POLITECNICO DI TORINO

Degree course
of Environmental Engineering
for Climate Change

Master degree thesis

Alpine glaciers retreat and high-altitude mountain huts: a water supply risk analysis

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Abstract

Climate change in the Alps is associated to several impacts, such as the evolution of high-altitude environments and glaciers retreat. Some studies highlight the complex connections between water availability, natural hazard, tourism perception and mountain huts adaptation: a comprehensive understanding of climate-related impacts is the first step for drafting future scenarios.

In this thesis, a database is built considering high-altitude Italian alpine huts which offer freshwater access to visitors, collecting main features and mapping their location. Then the alpine glaciers position and retreat data are analyzed, producing a map to confront the glaciers retreat with the huts positions, identifying cases potentially exposed to climate impact.

Finally, a risk analysis related to water supply is performed, introducing an indicator that takes into account the distance to the glaciers, the ice loss rate and the dimension of the huts. Results indicate that some huts are exposed to a maximum risk and interviews have been performed with some of them, expanding the complexity of water supply evaluation. The management staff confirmed the climatic variations of the high-mountain environment and the adoption of some adaptation strategies, although disagreeing on the level of risk that has been computed. The indicator points, in fact, more to a long-term risk than to a short-term one, mostly because in the short term a (temporary) increase in water availability is enabled by glacier melting.

Preface

The climatic variations are becoming a global issue, several countries in the world have already experienced crisis related to water, such as droughts and floods, the Conference of Parties presented by UNFCCC are more attended then last years and the necessity to face the climatic emergency influences the political stability of countries, affects the economical relationships and has the attention of the whole society.

A unite and comprehensive evaluation of the territory of the Alps is chosen, highlighting the importance of water supply and presenting the value of mountain huts activities, in order to enable the audience sensitivity and provide a consistent study about the actual but fragile situation over the Italian Alpine chain.

This study is consistent with the teaching pathway of the master degree course of environmental engineering for climate change and with the internship which have been attended at the CNR IRSA institute of Verbania: these three didactic choices support a future career deepening about the topic of the effects of climate change on water, underlining how these variations affects environment and human activities.

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1. LITERATURE REVIEW

1.1 CRYOSPHERE MONITORING AND CC OVERVIEW

1.1.1 World climate change on mountain environments

According to multiple studies presented in the last decades, the ice glaciers are both very sensitive elements which are strongly affected by climate changes and a proof that the effects of human activity on climate can’t be denied nor neglected. The processes which occur globally on ice-covered mountain regions show a pattern of modifications which can be explained only through a consistent global approach: the atmosphere warming related to the greenhouse effect damages the permafrost surfaces and makes great quantities of ice to melt, causing the glaciers to retreat and leading to an increasing occurrence of natural hazards such as surface displacements, rock detachments, rockfalls, avalanches, changing the availability of itineraries and limiting the accessibility of huts and refuges. Furthermore, a sudden variation in the yearly distribution of precipitations leads to water resource scarcity and ecosystems severe deperishment: understanding the altitude variation of temperature and precipitation is the first step to evaluate the modifications related to the hydrological cycle and the trends of freshwater precipitation, storage as ice/snow or as basins, groundwater replenishment and resource availability.

A preliminary analysis of the global variations involving glaciers and climate change on a global scale is presented by Pepin et al. (2021), combining temperature and precipitation data of the last century and evaluating how the elevation could be related to them (EDW: Elevation-dependent warming).

Results show how recent records express a increasing temperature trend respect to older ones, suggesting an acceleration in the last decades of the century, in particular after 1980, but without a substantial higher trend in high altitude warming, due to the higher variability among the regions; instead, comparing the data within the same region, it appears that the higher altitude areas have experienced a more enhanced warming then the correspondent lowlands and on a global scale the average temperature appears to be a more critical variable then elevation itself. According to this study, the global scale suggests a minor global elevation dependency of warming and precipitation; the limitation of the chosen area of interest is clear, the great differences among all the regions of the world make a global analysis less effective in terms of generating adaptation and mitigation strategies.

1.1.2 European cryosphere

Regarding the European territory, the changes on the cryosphere involving the effects of climate changes appear to have important consequences on the environment and the human activity of the region: for instance, the access to seasonal water resources is not as granted as in the past. The snowline and the treeline are shifting toward higher altitudes, the snow season is shorter, the snow thickness and duration are decreasing, the glaciers are melting and retiring, causing an increasing occurrence of dangerous events and a general ground instability. The sensitivity of the snow and ice regions is expressed in the rapidity of the changes that can already be experienced, causing several and urgent variations downstream, at low altitudes, related to agricultural, touristic, hydropower, forestry, ecological and human necessity sectors.

A more distributed monitoring program on the European cryosphere region is therefore necessary, combining the new collected data with the historical ones and use them to generate reliable scenarios; Beniston et al. (2018) proposed a general overview of the current situation in this region related to glaciers, snow and permafrost variations until now.

The snow, for instance, plays a critical role in high altitude climate variability, involving the reflected solar radiation, the meltwater seasonal generation and the thermal regulation of the ground: the snow cover uncertainty is therefore a very difficult step to overcome; in particular, as shows in figure *1*, the snow depth time comparison shows a negative trend all over the alpine chain due to a general higher temperature during winter and spring seasons, enhancing the liquid precipitation and snowmelt (figure *2*).

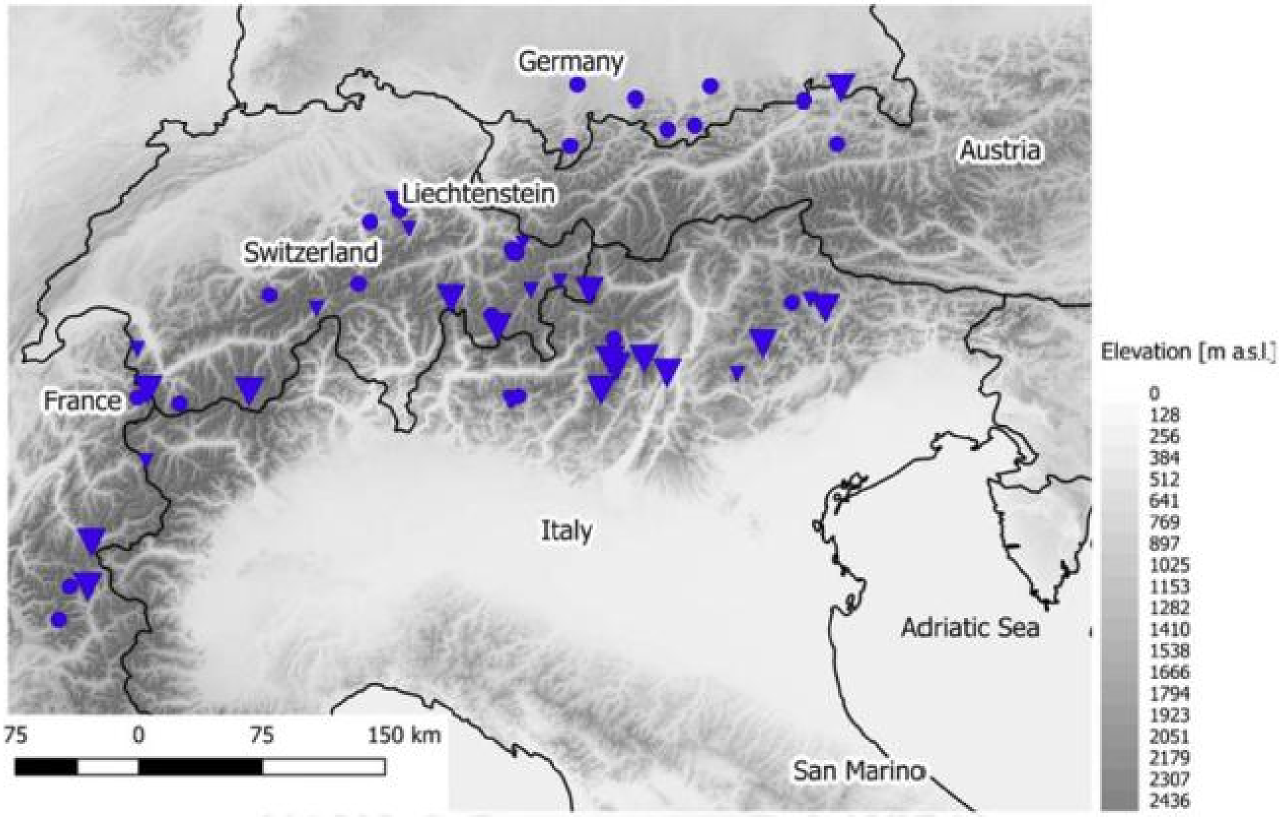


Figure 1 Geographical distribution of the 45-year trend (1968–2012) for 1 April snow water equivalent (SWE) in the Alps. (Adapted from Marty et al., 2017b.) (Beniston et al. 2018)

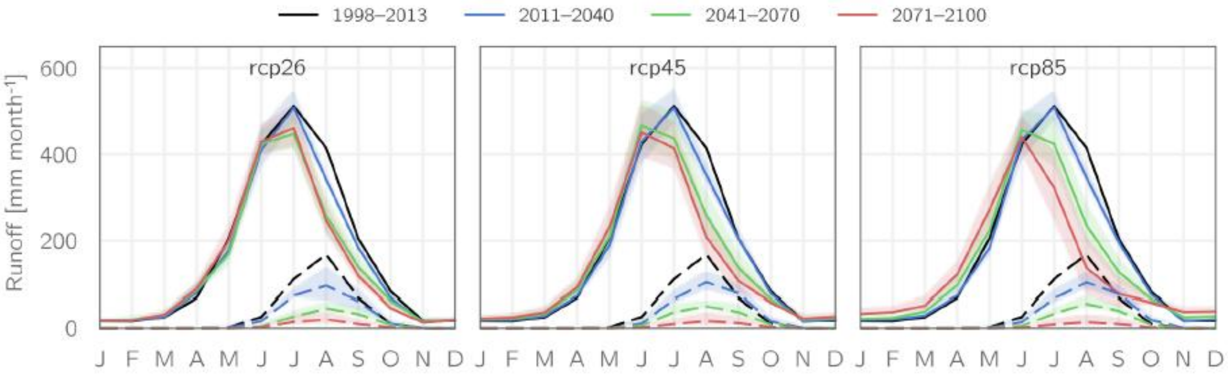


Figure 2 shifts of streamflow regimes for the Rofenache, projections for the RCP2.6, RCP4.5 and RCP8.5 scenarios

Regarding future snow cover projections, the data are very uncertain and very scenario-dependent, such as avalanches predictions for the next decades, even if the frequency trend is expected to increase; in particular, "Due to the highly nonlinear nature of avalanche triggering response to snow and weather inputs and to the complex relations between temperature, snow amounts, and avalanche dynamics, it remains unclear whether warmer temperatures will indeed lead to fewer avalanches because of less snow." (Beniston et al., 2018).

European glaciers have lost great quantities of ice too, the substantial decrease in depth, cover surface and volume has been detected since the end of 1800, with an increasing trend of mass loss (as shown in figure *3*), with a great expected volume loss for the future years, up to 90% for the Alps glaciers in 2100.

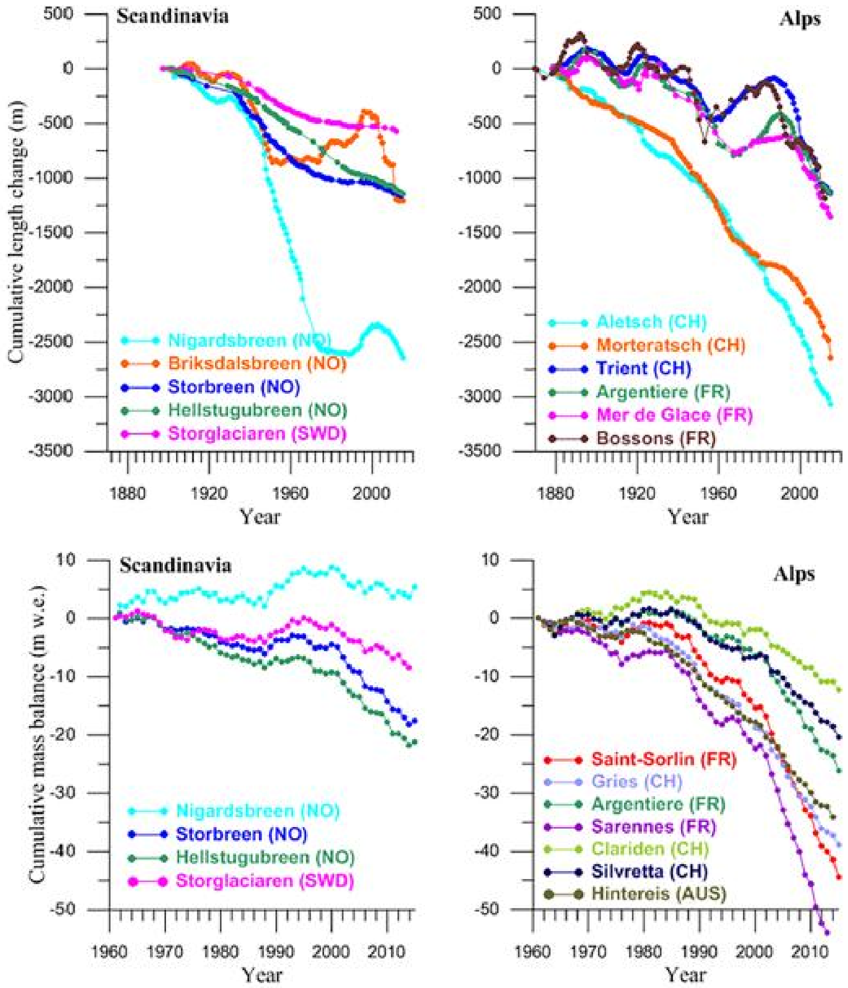


Figure 3 *Length and surface mass balance changes documented with in situ measurements for glaciers in Scandinavia and in the European Alps. (Beniston et al., 2018)*

1.1.3 Alpine climate change overview (21st century) and predictions reliability

The future climate projections also involve predictions about natural hazards such as rockfall and avalanches activity, but also precipitation extremes and flood potential; the recorded temperature increase rate on the Alps doubles the boreal hemisphere average, with a peak enhance from 1980.

Several predictions for the period 2020-2100 have been generated, including the temperature increase over space, the change in expected precipitation, humidity, global radiation (Gobiet et al., 2014): the results, as expected, show a substantial increase in temperature over the alpine region, during all the months of the year, with a higher rate at the end of the century.

Regarding the precipitations, a great decrease pattern has already been experienced, especially in summer, while they are expected to grow in winter in the last decades before 2100 (see figure *4*).

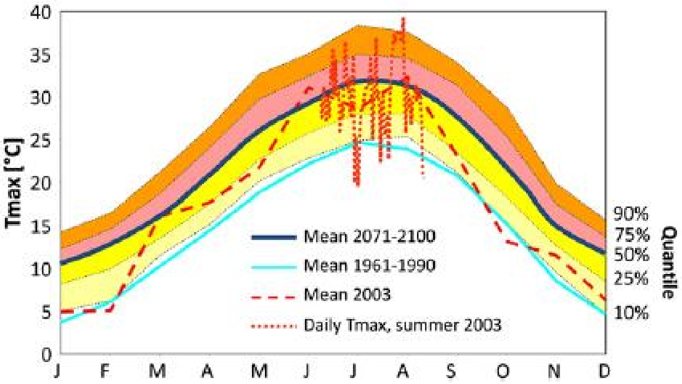


Figure 4 Future (2071–2100) monthly-mean daily maximum temperatures (Tmax) for Basel, Switzerland (mean and quantiles of the RCM ensemble). (Gobiet et al., 2014)

“Heavy precipitation events possess the potential to cause natural disasters and serious damage to infrastructure facilities. Subsequently such events can imply vast societal, economic and environmental impact. In this respect and with anticipated climate change, there is particular interest in the future behaviour of precipitation extremes.” (Gobiet et al., 2014). Understanding the intensity and the occurrence of them is a key-step to assess the correct adaptation strategies to limit and prevent the damages caused by floods, avalanches and other natural disasters.

A projection based on 10 regional climate simulation was generated, showing the precipitation events on the Alps at seasonal scale and, for the extreme precipitation events, a decrease in the return period is expected, that is their size and frequency is going to increase, typically during winter and spring.

On the other hand, the frequency and the duration of droughts are going to increase too, affecting the capacity of the agricultural and forestry sector, reducing the freshwater availability in basins and groundwater, limiting the hydropower potential which is widely distributed on the alpine chain; the consequences are going to get worse due to higher evapotranspiration caused by increased temperatures and higher water demand.

