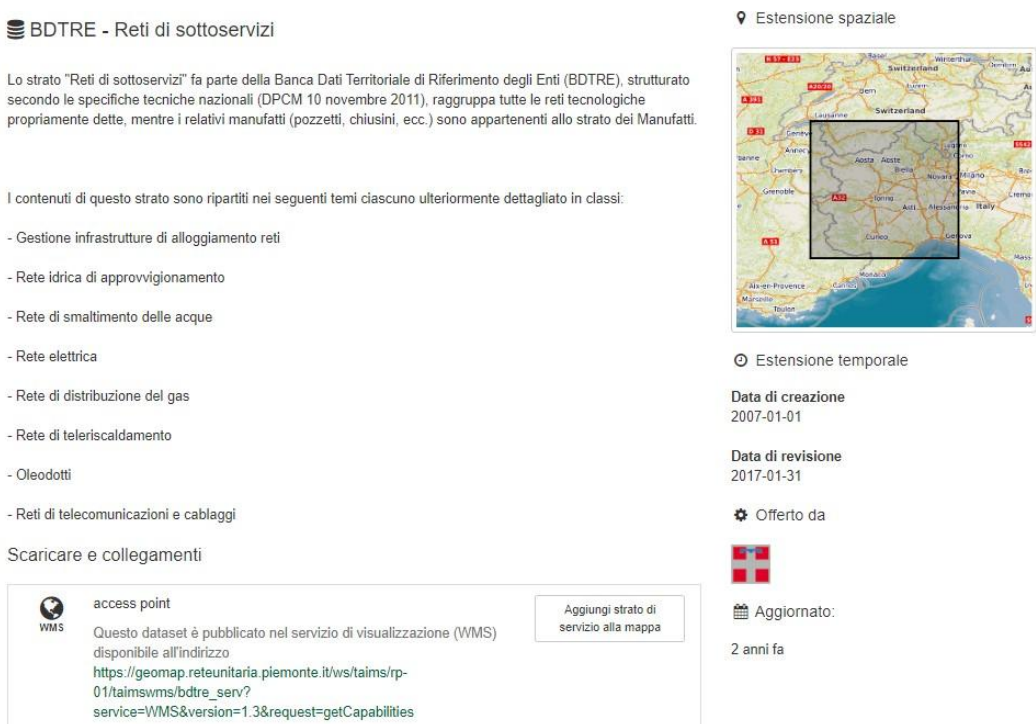


Figure 59. Infrastructure - Electric distribution networks
Source: Geoportale Piemonte