The snow depth is going to decrease too, as said above, with great consequences on the reflected radiation, the thermal equilibrium of the ground and the hydrological mountain cycle; also for this parameter a prevision has been generated (shown in figure *5*), expressing a substantial decrease caused by higher temperatures.

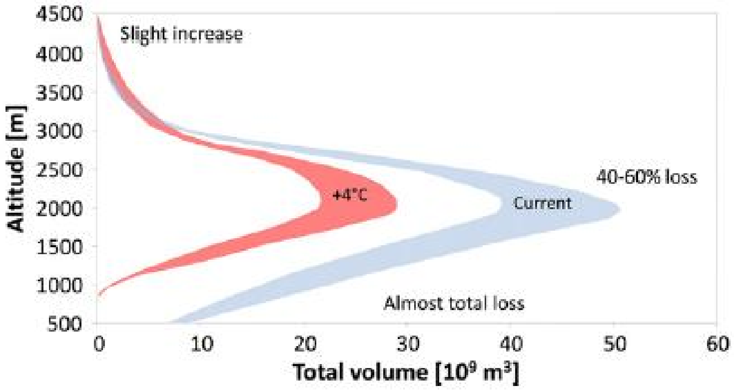


Figure 5 Snow volume under current climate and a possible future climate with winters 4 °C warmer than today (Gobiet et al., 2014)

1.1.4 Presence of black carbon aerosol affects the rapid glacial retreat.

The concentration of heavy aerosols in the atmosphere appears to have a connection with the effects of climate change in the alpine environment, especially regarding the black carbon, which is emitted since half of 19th century. The deposition of this aerosol on the snowpack of the Alps is a concerning driver of a higher absorbed radiation and therefore of the retreat of glacier, due to its high light absorption per unit mass and the albedo reduction.

The sources of BC can be natural, such as wildfires, but its concentration in the atmosphere is mainly related to fossil fuels combustion: through the extraction and analysis of alpine ice cores, Sigl et al. (2018) proposed a study about the deposition quantity of BC through 270 years of time over the Colle Gnifetti area obtaining evidence of the presence of the aerosol due to production and transport activity.

The results were compared with the detected rapid glacier retreat in 19th century, underlining that the enhanced concentration of BC occurred later then the acceleration of ice melt of that period, suggesting a lower agreement about the correlation between higher heavy aerosol emissions and glacial retreat. Nevertheless, the effects of the presence of carbon aerosol on snowpack and alpine ice are undeniable.

1.1.5 Ice loss prediction for one specific glacier (Switzerland)

Focusing on the alpine glaciers, a correct monitoring of the state of the ice cover surface, the stability conditions and volume losses are necessary; it's difficult to have a complete state of conditions of the entire alpine chain with a sufficient timeframe of record, therefore a selection must be applied.

There are several strategies that can be considered, including giving priority to most damaged glaciers or to areas with the highest temperature mean or the highest warming rate, the highest detected terrain instability or the highest volume loss.

For instance, Jouvet and Huss (2019) presented a monitoring study of one of the largest glacier of Europe, in the Swiss Alps, the Great Aletsch Glacier, with the aim to model its future evolution combining the ice volume loss rate with the climate prevision scenarios.

The results show a huge variation for the end of the century, with a 60% ice wastage for a mid-range GHG emissions scenario to a complete loss for the RCP 8.5 scenario.

Moreover, considering the temperature data of the past, the Great Aletsch Glacier would reach a steady-state after 100-150 years, showing the great inertia due to its high dimension: this suggests also that the present GHG emissions will affect the mountain glaciers for the next decades or even centuries, regardless of the global choices in terms of emissions and fossil fuels combustion.

1.1.6 Evaluation of a satellite monitoring method for a single glacier (Italy, Poli Glacier Lab)

Another example of alpine monitoring program, focusing on a single glacier, has been brought by the Glacier Lab of the Politecnico di Torino, related to Belvedere Glacier (Italian Alps); a monitoring program is used as a starting point and, generating a 3D digital terrain model (DTM), the possibility of a multitemporal comparison of surface variation and ice loss is available (Tonolo et al., 2020).

The aim of the study is therefore to understand whether a new monitoring analysis, based on a high-resolution satellite optical stereo, can be reliable for glacial monitoring.

As outcome, the UAV satellite technique can be chosen as a good monitoring strategy for glaciers, overcoming aerial surveys limitations. New monitoring technologies must improve in order to reach a higher knowledge of the high mountain environments, where physical (and sometimes even aerial) surveys are difficult and dangerous, with the possibility to apply old technologies used for other purposes (such as the SHERPA project (Marconi et al., 2012)).

1.1.7 Greening trends on the Alps

A quite important effect which can be easily detected on the Alps is a general greening trend and an enhancement of vegetation growth, the snowline and the treeline uplift changing the ecosystems equilibrium and forcing animal and vegetal species to move their habitats.

Filippa et al. (2019) presented a study relating to the greening trends on the Western Alps, the rates and the spatial patterns that can be observed through the different species; in the first 20 years of the 21st century, for instance, over 60% of vegetated lands have experienced a substantial trend and for high altitude the positive greening acted in both summer and autumn.

The greening trends (positive or negative) can also be caused by other factors, such as single natural events such as avalanches, rockfalls and weathering, but also by human land-use interventions.

The conversion from ice surfaces to vegetated ones, caused by ice melting, bedrock appearance and active layer formation, it’s a critical step for the mountain climate conditions due to the albedo effect: less ice and more vegetation, which can absorb a substantial portion of solar radiation, means a very lower albedo component and, therefore, an enhanced warming.

As a final remark, the NDVI expression of the high-resolution satellite data, as mentioned before, can be a useful instrument for glacier monitoring, combining the conditions of glaciers with a prevision of occurrence of natural hazards and extreme events.

1.2 PARAGLACIAL PROCESSES: ROCKFALL OCCURRENCE INCREASE AND PERMAFROST DEGRADATION

1.2.1 Rockfall monitoring on the Austrian Alps

The high mountain environment is taken into account, due to the correlation to the paraglacial processes (for instance, the alternate stress of glaciation and deglaciation on the rock fractures) which are the main responsible for the rockfall activity, showing how the average temperature is increasing in these areas, the ice thickness is rapidly reducing and the permafrost surfaces are degrading, leading to an altered ground thermal conditions and to a higher slope stress.

Hartmeyer et al. (2020) published an inventory of the paraglacial mass material for the Kitzsteinhorn area (Austria) (which however can not be considered consistent with other areas of the European Alps due to its high site specificity) and a topographic representation of the elevation change of a glacial area, expressing the ice loss in time comparing airborne laser scanning and UAV photogrammetric images. This analysis could be a useful approach for the whole Alps chain and it’s the starting point to evaluate the increasing risk involving the environment above 2000 meters high.

Even though the collected data, as said above, are site specific and cannot be applied to further step of areas risk assessment, the showed elevation change of the glacier expresses the necessity to consider how the high mountain environments are evolving and how rapidly the ice volume is melting; furthermore, a complete overview of Alps ice loss could lead to more sensitive and consistent national and international policies.

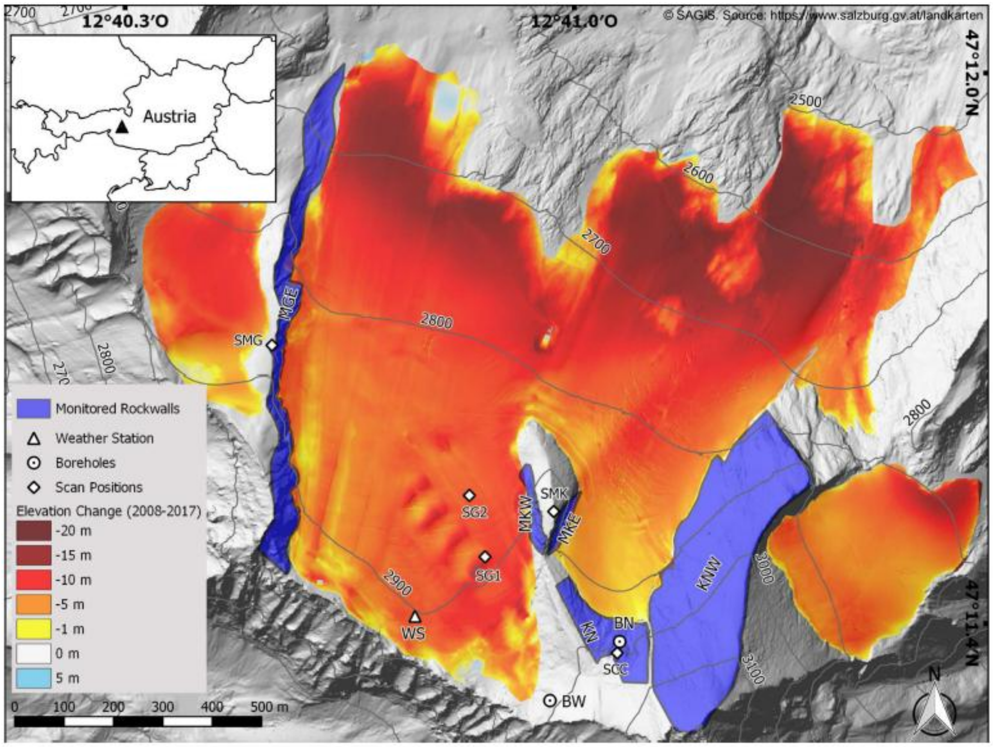


Figure 6 Hillshade of study area with monitored rockwalls, scan positions and elevation changes of the surface of the Schmiedingerkees glacier between 2008 and 2017 (Hartmeyer et al. (2020))

Moreover, the analysis of the results of the inventory confirms that the rockfall occurrence concentrates along pre-existing instability joints and weaknesses, it confirms that the greatest activity is related to the paraglacial environment and the seasonal temperature variations lead to thermal stresses, the formation of an active layer and a consequent destabilization of the glacier-proximal area.

1.2.2 Permafrost degradation and structures vulnerability assessment

Permafrost degradation typically causes critical destabilisation of the structures built in high mountain areas, such as huts, refuges and bivouacs, which are also endangered by the rockfall activity and the water scarcity for human activity and hydropower production. The tourism activity is widely present through the European Alps, then the consequences brought as effects of the climate changes involve both the pathways and the structures related to this economic sector, such as communication systems and hydropower structures.

Advancing a precise and complete risk assessment for high mountain environments also involves prevention systems, related to extreme and single events (flash floods, large rock detachments, avalanches), taking into consideration collected data about glaciers retreat, permafrost degradation, terrain instability and movements and merging them with climate change projections (temperature increase and precipitation quantity and yearly distribution).

On the other hand, the vulnerability and the exposure of the infrastructures must be considered and the identification of the most exposed and vulnerable structures allows to apply adaptation and mitigation strategies; Ruvillard et al. (2021) proposed an inventory of exposed infrastructures built on permafrost in the French Alps area, involving the strategies to prevent the damages or face the terrain destabilisation: the inventory is compared with the available Alpine Permafrost Index Map and the structures are ranked in terms of hazard characteristics (terrain susceptibility to processes related to permafrost degradation) and structural vulnerability.

The hazard characterisation shows passive and active factors, while the structures vulnerability is expressed through levels from I to IV; then, the combination of the parameters allows to classify the structures depending on the level of risk, from ‘low’ to ‘very high’.

Obtaining a ranked list of the shelters and refuges is not the final objective though; therefore, the most-at-risk structures are compared with adaptation and mitigation strategies applied by local stakeholders, distinguished into ‘Proactive strategies’, which act reducing the heat transfer through the permafrost surface, and the ‘Reactive strategies’, which instead involve foundation reinforcements. Among all the selected sites, these last types of strategies were the most chosen by stakeholders.

1.2.3 Surface displacement and vegetal indicators

Furthermore, the prediction of surface displacement has been studied using several approaches, such as the evaluation of the Ground Heating Index (GHI) and how the vegetal species shift their habitat due to the parameter variations, as said above regarding the greening trends; the aim of the study of Ponti et al. (2020) was to consider the presence of florist vegetal indicators as correlated elements of permafrost degradation and, therefore, of increased terrain instability.

Combining DEM and vegetation maps of the study area (Stelvio Pass), the results confirmed that slope and GHI are the most important factors for surface displacement due to permafrost degradation, highlighting higher values for lower altitudes.

1.3 HOW THE CLIMATE CHANGES ARE AFFECTING THE MOUNTAIN ITINERARIES

The consequences of glaciers retreat on the European Alps have been detailed before, introducing here a specific focus on the changes involving the mountaineering and hiking itineraries, considering the damages to the pathways due to the instability of the terrain or the increase occurrence of natural hazards.

Among the several modification of the high mountain environment on the Alps, which can be distinguished as temporary, seasonal and permanent, the high altitude pathways, routes and itineraries are strongly affected by the effect of climate change, as the increasing temperature and the change on seasonal meteoric precipitation cause glacier shrinkage and retreat, such as permafrost degradation, making many areas instable and not viable for high altitude experiences; in particular, the environment above 2000 meters high is taken into consideration, where the paraglacial processes occur, the ice of glaciers melts and the slopes are endangered by debris detachments, falls and moraines fragmentation.

The statistical increase of natural hazards such as rockfall and landslide events, which have been correlated to the loss of ice volume of alpine glaciers, affect the possibility to access lots of areas along the glaciers, damaging or covering the pathways with debris, such as representing a constant danger due to the high frequency of rockfall or the higher instability of the layers due to the loss of ice thickness.

Considering the mountaineering itineraries, many of which have been set upon the glacier surface, some have been totally covered by debris and rock materials, while others have been affected and the climbing parameters change from year to year. This issue leads to an increase in technical difficulties in climbing and reduces the possibility use these routes to short periods along the year as long as be in sufficient safety conditions.

Moreover, these processes modify also the accessibility to refuges and huts which are involved in the increasing risk link the rockfall safety and structural stability, such as to the viability condition of the trekking or climbing pathways used to reach them: if the high-altitude processes caused by glacier retreat and permafrost degradation affect the itineraries, it could lead also to total isolation for private huts, guarded shelter and bivouacs.

The geomorphological processes which affect the trekking and mountaineering pathways have been identified thanks to studies over different areas of European Alps (Ritter et al., 2011, Austrian Alps, *22 processes*; Purdie and Kerr (2018), Mourey et al. (2019a), Mont Blanc Massif, *25 processes*), evaluating their occurrence and the percentage of the routes that have become more dangerous.

“On average, each of the 95 itineraries studied is affected by nine different processes such as rockfall, glacier slope angle increase, ice apron retreat, appearance of smooth slabs of bedrock or serac fall. […] As a result, 36% of the itineraries have become more dangerous and difficult and are unclimbable during certain periods of the year, […] while 27% are no longer climbable in summer, as the processes affecting them lead to an excessive level of danger and/or technical difficulty. Finally, 3% of the itineraries have already disappeared, either due to glacial retreat or rockfalls." (Mourey et al., 2022).

The safety and conditions of routes and itineraries firstly depend on the frequency of occurrence of dangerous events, assessing their increasing risk related to the natural hazards caused by glaciers retreat and permafrost degradation, as said above; in particular, the lateral side of glacier are more likely to be subjected to debris fall events, while the upper part of ice, subsiding, uncover jointed and unstable rock masses (Ritter, Fiebig et al., 2011).

These events then can be distinguished in single events or quasi-continuous events, which have both an important effect involving the mountaineering and trekking pathways, but with different consequences such as high risk for hikers safety as the first and damages to the routes conditions as the second.

Regarding the accessibility of the terrain, some of the processes described above modify the terrain without increasing the risk or involving people safety: the areas in which the ice is absent are subject to changes with a slower pitch, but, on the contrary, the ice surfaces change rapidly and they are more sensitive to seasonal temperature peaks and precipitation scarcity; moreover, single extreme precipitation events could trigger great rock and ice detachments and slides.

Finally, the most occurring process (in the Austrian Alps study) is the glacier retreat and the uncover of the bedrock, which occur in the 94% of the chosen cases and it’s also the most frequent process related to huts and refuges access limitations; it’s due to remember, then, that dangerous natural hazards can cause more damages or abandonments caused by high correlated risk.

Even though these studies are applied on the Austrian and Swiss Alps, their reliability is substantial even for the Italian Alps, due to the generality of the consequences of glaciers melt and retreat, and their applicability is sustained by the authors too. Finally, a scheme of the occurring processes is shown in figure *7*.

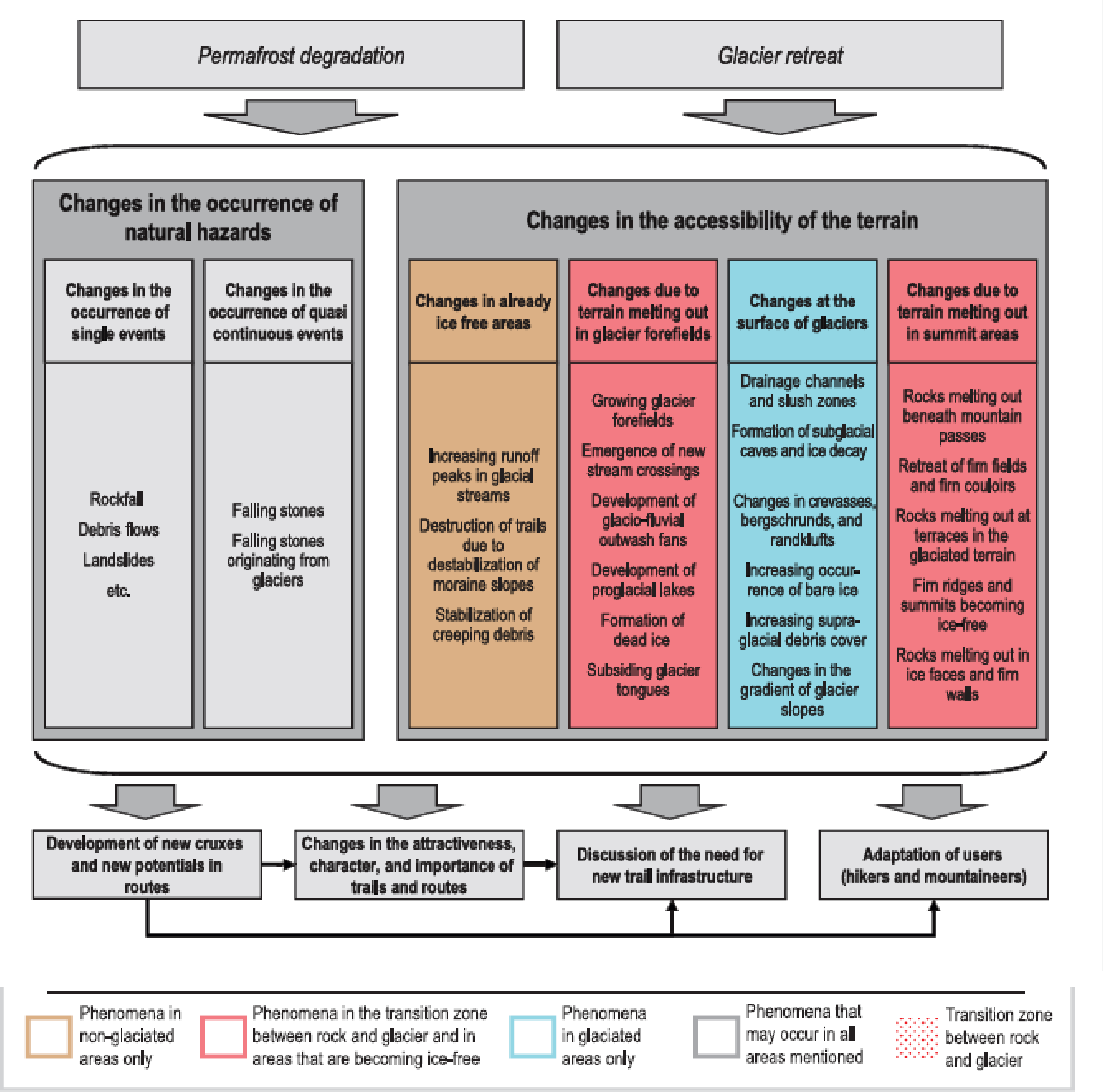


Figure 7 *Overview of phenomena and the resulting changes affecting the high Alpine route and trail network. (Ritter, Fiebig et al., 2011)*

1.4 MOUNTAIN HUTS ENERGY ASSESSMENT

1.4.1 Towards sustainable mountain huts

Mori et al. (2019) presented a study to compare different technologies related to energy supply in high altitude environment and huts management to identify the best ones in terms of low environmental impacts, supported by the 'EU SustainHuts Project'.

A Life Cycle Assessment method (LCA) has been chosen to address the impacts of different energy production technologies, considering all the differences among them.

"A mountain hut is an isolated construction in the mountains, where not only the access to utilities is complicated, but it's also difficult to transport anything to the hut. […] electricity and heat are needed as two main energy sources that provide comfort and are needed for basic operation. Nowadays systems providing energy are mainly fossil fuel-based. In addition, fuel needed for the operation must be transported to the hut that additionally impact environment due to truck, car, ropeway or helicopter use." (Mori et al., 2019)

It's quite obvious that renewable resources allow to produce energy with almost zero GHG emissions, but it's not always easy to install renewable technologies such as solar panels (for both electricity and heat production), hydropower plants or wind turbines, depending on the type of environment which the huts is located in, the typology of terrain, the energy demand and the seasonality of usage.

All the physical elements of these structures have also to be transported near the hut, therefore involving trucks, ropeways or helicopters; moreover, the installation of these energy production systems must take into account their average lifetime, cost, maintenance necessity, available surface, sun exposure.

The more difficult characteristics of RER to be faced is that they are not dispatchable: a solar panel produces electricity or hot water only when exposed to solar radiation, wind turbines are strongly dependent on air-motion through the area and hydropower plant and dams need a surface water flow, enough territory to fill a water basin and this RER is affected by irregular climate and seasonality too.

Even if a high-altitude hut can be improved in terms of sustainable energy production, the renewable energy is unlikely to be able to cover the whole energy demand through all the year and all day; this issue could be solved with a sufficient energy accumulation system, but the cost and the production environmental impacts would make this choice the least sustainable one.

Finally, the LCA assessment allows to consider even different system which the environmental impacts are generated to: for instance, covering the electricity and heat baseload demand with wood combustion produces less GHG emissions then fossil fuels combustion (therefore it causes less global impacts), but it has a stronger local impact due to the substances emission in the air which affect water and human health.

By now, each mountain hut manager must take into account all these factors and combine them with the strong and urgent necessity to move towards a more sustainable approach, for the local and global climatic, economic and social benefits.

The LCA assessment has been applied to 10 mountain huts located in four nations (Italy, Slovenia, France and Spain), taking into account all the different combinations of electricity and heat production technologies, transport modalities and impacts methodology used, how they improved their management which changes have been applied.

The results showed that diesel generators have the highest impacts considering all criteria for both electricity and heat production, while regarding RER hydroelectric and wind plants are the best options in terms of low impacts and they are better than solar panels. For heat production, the best solution is a mixed combination.

Methane combustion is less sustainable than wood combustion in a global view but can be a better choice if the local indicators suggest it. Considering the transport system, the helicopter is the most impacting way to address the material supply, but it’s a necessary choice in some situations.

1.4.2 Mountain huts environmental impacts

The impacts of the huts are then taken into account by Bobovnik (2014) on a Slovenian high mountain range, for instance underlining four categories of environmental issues related to the structures: firstly, the supply management, which could involve a substantial quantity of energy and resources, depending on the typology of hut and the supply transport choices (e.g. cargo lift, horses, helicopters). Then, the treatment and transport of waste is a useful sector in which the management can be improved, reducing the quantity of produced waste and evaluate potential treatment strategies.

The electricity and heat production plays a key role considering the huts sustainability, the old fuel combustion systems produce great quantities of greenhouse gases and air pollution, while installing solar panels (for both heating the water and electricity production) and wind turbines must be the direction which all the structures should move towards, but for many structures wood combustion for heating is still the predominant choice.

The usage and treatment of water is then one of the most concerning topics, involving the water scarcity due to the seasonal variations caused by climate changes, therefore the quantity of used water must be reduced, especially for toilets and showers. The wastewater, then, must be treated before re-entering the water system in superficial basins or groundwater, limiting the effects of pollutants in the area.

Finally, the quantity and the behaviour of the visitors can be affected too and the people moving through the high mountain areas can be educated and must become sensitive to their own impacts.

1.4.3 Energy supply of high-altitude users

In particular, the difficulties related to material, resources and energy supply can be higher in the case of high-altitude isolated users (‘Energy supplying of high-altitude isolated users’, Alberti), considering the occurrence of harsh weather conditions and the seasonal use of many refuges and guarded shelters.

The distance between the activity structure and the urban facilities leads to a more convenient, and sometimes even necessary, application of renewable energy, which is available locally without the need to transport fuels nor electrical wires nets.

The energy demand obviously depends on the typology of the structures, starting from holiday huts, which are typically related to low energy need due to the low number of facilities, to alp farms, where the milking and animal husbandry devices must be considered, and to refuges, guarded shelters and mountain huts with a high number of beds and therefore a higher energy consumption.

Considering the different RERs, each structure has high specific characteristics in terms of location, type of terrain, sun exposure, surface availability and necessary energy power, so a cost-benefits analysis shall be performed for every activity structure.

The solar energy, for instance, can cover the whole energy demand in the case of a holiday hut attended only during the summer period, while it's not sufficient for bigger facilities: in that case, the number of panels and accumulators could be an investment not easy to overcome, in terms of both surface and cost, while wind turbines can eventually integrate, reducing the number of panels.

The hydraulic energy production is surely more constant during the day, without the daily oscillations of wind and solar energy, even though the seasonal variations must be considered; when necessary, a cogeneration system with the application of fuel combustion is typically used, even if it's less sustainable, because it's able to cover the dispatchability loss.

1.4.4 Environmental decision support for the construction of a green mountain hut

A specific mountain structure energy renovation in order to reach a 'green' hut was presented (Goymann et al., 2008), a new sustainable design for the Monte-Rosa hut (CH) to build a structure with almost energy autonomy RER related, modern facilities for the visitors and wastewater management. A LCA assessment approach was applied for decision strategies.

A energy flow analysis was performed and the result showed how the computed GHG emissions were substantially lower than the previous ones, even considering the increased energy demand.

This paper shows how the alpine structures, which typically are old and their energy systems have low efficiencies, can be renewed to drastically reduce the emissions in the high-altitude mountain environment.

1.4.5 Quality analysis of integration of solar panels in mountain huts energy production

Regarding the solar energy, in particular, Vanbalberghe et al. (2018) promoted a multicriteria approach to improve the potential of use for alpine huts energy supply, selecting eight structures located in the French Alps.

The natural environment is considered, evaluating the sun exposure and how it's affected by the surrounding buildings or mountains, using Heliorama, "an online lighting calculator that takes into account far shading for each mountain hut, using its latitude and longitude coordinates" (Vanbalberghe et al., 2018).

The orientation, the number and the distribution of the architectural features are taken into account, such as windows and opaque walls, but also the possibility to integrate the solar panels in the landscape, a sometimes-difficult approach to follow.

The third approach is referred to the energy production through the PV panels, considering their number, position and orientation and obtaining a reference power value; the last computation involved the energy demand estimation, based on the Energy Performance Diagnosis, and therefore all the consideration has been merged, obtaining the results of a multi-criteria approach which can be applied to all the existing high-altitude huts on the Alpine chain.

1.4.6 Rural development through improving the water supply.

One last consideration on the mountain huts renovation is presented, published by Foris et al. (2018) and evaluating the water supply management of a sustainable structure, given that the climate change effects on the Alps are strongly reducing the water resources such as surface basins shrinkage, constant and intermittent flows with lower volumes, groundwater levels lowering, glacier retreat and reduced occurrence and intensity of precipitation.

The rainwater management plays the key role for this approach, understanding how to balance its recovery, storage and usage during the year and combining it with the necessity of the structure.

A collection and storage system for meteoric water has been used even in the past in order to guarantee a sufficient water supply during the summer, using the liquid resources collected during the winter; most of them are not efficient though and they are able to collect only a fraction of the rainwater fallen over the hut surface.

Moreover, if the possibility to convert meteoric water into drinkable water is considered, a chemical and bacteriological analysis has to be performed: in some cases, the values of the contaminants are below the normative thresholds for drinkable water and therefore it can be used for such aim, although the stored water, even if not potable, can still be used for sanitary purposes.

1.5 WATER ESTIMATION

1.5.1 Bibliometric approach to water recharge and climate change

The groundwater studies are increased in the last decades (Castillero et al., 2021), due to the strong correlation to climate change and specifically to water recharge variation, which is mainly affected by the precipitation scarcity and the temperature rise, leading, at least in some regions, to lower water levels underground, a slower recharge and a critical loss of freshwater resources.

Studies and analysis from the whole world have been merged, underlining how the lower values of groundwater recharge are located in dry and arid areas, while higher values are referred to norther regions or higher altitude, where the snowmelt and the glaciers shrinking are able to stabilise the recharge capacity, although reducing the long-term solid water storage.

The bibliographic studied presented by Castillero et al. aimed to identify a possible search increase around the world on this topic, consider which countries contributed more to this analysis and, finally, evaluate the effects of climate change on groundwater recharge, merging over 200 papers published in the last 40 years.

First, the topic research grew showing also an acceleration in the last years, mainly focusing on aquifers and climate change; during the period taken into exam, over 50 countries contributed with analysis and publications, starting with developed countries during the 1980s and 1990s, followed by developing and underdeveloped ones. This result shows how the freshwater resource scarcity is becoming more and more a critical topic for several areas.

Moreover, several collaborations took place among nations, enforcing the studies and the sharing of data and results about aquifers and climate change effects on them.

The positive or negative impacts on groundwaters have been evaluated considering three factors: precipitation, temperature and evapotranspiration (ET) trends. In arid regions, for instance, the temperature increase leads to a rise in ET and droughts, but the mountains are very sensitive to negative impacts too.

On the other hand, as said above, a substantial and rapid melt of snow and ice, especially in regions at high latitudes or at high-altitude, contributes to a sudden and large quantity of water released in the aquifer and to the water level to rise; obviously, this last term depends also on water usage due to agriculture and other human activities, sometimes close to the overexploitation of the freshwater storage.

1.5.2 Glacier melt runoff controls bedload transport

Considering only the glacierised areas, the glacier retreat is affecting the aquifers, but also the surface terrain, in terms of water runoff and therefore the bedload transport. This topic has been presented by Comiti et al. (2019), underlining how the coarse sediments dynamics are subjected to the seasonal runoff, modifying the equilibrium of the environment.

As said before, the glacier retreat and permafrost degradation are responsible for the increase in debris and rock fall occurrence, which can deposit on river channels modifying the elevation and geometry of rivers, a critical situation in terms of risk assessment.

Therefore a study about the link between hydrological drivers and bedload transport has been presented, taking into account the possible seasonality variations, the origin of sediment supply and the climatic drivers which more affect these processes.

“We thus envisage for the second half of the century, in catchments almost completely deglaciated, a shift from current glacier-driven, supply limited conditions to transport-limited dynamics where episodic, storm-related floods will dominate bedload transfer by eroding the newly available sediments.” (Comiti et al., 2019)

1.5.3 The role of snowmelt in spring variability

Given the variability from the stable seasonal precipitation trends, it’s fundamental, in order to efficiently estimate the correct hydrological cycle of a region, to generate reliable scenarios of the snowmelt and precipitation for the future years, when the effects of climate changes will be even more pronounced.

“Results from this study may be used to develop more accurate water management strategies in mountain catchments and to cope with future climate-change predictions that indicate a decline in the snow volume and duration in Alpine regions.” (Lucianetti et al., 2020).

As said above, the meteoric water, the snowmelt and the glaciers melting runoff contribute to the aquifers, therefore, especially at high-altitude areas, also the springs flow quantity and stability are very sensitive to climate and hydrological drivers.

“In this framework, understanding recharge processes and quantifying the contribution of rain and snowmelt to spring water is necessary to properly manage groundwater resources and cope with future changes in the spring regimes.” (Lucianetti et al., 2020).

For the presented study of spring yield variability, stable isotopes of hydrogen and oxygen has been chosen, in order to trace the underground flow, comparing the different relationship slopes between the concentration of the isotopes sampled in different locations of the catchment.

The study was performed on an area of the Dolomiti, in the Italian Alps, firstly defining the hydrogeological complexes of the terrain and locating the monitoring points. The results show how to understand the different contribution of precipitations and snowmelt in the springs, as shown in figure 8.

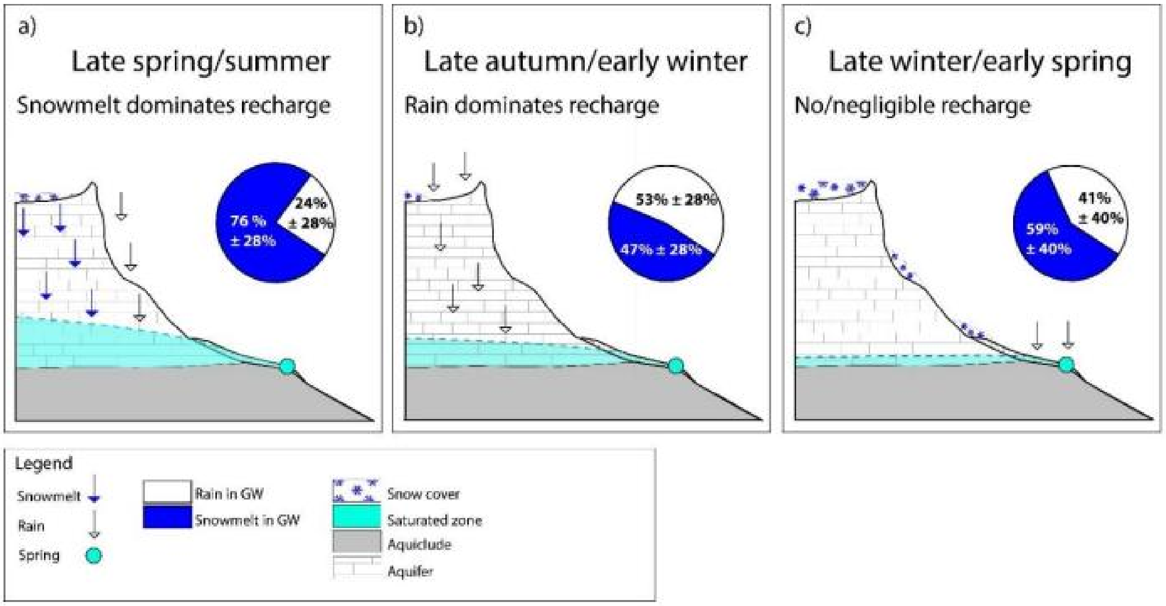


Figure 8 Simplified conceptual scheme representing the different contributions of snowmelt and rain to spring recharge and their seasonal variation (Lucianetti et al., 2020)

In particular, the higher altitude aquifers of the Dolomitic group appear to be more affected by the snowmelt contribution rather than the precipitation.

Obviously, the distribution of the snowmelt fractions appears to be heterogenous over the study area and the specific values of this study cannot be applied to other regions, but it’s a consistent study in which it’s possible to determine how the springs are affected by the snowmelt presence and variations during the years.

1.5.4 Liquid and solid storage of water (rock and ice glaciers)

A more specific study has been conducted on Austrian Alps (Wagner et al., 2021) in order to estimate the water storage potential of rock glaciers, in a nation-wide comparison to ice glaciers; they are able to store water in both solid and liquid form, which has been estimated with hydrogeological analysis and thickness estimation of permafrost and ice.

Glaciers volume is drastically decreasing in time, therefore the computation of the volume must integrate future glacier coverage scenarios; "Within the Austrian Alps and according to the existing inventories, a substantial volume of water in its solid state of ice is (still) stored in rock glaciers and glaciers with an estimated ratio of 1: 12.0" (Wagner et al., 2021).

1.5.5 Hydropower potential in the alps in CC scenarios

The stored water in mountain region is, especially in northern Italy, an important resource for energy generation: there are several dams and hydropower plants distributed in the chain and the hydropower generation contributes the Italian electric grid with a substantial percentage, as a renewable resource with a daily production which is more constant then solar and wind energy (as said before).

Duratorre et al. (2020) published a study related to the hydropower potential of one of the Italian region (Val d'Aosta), applying different climate scenarios (RCP 2.6, 4.5 and 8.5 within a timeframe up to 2100) on a specific power plant (Chavonne Plant).

Regardless of the results of the study, the future uncertainty is the key factor which the hydropower strategies must focus, the change of flow quantity and the seasonal shifts could allow several difficulties on the electric production on the Alps.

1.5.6 Glacier retreat and hydropower potential

Taking into account a larger region instead, Schaefli et al. (2019) published a study related to the hydropower potential (HP) of the Alps, starting from the swiss electric mix point of view.

"In the European Union, hydropower represented 11% of the gross electricity consumption of the 28 member states in 2016 and high shares of hydropower production can in particular be found in high latitude and high elevation regions, where part of HP relies on water resources that are temporarily stored in the form of snow and ice, and are thus particularly vulnerable to climate warming." (Schaefli et al., 2019).

As said right above, it's difficult to correctly model a large region or a whole mountain chain like the Alps, typically all the studies and the information about glaciers retreat and hydropower potential (HP potential) trends are related to single case studied.

The paper, although, presents an estimation of how much the swiss HP is related to annual ice mass loss, with the goal to be an example for the other alpine countries and even countries in other regions.

In Switzerland the 55% of the electric mix derives from hydroelectric production (2019), with an order of magnitude of tens of TWh, with typically two types of hydrological regimes: glacier-dominated regimes and rainfall-dominated regimes.

In general, the springtime is expected to show an increased streamflow, while the summertime a decreased one; the comprehensive analysis of swiss ice and snow coverage predicts that the temperature increase will drastically reduce the snow duration, the snow coverage and the glacier surface.

The contribution to HP is considered through two parameters, the ratios of annual ice mass loss and the discharge, and then the elevation-dependent electricity production factors.

The results show how the hydroelectric production will be affected by the lower discharges and it'll decrease in the next decades up to a 1 TWh each year in 2100.

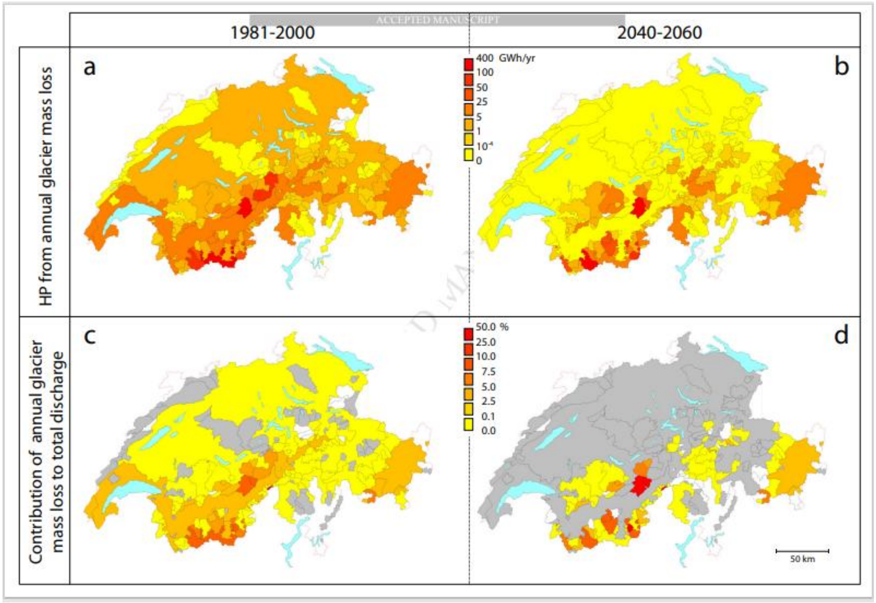


Figure 9 Glacier-related HP and ice mass loss contribution to total discharge (Schaefli et al., 2019)

1.6 TOURISM EVALUATION

1.6.1 Tourists' perspective of ice shrinkage in a glacierised area

The evolution of the alpine landscape contributes to affect the dynamics of mountain tourism, changing the seasonal routines of travellers who are interested in trekking and mountaineering activities, but also the families and the communities who chose to dedicate their efforts to maintain and protect the coexistence of mountain environments and human activities.

The glaciers retreat imply a new view of the high-altitude areas, with much less glacierised areas, with different seasonal water recharge, moved snowlines and treelines, new itineraries and pathways and a general increase in natural hazard risk.

Garavaglia et al. (2012) proposed the results of a questionnaire applied in 2009 over the Forni Valley (Stelvio National Park) to evaluate the knowledge of the tourists about the changes in the area and the detected variations due to climate changes. The goal was to understand the best dissemination strategies considering the site and the categories of tourists who are interested in it.

This study has been published almost fifteen years ago, the range of interest is related only to the locality named above and the sample of data is very little (about 160 visitors): due to all this reasons, the results can not be representative of the whole alpine situation.

Nevertheless, the outputs are presented: most visitors are more interested in mountain flora and fauna then the geomorphological features, even if they were aware of the changes in the landscape; the volume shrinkage of the ice was detected, but the quantification wasn't so easy to be evaluate.

1.6.2 Decision support model towards ecotourism and minimum env. impacts

A new behaviour model has been presented by Stubelj Ars and Bohanec (2010), involving a qualitative assessment for strategy development in high mountain huts, based on four mountain huts on Slovenian Alps; the goal was to address ecologically sustainable tourism (ecotourism) regarding the behaviour of both huts managers and visitors.

The sectors which can be improved in a more sustainable view have been presented above and given that sustainability and tourist service are part of a complex system where it's very difficult to generate the best solution, all these sectors must be addressed simultaneously.

1.7 ALPINE MOUNTAIN HUTS MANAGEMENT AND CLIMATE CHANGE FACING

The complexity of the issues related to glaciers shrinking on the Alps shows how can be useful trying to merge all the information described above and collect the choices of mountain tourism stakeholders in the last year; they interpret the analysis and apply the strategies through different ways, generating changes in the glacier tourism approach.

A classification of these strategies, related to six categories of glacier-CC issues, has been presented by Salim et al. (2021), underlining how the main causes of glacier retreat on the Alps are affecting the mountain tourism in similar way, even if the territories vary over the chain. Moreover, this study it's a comprehensive collection of stakeholders evolution management coming from different countries, merging and unifying the information from Austria, Switzerland, France.

In general, the study was focused on the stakeholders' perception and what changes they would apply in the near future, so the main actions, after the site selection, has been in interview modality: some of them were performed during 2020, some others previously (between 2013-2017). The rest of the study was based on a selection of over 70 papers (most of which were referred to areas in the proximity of the study sites).

The results shown that the most researched parameters are the evolution of glaciers length, thickness and velocity for all the sites, confirming that the paraglacial processes have been more frequent starting from 1990, affecting the safety of the terrains as we have described before.

"[…] indicated that the effects of the current paraglacial period on itineraries include an increase in the height of moraines with steeper slopes, the destabilisation of some of them, leading to rock falls, and the development of proglacial torrents, which can make some sections inaccessible." (Salim et al., 2021).

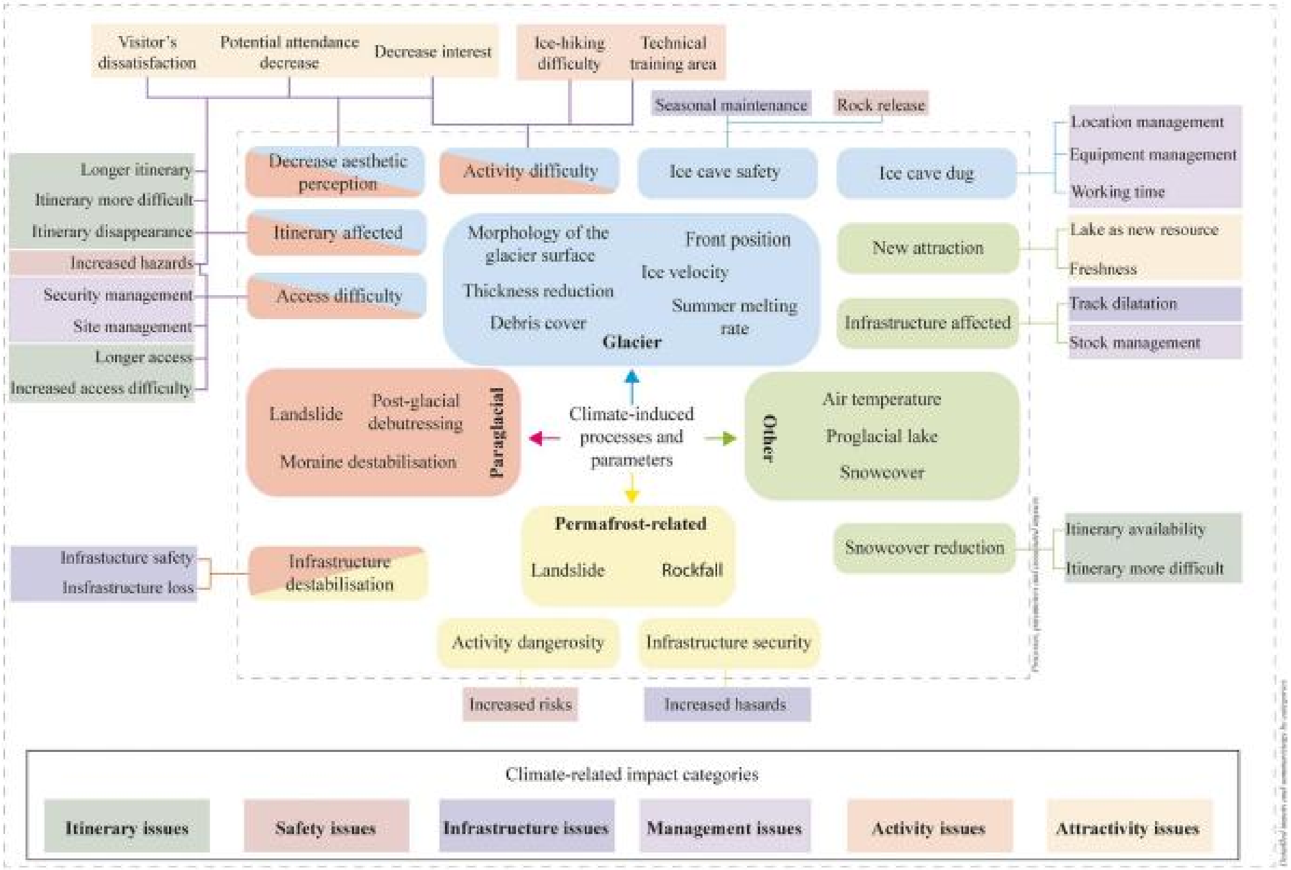


Figure 10 Processes, parameters and effects of mountain tourism (Salim et al., 2021)

Salim et al. collected all the processes in a summary graph which is reported in figure 10, it's easy to determine the categories of effects concerning the tourism activity related to climate change effects, such as the natural hazards occurrence and predictability, the change of geomorphology and geological shapes, the instability of the terrain and the variations of itineraries and pathways, bringing then attention to the visitors perspective and the influence on satisfaction, attendance and interest on the high-altitude environment.

In particular, the paper highlights how stakeholders are aware of the changes and express their concern about the loss of involvement due to itineraries length, slope and climbing difficulties, safety and landscape appearance.

The issues can be summarised into six categories: itineraries, safety, infrastructures, management, activity and attractivity; the outcome of these climate change consequences sometimes leads to management issues such as loss of interest for the activity and, if correct adaptation strategies are not applied, the abandonment of the area.

Therefore, several strategies have been implemented in the selected sites to face the processes showed above, some of which are short-term related, and they can be classified in eight groups; the structural stability has been renovated to cope with glacier shrinking and permafrost degradation, but also access and itineraries maintenance to keep them safe, also through the support of formed staff.

Glacier melting can be mitigated through technologies such as ice surface covers application, a solution which is functional and has been chosen is several mountain areas of Europe.

The long-term strategies involve some modifications on the approaches, a new perspective of diversification for the stakeholders and new proposals for the visitors, redefining the tourists offers; a new environment can be an occasion for new activities; depending on the different situations, transformation or diversification approaches can be chosen, allowing to maintain some old activities and integrate them with new ones.

Moreover, the adaptation strategies able to face the urgent changes in the high-altitude environment shall consider the long term birth of new climate-adapted models.

1.8 RAPID GLACIER RETREAT AND DOWNWASTING THROUGHOUT THE EUROPEAN ALPS IN THE EARLY 21ST CENTURY

Considering the measurements on the glacierised area of the European Alps, evaluating how the glaciers retreat occurred in the last decades, its variation through the alpine chain and estimating how much surface, thickness and volume of ice melted.

A specific paper has been considered (Sommer et al., 2020), a numerical analysis of the glacier changes over the European alps during the period 2000-2014, concerning specifically the acceleration of the last period of time, comparing two DEM from radar interferometry missions.

The ice melting, as said before, affects the seasonal shift of runoff and freshwater discharge of the catchments, especially during dry periods, also involving the hydropower potential of each region, forced to vary its seasonal stability of predicted produced energy. To predict future water availability, correct projections must be generated.

The goal of the study is a comprehensive and cross-border analysis of the Alpine glaciers changes of the last twenty years, one of the most consistent choice in order to better understand the acceleration trend of high-altitude temperature increase and glaciers shrinking.

In particular, the Lepontine and Rhaetian Alps show the highest mass loss values, while the western Alps appears to be more heterogenous. In general, the total mass loss rate (assuming a constant surface) is about 14%.

In general, the altitude changes seems to be correlated to glaciers size and elevation, the greatest surface reduction values are high-altitude related and the lower ranges are expected to be ice-free by the end of the century.

The results were compared with a dense and rich sites measurements obtained in the last decades, due to the importance of the chain, the Alps are indeed one of the most surveyed mountainous areas in the world.

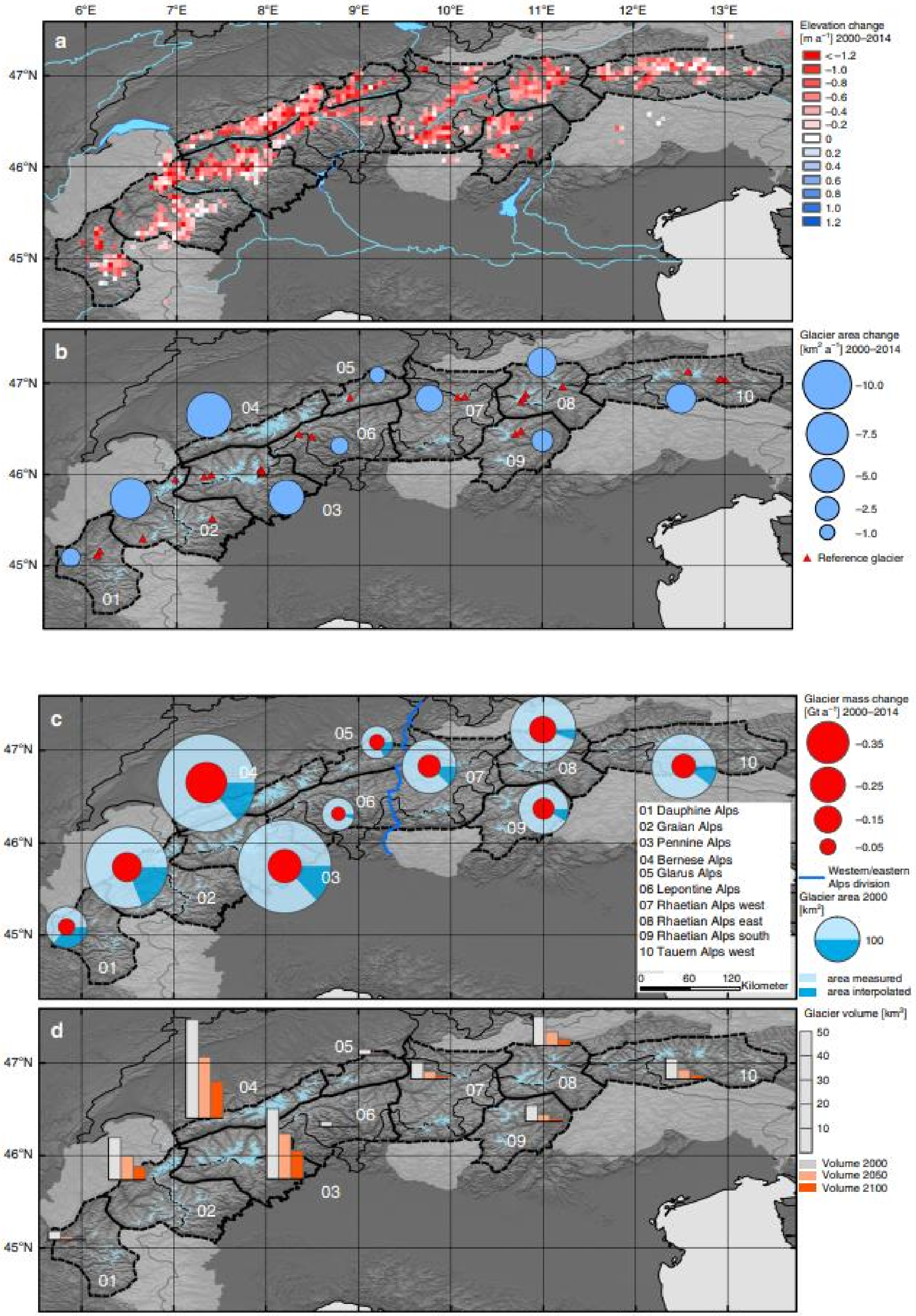


Figure 11 *Glaciers changes in elevation, surface, mass and volume (Sommer et al., 2020)*

2. GOAL OF THE STUDY

As presented above through the detailed studied about glaciers retreat on the Alps and the complexity of effects involving the high-altitude tourism and the mountain huts management, it can be useful to combine these factors and evaluate how the glaciers retreat of the last decades are affecting the quality of structures running in this environment.

A higher ice loss trend in the area can affect the local environment through several effects, as said above, such as greening trends and fauna/flora diversity imbalances, natural hazards occurrence frequency and itineraries modifications, water scarcity and slope instability. This study focuses on the possibility, for the mountain huts, to be affected by water supply difficulties due to glaciers retreat and a lower freshwater availability for the seasonal activity of the structures.

Ice coverage shrinkage, as discussed before, can lead to different ice melt and snowmelt flows during the year in terms of quantity and time distribution, it's therefore fair to assume that mountain huts, shelters and bivouacs built close to the glaciers, set downstream these flows, are directly affected by these changes for both surface and underground basins and flows.

Water supply is a fundamental necessity for any kind of human activity and, even for structures which are not used in terms of touristic attraction such as bivouacs, an available access to freshwater must be present inside the building or possibly very close to it, such a natural spring: in this case, the usage of the resource involves beverages and cooking, personal hygiene and cleaning, for a few people at a time.

Regarding larger and more organised structures such as refuges and guarded shelters, in which all the previous necessities must be guaranteed and several more services are offered, such as toilets, showers and meals preparation, involving much more people, sometimes hundreds of visitors at a time, the freshwater availability difficulties can lead to more critical situation in terms of activity management.

It can occur that water accumulation systems have been built close to the structures, such as rainwater collectors, or natural flows and basins have been modified using artificial channels, deviations, basins, in order to overcome the seasonal variations that was already an issue some decades ago; furthermore, water pumping system can be present, such as larger natural basins or functional groundwater extractors, therefore a high site-specificity must be taken into account.

Nevertheless, the mountain huts on the Alps have been built considering the freshwater availability in the area, a rapid ice coverage shrinkage caused by higher temperature trends and different yearly precipitation distribution is leading to strong a distributed water supply criticalities for guarded and unguarded shelters, alp farms, bivouacs and refuges. In particular, the goal of this study is to collect the geographical distribution of mountain huts and glaciers retreat over the Italian Alps area, compare them and select the structures which, according to the results, are more endangered due to local ice shrinkage and related water supply criticality. A selection steps have been set in order to select a specific catalogue of mountain huts, with their information, and compare their geographic locations to the glaciers position and their monitored shrinkage, mapping all the obtained parameters and the computed results in a graphic visualisation.

This analysis is focused on the mountain huts located on the Alps, with an altitude equal or higher than 2000 meters and inside the Italian borders: this selection have been chosen in order to consider only the structures which are present on the Italian Alps, in order to have a reduced number of structures in the catalogue and a more consistent research availability. The altitude threshold has been set to filter the huts located in a high-altitude environment, where the paraglacial processes regarding the glaciers occur.

3. MOUNTAIN HUTS ANALYSIS

Among these hundreds of visiting structures, a further selection has been chosen, regarding the freshwater availability inside/outside the structures: given the goal of this analysis, the bivouacs or refuges where it's known that the water access is not present have been neglected.

After these selections, a total of 259 structures are considered: they are described to be guarded or unguarded shelters, bivouacs, emergency shelters or social huts.

The mountain huts are divided into two groups, depending on if they joined the CAI network or, even if they are located inside the Italian borders, their management is not linked to the CAI network.

The CAI network ('Club Alpino Italiano', *Italian Alpine Club*) is an Italian association founded in 1863 collecting hundreds of thousands of associated people with the collective aim of alpinism, mountain knowledge and studies and natural environment defence. It's divided into 512 sections and its objectives are alpine-related, supporting excursions and scientific and cultural knowledge tours, organising lessons and tutoring hikers to be trained for mountaineering activities, monitoring the environment and terrain quality and stability, taking care of the quality of pathways and itineraries, and managing a network of mountain huts and refuges.

This association has been chosen because it's very popular for alpine mountain visitors, it provides clear and precise information about the structures, therefore most of the huts chosen for this analysis are part of the CAI network.

The mountain huts which are associated to the CAI network, but not located on the Alps, have been neglected for clear reasons, such as the ones which are closed, dismissed or structurally unavailable.

The CAI refuges database collects 722 structures and only 373 are located above 2000 meters of altitude; among these, only 158 are provided with an available access to freshwater: these last selected units form the first group of structures and, from this point, they are named 'CAI' study group. Their geographic coordinates are used to reference each hut to a point on an Alps map, as shown in figure *12*.

In order to better differentiate and compare the different huts, a *dimension* parameter is introduced, which is not related to the dimension of the building or the rooms, but involves the number of beds offered for the visitors: this specific information is chosen to cover a useful role in terms of evaluating the number of people which the structure is able to host, therefore the quantity of water needed at a time. The number of beds of a mountain hut is also typically proportional to the actual dimension of the building, the number of offered services and the complexity of the management.

The guarded shelters offers services through a present and paid staff, during the whole year or only for seasonal periods, on the other hand many bivouacs, especially at very high-altitude environments, are available and kept clean by maintenance staff (associated to CAI network, for instance) every few months.

For each saved hut, some information has been searched and associated into the database:

- Name of the structure
- Identification code for CAI database research
- Hut typology
    - GS: guarded shelter (142 structures)
    - UG: unguarded shelter (8 structures)
    - ES: emergency shelter (0 structures)
    - B: bivouac (2 structures)
    - SH: social hut (6 structures)
    - RP: resting point (0 structures)
- Altitude (m.a.s.l.)
- Coordinates (RS: WGS84, EPSG: 4326)
- Dimension (number of beds)

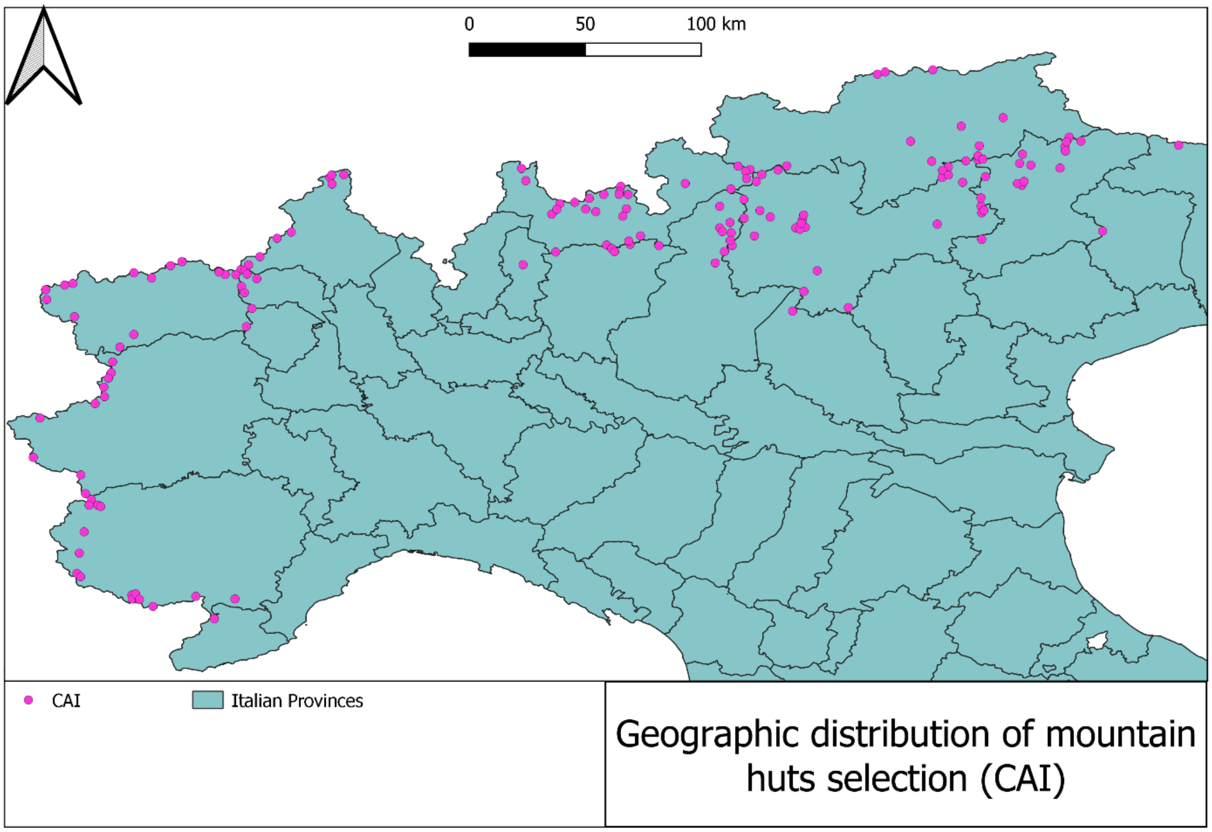


Figure 12 Geographic positions of the CAI mountain huts [159 structures] (image source: QGIS, WGS84, EPSG: 4326)

/	NAME	#	Hut type	Altitude	Longitude	Latitude	Dimension
1	CAPANNA MARGHERITA	930010001	GS	4554	7.877047365	45.92712232	82
2	CAPANNA RESEGOTTI	921200202	B	3624	7.900583657	45.92631602	16
3	RIFUGIO MARCO E ROSA	921600101	GS	3609	9.910612965	46.37369254	104
4	RIFUGIO SELLA (AL FELIK)	921200501	GS	3585	7.792846555	45.90111693	142
5	RIFUGIO VIOZ	921800101	GS	3535	10.63581855	46.39917194	66
6	CAPANNA GNIFETTI	921200203	GS	3611	7.849936808	45.89987034	176
7	RIFUGIO TORINO	921200102	GS	3375	6.933732949	45.84432256	150
8	RIFUGIO CASATI-GUSATI	921600316	GS	3254	10.60248819	46.46315447	192
9	RIFUGIO BOE'	921800106	GS	2873	11.82352706	46.51465451	69
10	RIFUGIO MARINELLI-BOMBARDIERI	921600105	GS	2813	9.905268222	46.34457108	159
11	RIFUGIO TORRANI	922001801	GS	2984	12.05685031	46.37857089	34
12	RIFUGIO OBERTO-MAROLI	921205001	GS	2796	7.978984904	45.99680077	24
13	RIFUGIO MEZZALAMA	921200105	GS	3004	7.759460342	45.91371146	30
14	RIFUGIO QUINTO ALPINI	921600314	GS	2878	10.53819009	46.48168261	50
15	RIFUGIO GONELLA	921200129	GS	3072	6.83222753	45.81927222	24
16	RIFUGIO CHIARELLA	921200106	GS	2779	7.304706795	45.9103112	37
17	RIFUGIO PIZZINI	921600313	GS	2706	10.57862776	46.45280131	96
18	RIFUGIO AOSTA	921400102	GS	2788	7.561425951	45.96956821	36
19	RIFUGIO NACAMULI	921200109	GS	2818	7.50061555	45.9484756	74
20	RIFUGIO GASTALDI	921200115	GS	2659	7.143450692	45.29790399	99

Table 1 first 20 elements of the 'CAI' group

Regarding the structures which must be taken into account (they are located inside the Italian borders, above 2000 meters of altitude, they are not dismissed nor damaged and they have access to freshwater), a smaller group is represented by the mountain huts that are not associated with the CAI network. Their information is not present inside the CAI database, nevertheless they are considered in this study; other databases have been used to compare the refuges catalogues, filtering them with altitude and location conditions, obtaining a reliable list of 101 huts which, from this moment, are named ‘non CAI’ group. In this case the research proceeded with a slight different method, given that the found catalogues are not as reliable as the CAI available database, the information and data reliability has been supported by several comparisons about the structural conditions, the freshwater availability, the offered services and the number of beds inside the structures.

Unguarded shelters and bivouacs, which rarely have an associated specific website, carry some uncertainties involving the precise number of beds or the offered services, but the catalogues found on the following websites, after several comparisons with the specific websites of the guarded refuges and huts, proved their reliability for the provided information:

- Wikipedia/Rifugi delle Alpi
- Escursionismo/Rifugi e Bivacchi

The information is merged and only one structure among the 101 selected ones of the ‘non CAI’ group has proved not to have available water access, while for the others this service is assumed to be probable or verified; it’s necessary to underline, although, that for 6 bivouacs the freshwater access is considered as ‘unlikely’. As above, for each saved hut in the ‘non CAI’ group, some information has been searched and associated into the database:

- Name of the structure
- Hut typology
    - GS: guarded shelter (142 structures)
    - UG: unguarded shelter (8 structures)
    - ES: emergency shelter (0 structures)
    - B: bivouac (2 structures)
    - SH: social hut (6 structures)
    - RP: resting point (0 structures)
- Altitude (m.a.s.l.)
- Coordinates (RS: WGS84, EPSG: 4326)
- Dimension (number of beds)
- Access to freshwater
    - V: verified
    - P: probable
    - U: unlikely
    - N: non present

/	NAME	Hut type	Altitude	WATER	X	Y	Dimension
1	BAITA MARINO PEDERIVA	GS	2275	P	11.63074	46.41983	8
2	BIVACCO AMBROGIO FOGAR	B	2114	U	8.153281	46.10037	12
3	BIVACCO CAMILLOTTO PELLISSIER	B	3325	U	7.612976	45.95662	9
4	BIVACCO GIORGIO E RENZO NOVELLA	B	3708	U	7.620759	45.97206	9
5	BIVACCO LA LLIE'E	B	2422	V	7.40084	45.81777	18
6	BIVACCO LAGO TZAN	B	2459	V	7.549183	45.86131	9
7	BIVACCO LAURA FLORIO	B	3320	U	7.585424	45.92033	9
8	BIVACCO PAULUCCIO	B	3572	U	7.586444	45.93493	9
9	BIVACCO RENZO RIVOLTA	B	2890	U	7.559174	45.87764	12
10	BONNER HUTTE	GS	2340	V	12.27477	46.77847	25
11	MALGA TASSULLA	B	2087	P	10.94192	46.30902	8
12	ORESTES HUTTE	GS	2625	V	7.850126	45.87436	35
13	RIFUGIO 3A	GS	2960	V	8.335195	46.4238	90
14	RIFUGIO AI CADUTI DELL'ADAMELLO	GS	3040	V	10.56482	46.1687	120
15	RIFUGIO ALFREDO SERRISTORI	GS	2721	V	10.61751	46.54736	65
16	RIFUGIO ALPE DI TIRES	GS	2440	V	11.6329	46.4972	72
17	RIFUGIO ANGELO ALIMONTA	GS	2580	V	10.89187	46.17394	94
18	RIFUGIO ANGELO BOSI	GS	2205	V	12.25117	46.61079	20
19	RIFUGIO ARBOLLE	GS	2507	V	7.345718	45.6676	66
20	RIFUGIO ARP	GS	2446	V	7.777117	45.78728	100

Table 2 first 20 elements of the 'non-CAI' group

The two groups of 'mountain huts' elements are then merged into one single database, which is going to be compared to the geographical information about the glaciers in the following steps of this study.

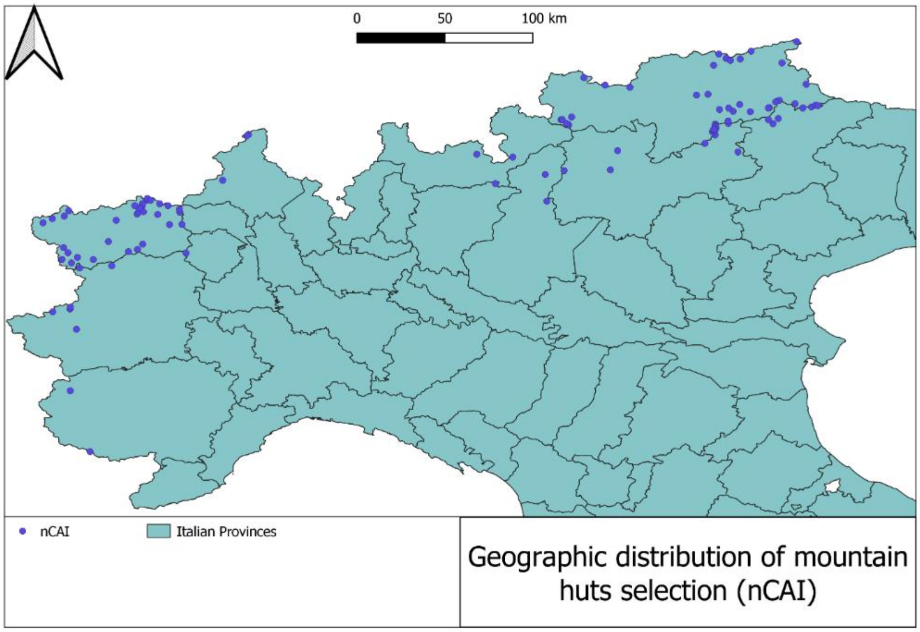


Figure 13 *Geographic positions of the 'non-CAI' mountain huts [101 structures] (image source: QGIS, WGS84, EPSG: 4326)*

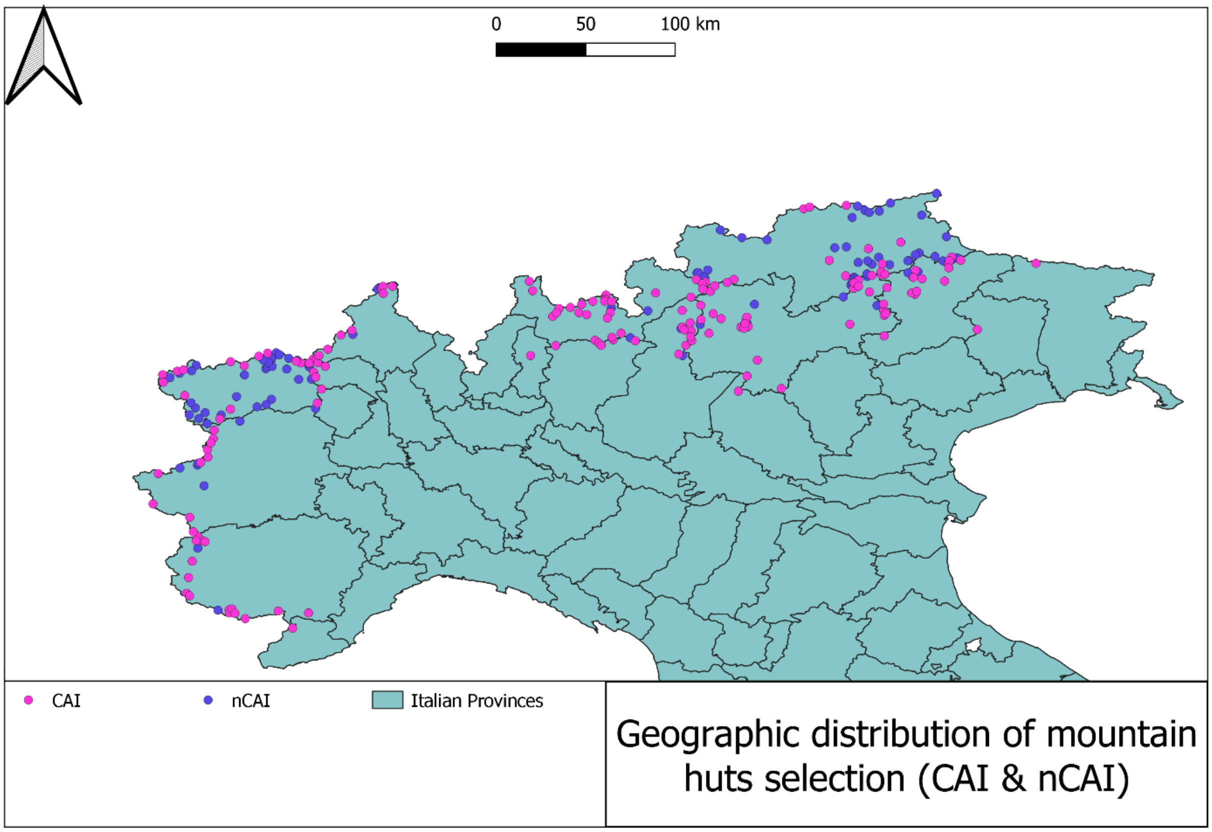


Figure 14 *Geographic positions of the mountain huts [259 structures] (image source: QGIS, WGS84, EPSG: 4326)*

The high-altitude mountain huts are spatially distributed in a heterogenous manner, as in some regions of the Alps they appear more present than in others (figure 14); they are typically close to the Italian borders, which leads to the concept that several other structures, very similar in terms of management and climate-change-related difficulties, are located very close to the selected ones, just beyond the German, French, Swiss, Austrian and Slovenian borders: they are not considered in this analysis, but they could be part of a future more comprehensive huts-glaciers study of the Alpine chain.

Regarding the altitude distribution of the structures, the majority is located between 2000 and 2500 meters of altitude, while less then 10% of the selection (23 huts over 259) was built over 3000 meters (figure *15*).

This heterogeneity obviously derives from the issues related to higher altitude managements associated to longer distances to reach the structures and less transport pathways, on the other hand this imbalance mustn't be considered as representative of the real distribution of mountain huts in high-altitude environment, due to the selection that has previously described and through which all the structures, especially bivouacs, without an available access to water are been neglected.

The higher the altitude of the hut, in fact, the less guarded shelters and the more bivouacs are present, especially without a safe and close access to freshwater; therefore, if this study had been evaluated all the structures above 2000 meters of altitude, the parameter distribution shown in figure *15* would have been different, with higher values for 3000-and-above meters structures.

Considering the number of beds (figure *16)*, which is the chosen parameter used to evaluate the *dimension* of the mountain huts, lower values are more frequent thanks to a more feasible management and maintenance, while structures with very high values of *dimension* are rare: in this selection, only the 8% of huts (21 over 259) offer at least 100 beds at a time.

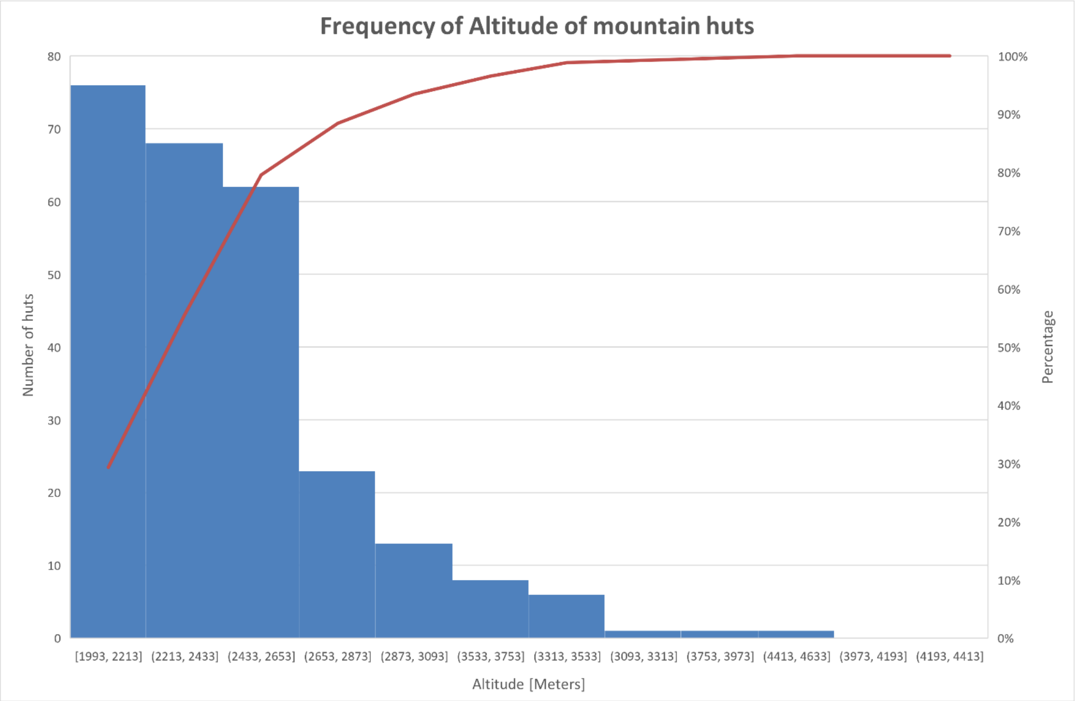


Figure 15 Altitude distribution of selected mountain huts (histogram)

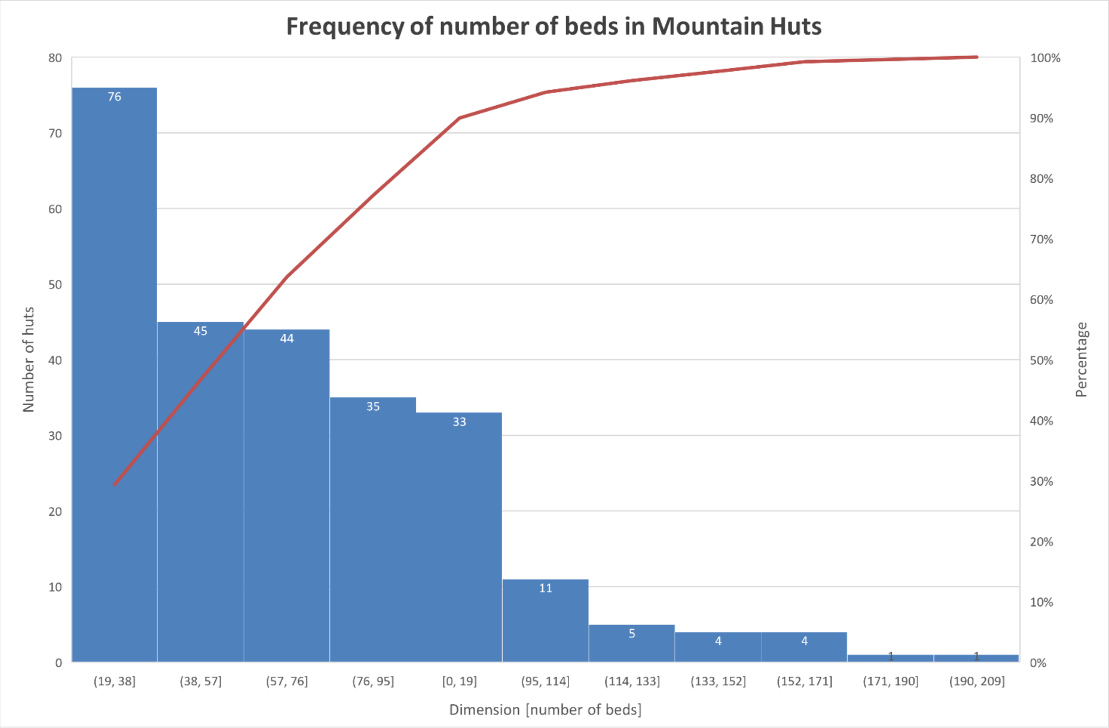


Figure 16 *Number of beds distribution of selected mountain huts (histogram)*

4 EUROPEAN AND ALPINE GLACIERS _ ACTUAL STATE AND CONDITIONS

The paraglacial processes have been described, analysing how the high-altitude alpine environment is subjected to rapid modifications in terms of hydrological cycle, terrain stability and natural hazard occurrence, geomorphological changes of shapes due to debris detachment and accumulation, ground heat transfer and human activity. Focusing on the specific state of conditions of the european glaciers, the majority of the glacierized areas are in the central part of Europe, in particular on the Alps, with Aletsch glacier as the largest present in the continent, on the Pyrenees, on the Appennine and on the East Europe area, with a collected total surface of about 2000 km^2 in 2019 ('Global Glacier Change Bulletin', WGMS) and a monitored decrease of ice surface, volume and mass distributed, even though with a heterogenous behaviour, on all the areas (figure 17 and 18*)*.

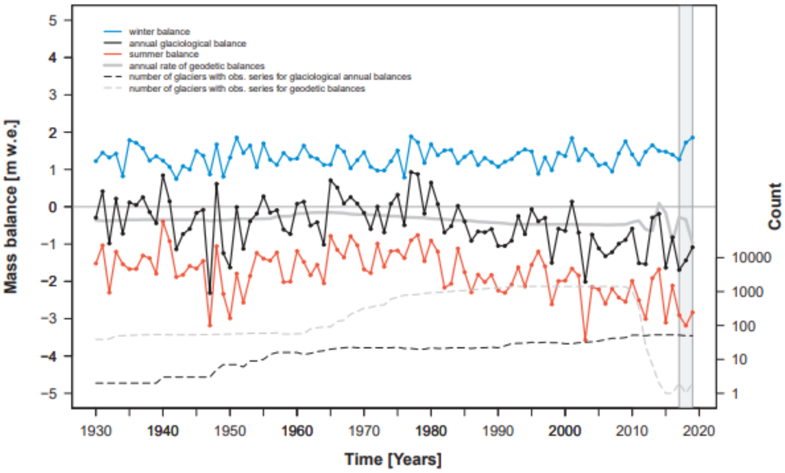


Figure 17 Regional mass balances ('GGCB', WGMS, 2021)

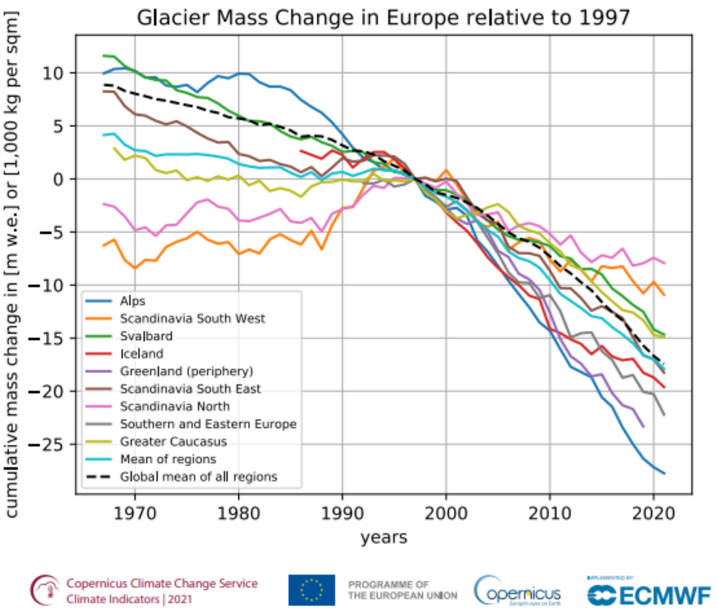


Figure 18 Cumulative mass changes in Europe from 1967 to 2021 for glaciers in nine different regions (C3S/WGMS, 2021)

Several European and Italian glaciers cadastres have been published since 1970's, when the International Commission for Snow and Ice (ICSI) suggested that a precise and comprehensive list of glaciers would have been fundamental to enhance the understanding of hydrological cycle, to obtain the sufficient data for a correct management of water resources and contribute to climatic and environmental phenomena studies ('Il nuovo catasto dei ghiacciai italiani', Smiraglia, Diolaiuti, 2016).

The CGI (Comitato glaciologico Italiano) published in 1925 the very first italian glaciers cadastre which collected 774 glaciers, thanks to Carlo Porro, followed by one of the most important documents for CGI, the 1959-1962 cadastre drawn up with CNR (Consiglio Nazionale delle Ricerche) which presented nearly 840 glaciers with a total glacierised surface of about 500 km^2.

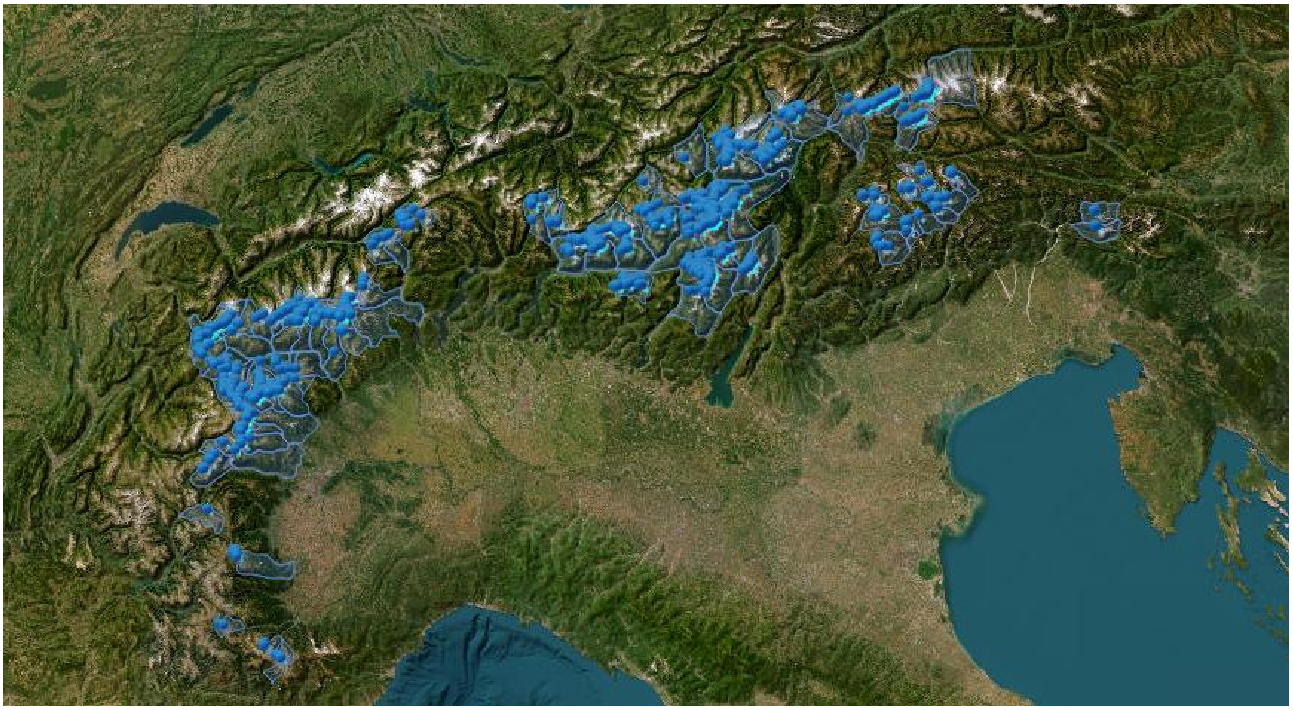


Figure 19 Italian Glaciers, CGI-CNR, GLIMS Project, interactive map

In the next years the CGI presented the information and the data about the Italian glaciers into the WGI (World Glacier Inventory) and then into the WGMS (World Glacier Monitoring Service) and NSIDC (National Snow & Ice Data Senter), in which the digital platform collect all the information about the global changes related to glaciers retreat, especially related to climate change effects. Inventory parameters include geographic location, area, length, orientation, elevation, and classification.

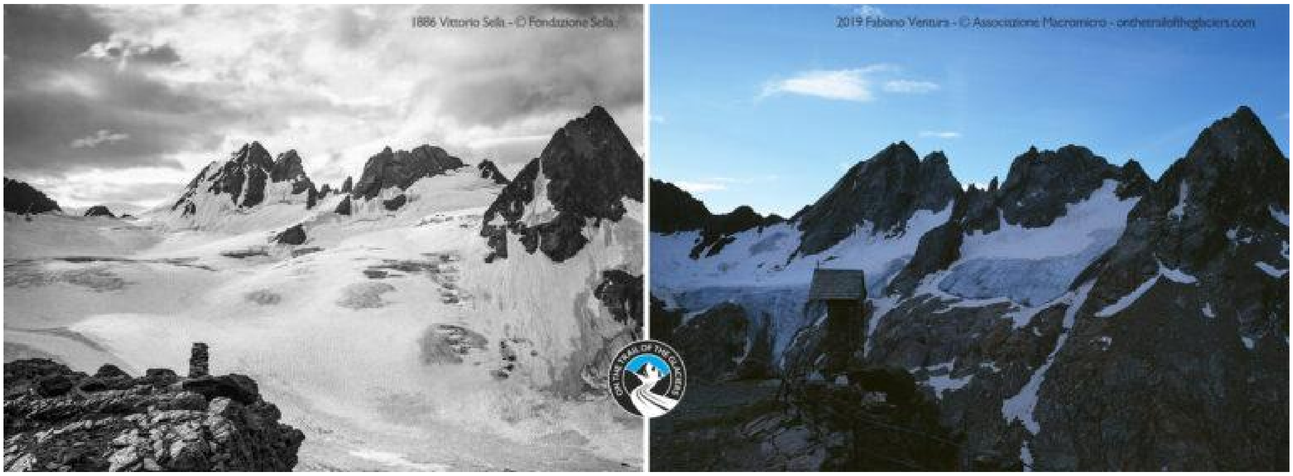
The ice surface within the Italian borders is about 1/5 of the whole glacierised area of the alpine chain (Smiraglia, Diolaiuti, 2016), with over 900 surveyed glaciers and about 360 km^2, highlighting how the exposition is mainly North-orientated clearly due to sun exposition. The cadastre also gathers the glaciers into size classes and Italian region where they are located.

The timeframe comparison is clearly fundamental for a glaciological study, due to the sudden changes related to climate changes, in fact the total area diminished of 30% and about 180 glacial apparatus are not registered in the last cadastres because they are signed as 'extinct', underlining how critical is the situation of the Alps in terms of ecosystems and human safety and activity.

Regione *Region*	Numero ghiacciai *Number of glaciers*	Area Nuovo Catasto (km^2) *Cumulative area - New Inventory (km^2)*	Area Catasto CGI (km^2) *Cumulative area - CGI Inventory (km^2)*	Riduzione area (km^2) *Area decrease (km^2)*	Riduzione area (% per Regione) *Area decrease (% with respect to the CGI Regional value)*	Riduzione area (% sul Totale) *Area decrease (% with respect to the total area reduction)*
PIEMONTE	78	28.62	50.96	22.34	44%	16.30% (16.52%)
VALLE D'AOSTA	156	132.74	174.56	41.82	24%	30.50% (30.93%)
LOMBARDIA	156	86.64	114.07 (108.07)	27.43 (21.43)	24% (20%)	20.00% (15.85%)
TRENTINO	72	29.75	44.76 (48.76)	15.01 (19.01)	34% (39%)	13.90% (14.06%)
ALTO ADIGE	132	83.29	112.90	29.61	26%	21.60% (21.90%)
VENETO	23	2.51	3.36	0.85	25%	0.60% (0.63%)
FRIULI V.G.	4	0.17	0.29	0.12	41%	0.09% (0.09%)
ABRUZZO	1	0.04	0.06	0.02	33%	0.01% (0.01%)
TOTAL	622	363.76	500.96 (498.96)	137.2 (135.2)	27% (27%)	100%

Figure 20 Variazioni glaciali (Smiraglia, Diolatiuti, 2016)

The 'Alpi 2020' expedition occurred during 2019, in order to take live images of the landscape changes of the whole Alps, comparing the glaciers photographs with older ones of the same glacier. Some comparisons are presented below, they are a visual characterisation of the great changes of the last decades, but the panoramic modifications are only a very little component among all the effects of glaciers shrinkage on the chain.



1886 Vittorio Sella - © Fondazione Sella

2019 Fabiano Ventura - © Associazione Macromicro - onthetrailoftheglaciers.com

Figure 21 glaciers images comparison (Money, Scerscen and Caspoggio glaciers), Alpi-2020 project

A series of database by Copernicus (the European Union's Earth Observation Programme), based on the WGMS collected information of Fluctuation of Glaciers (FoG), provides glaciers elevation and mass change data for the global perspective, with two timeseries which involve geodetic and glaciological methods, but also the Randolph Glacier Inventory (RGI), a dataset which provides a single time-slice of aerial images collected through the years.

The RGI is complementary to the GLIMS (Global Land Ice Measurements from Space), an initiative created to use aerial and satellite images to monitor the glaciers variations, it involves over 60 institutions from different countries

Some datasets are focused only on a portion of the glaciers, which are called 'Reference Glaciers', which have more than 30 years of ongoing glaciological mass-balance measurement and they can provide reliable information about long-term globally distributed observation series. For Italy, the only WGMS Reference Glacier is the Careser Glacier, observed and measured since 1966.

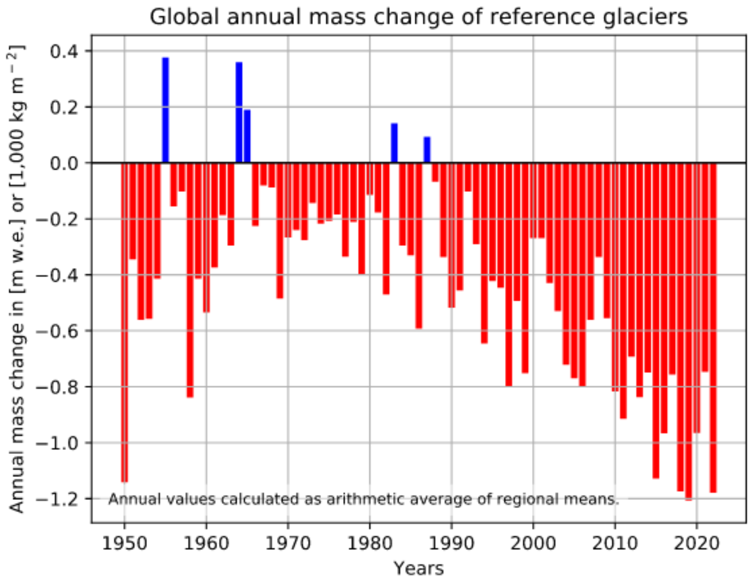


Figure 22 Reference Glaciers annual change, WGMS, 2021

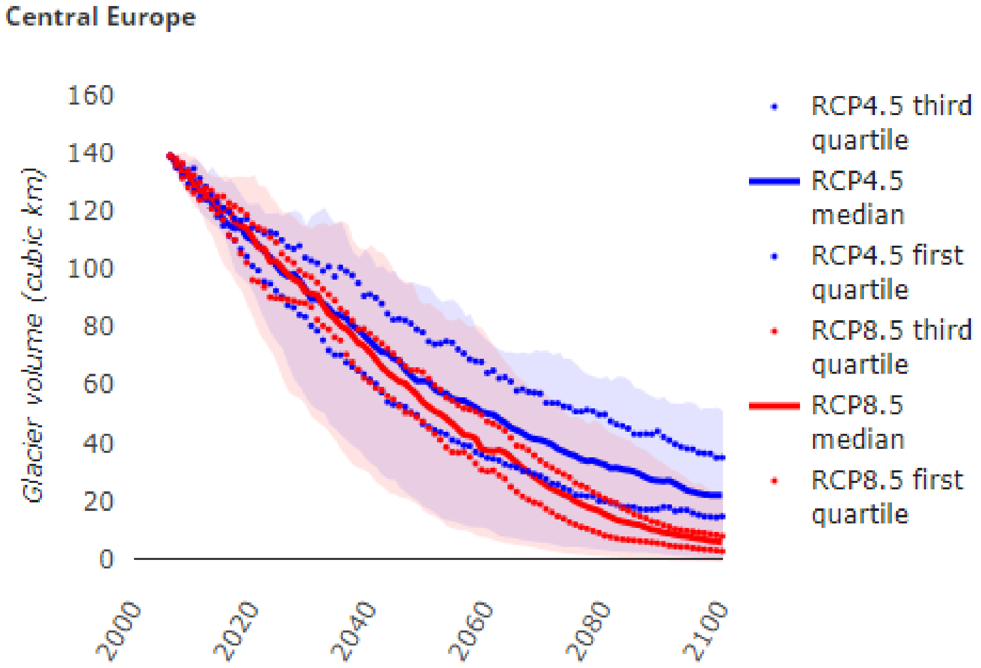


Figure 23 projected volume change for European glacierised regions ([European Environmental Agency]())

Many of these agencies also provide online interactive maps for glacier position, pathways and itineraries, mountain huts and glacierized areas coverage loss and surface change.

5 ALPINE GLACIERS ANALYSIS

5.1 ALPINE GLACIERS POSITION DATABASE RESEARCH

The most updated cadastres and bulletins about alpine glaciers provide also available data for georeferenced analysis, which have been evaluated and selected for the analysis. The WGMS provided the punctual information about the glaciers and an inventory of the metadata includes parameters as geographic location, area, length, orientation, elevation, and classification.

Firstly, the glaciers position is collected and graphically evaluated using QGIS software: for this step, some georeferenced data have been compared:

- Copernicus 'Fluctuation of Glaciers' (FoG) for Elevation change series and Mass-balance series
- PANGAEA Data Warehouse Cryosphere (2000-2014 series)
- RGI Inventory (NSIDC) glacier inventory
- GLIMS (EarthData)
- WGMS FoG database 2021

5.1.1 PANGAEA

The PANGAEA raster information is then chosen, due to the higher resolution of the data and the raster file availability for the database download: this typology of file better represents the geographical distribution of glacierised areas on the Alps and allows a clearer visual comparison then vector files.

This database is directly linked to the paper 'Surface elevation changes of glaciers in the European Alps between 2000 and 2014' published by Sommer et al. for PANGAEA in 2020, one of the chosen documents of the glaciers and mountain huts literature research. The datasets associated with the literature paper are presented to be fundamental for future socio-economic research and for validation and calibration of glacier change projections.

The PANGAEA download section provides GeoTiffs files related to glacier elevation changes of the Alps for the periods 2000-2012 and 2000-2014, obtained differencing DEMS of the SRTM (Shuttle Radar Topography Mission) and TanDEM-X satellite results. Given the purpose of this analysis, the elevation-change values haven't been taken into consideration, due to the old measurements and the low reliability of ice loss evaluation related to the first 14 years of the century.

Nevertheless, they provide a high-resolution raster file of the alpine glaciers: the 2000-2014 series has been read using the Matlab software and converted into a longitude-latitude matrix in which each cell provides the information about the presence or the absence of a glacier in that cell.

The matrix has a defined number of cells: 10 000 cells over longitude, 5 000 cells over latitude, which results in a satisfactory resolution value, given that each cell represents a geographical area of dimension approximately equal to 160 x 140 meters; higher values would have led to computational issues, on the other hand lower ones would have been associated to information losses.

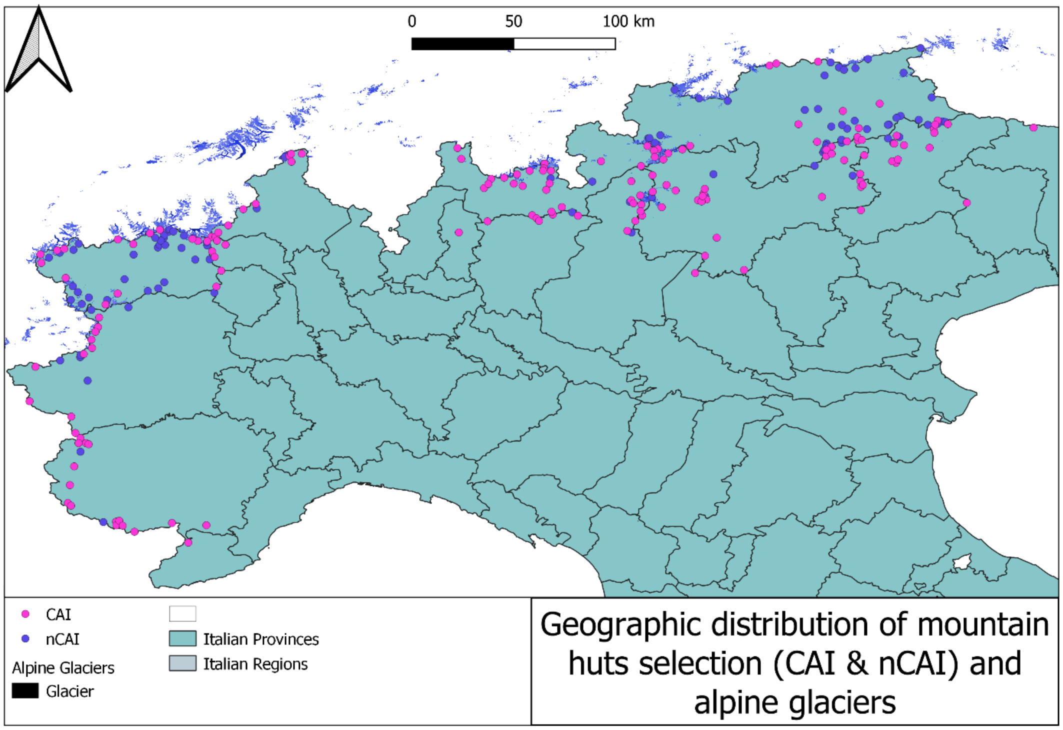


Figure 24 Geographic position of 'CAI' group huts [purple dots], 'nCAI' group huts [blue dots] and PANGAEA dataset glacier raster [grey pixels] (image source: QGIS, WGS84, EPSG: 4326)

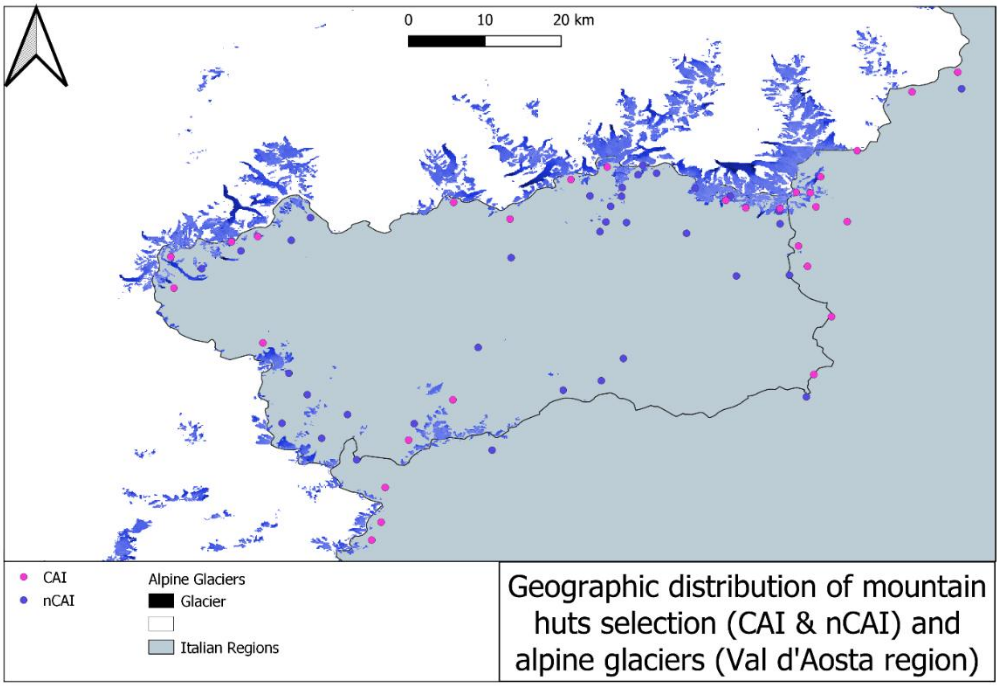


Figure 25 Valle d'Aosta region, geographic position of 'CAI' group huts [purple dots], 'nCAI' group huts [blue dots] and PANGAEA dataset glacier raster [grey pixels] (image source: QGIS, WGS84, EPSG: 4326)

5.2 ALPINE GLACIERS _ ICE LOSS MEASUREMENTS RESEARCH

Once the PANGAEA raster is visualised, the associated values of elevation change are not considered, a numerical estimation of glaciers shrinking is needed to consider which areas of the alpine chain are more affected by the paraglacial processes.

Unfortunately, the datasets listed above don't provide a complete, homogeneous and high-resolution information about this topic because the majority of the database, if recent and accurate, are related to a single reference glacier or a chosen study area (Tonolo et al, 2020; Hartmeyer et al., 2020; Ponti et al., 2020); on the other hand, more comprehensive analysis of the glaciers situation of the whole Alps are older or less accurate (Beniston et al., 2018; Sommer et al., 2020).

As said above, the **PANGAEA** data warehouse provides available and accurate values of the whole alpine chain, but they are referred to a not recent period (2000-2012 or 2000-2014 series); the **GLIMS** (EarthData) provides a vector file of the glaciers, with an associated inventory parameters such as width, length, area, elevation, but without any information about their temporal variability through the decades.

Regarding the **NSIDC**, it provides a list of the most observed reference glaciers and a mass-variation graph of them, therefore it would be selected for an analysis focused on a specific study area. The **Copernicus FoG** elevation-change series and mass-balance series, on the other hand, provide punctual position of the glaciers on a partial area of the Alps and the ice variation values are not available.

Therefore, the **WGMS FoG** database (updated in 2021) is selected for the ice loss quantification, the data are uploaded and merged using QGIS software and visualised as a georeferenced layer.

5.2.1 World Glacier Monitoring Service _ Fluctuations of Glaciers

The World Glacier Monitoring Service offers several databases glacier-related, many years series are saved and different glacierised areas can be chosen for the available data files download; the Fluctuation of Glaciers (FoG) section is updated every year, it's associated with the yearly Global Glacier Change Bulletin and the data inventory includes the geographical coordinates of the measurements, area, length, volume, mass and measurements date, based on surveys that had been performed in-situ, through aerial vehicles or using remote sensing and satellite images.

5.3 DATA ANALYSIS

The datasheet contains a list of 8 files associated with a specific attribute parameter group: for each file, the punctual information where that parameter is available is saved and the value of the parameters is associated with the point. The attributes are listed below:

1. Glacier ID
2. Glacier information and classification
   a. Name, ID, Coordinates, Classification
3. Glacier State
   a. Elevation, Length, Area, Survey date
4. Front Variation
5. Change
   a. Elevation boundaries, Area Change, Thickness Change, Volume Change, Survey date
6. Mass Balance
7. Special Event
   a. Event description and date
8. Reconstruction series

File	1	2	3	4	5	6	7	8
Number of points	*40.781*	*42.212*	*19.640*	*46.678*	*117.318*	*49.414*	*4.818*	*40*

Table 3 number of attribute points for each WGMS FoG 2021 file

The number of surveyed points varies from file to file, depending on the different surveys that have been performed on the areas; some parameters are present in more files, such as the Glacier Name or the WGMS ID, but the coordinates, which give the geographical position of the measured glacier areas, are present only in file 2 (*Glacier Information*), therefore an immediate relationship between the points position and ice loss is not trivial.

5.3.1 PARAMETERS SELECTION AND APPLICATION

From all the parameters, the most useful are selected and listed below:

• Glacier WGMS ID	All Files
• Coordinates	File 2 (*Glacier Information*)
• Elevation	File 3 (*Glacier State*)
• Volume Change	File 5 (*Change*)
• Thickness Change	File 5 (*Change*)
• Elevation Change	File 5 (*Change*)
• Mass balance	File 6 (*Mass Balance*)

The aim of this glacier analysis is to create a georeferenced matrix in which each cell corresponds to a specific and localised area on the Alps where a glacier is present and each cells contains the information about elevation and ice loss for that area.

Considering the number of surveyed points for each selected parameter (*Table 1*), the imbalance of information among the different attributes is clear, due to the fact that this database is a merged collection of an high number of surveys, measurements and digital terrain comparisons, based on a high timeframe and on a very large area (the whole alpine chain), so trying to merge all the information together is not a trivial task, even because the position of the points is not always specified.

5.3.2 Reference parameter

Firstly, WGMS ID is selected as *reference parameter* because its information appears in all the attribute group tables (see above), therefore all the selected parameters are referred to a glacier point which also have a corresponding WGMS ID value.

For instance, as shown in *Table 2* and *Table 3*, the WGMS ID attribute is used as merging reference to associate elevation and ice loss information to the coordinates, therefore to specific locations on the Alps.

FILE	Numeric	2	3	5
WGMS ID	5 digits numeric	5568	5568	5568
Latitude	Degrees	40,056		
Longitude	Degrees	7,529		
Median Elevation	Meters		2722	
Thickness Change	Centimetres			-11264

Table 4 single point parameters example (part 1)

WGMS ID	Latitude	Longitude	Median Elevation	Thickness Change
5568	40,056	7,529	2722	-11264

Table 5 single point parameters example (part 2)

Considering that, not all points which are identified by the *reference parameter* WGMS ID are associated to coordinates, altitude and ice loss information: due to the high variability in data acquisition, as said above, the majority of the measurements have not all the corresponding measurements of these parameters and, selecting only the WGMS IDs which have the associated coordinates, elevation and ice loss values, the number of points is critically lower.

5.3.3 Parameters selection: median elevation and thickness change

In order to limit this neglection, among the different types of Elevation parameters, the m*edian elevation* presents more available values and therefore is selected; following the same procedure, among the different approaches which can be chosen to evaluate the glacier shrinking, the *thickness change* is chosen.

The merged points matrix collects 2264 points, identified using the WGMS ID parameter and expressing the elevation and the measured thickness change in the terrain area identified by the cell.

5.3.4 Data Availability Discrepancy

The *thickness change values* are expressed in centimetres as unit of measure and each survey information are collected inside the File 5 (*Change*) for each *thickness change* value, but the date of survey and the date of reference of the points are not consistent among them: some glaciers have been surveyed recently, using satellite images and remote sensing, while others are linked to a *thickness change* measurements surveyed in-situ over forty years ago.

Moreover, there is not correspondence among the survey date, nor among the reference date, nor among the difference of years between the two corresponding surveys of the glaciers; in order to limit the discrepancy of this big data limitation, the difference between the two corresponding dates, for each WGMS ID, is computed and named *delta years*.

Each *thickness change* value is then divided by the corresponding *delta years* value to obtain an average annual value of thickness change for each point, in order to limit the dates discrepancy described above; the results are used as parameter values expressing the glacier shrinkage situation for the following steps of the study.

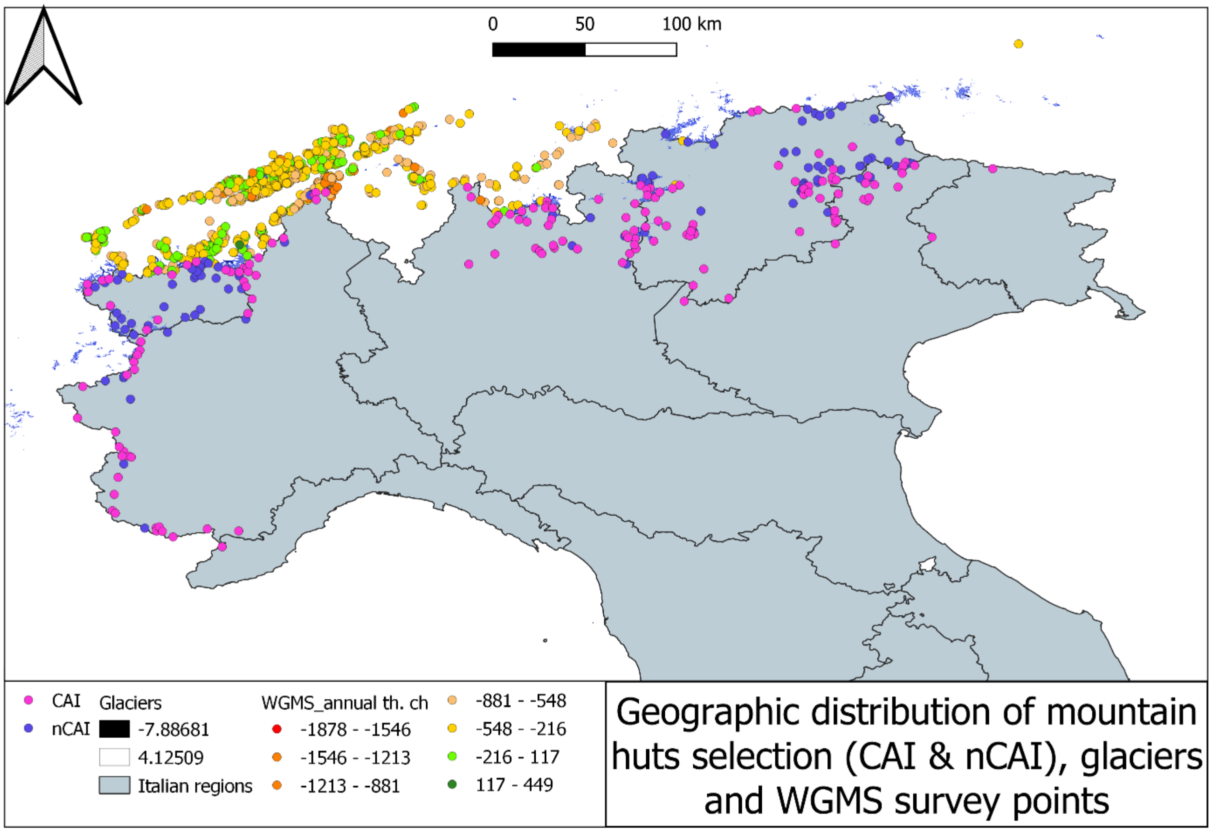


Figure 26 Alps, geographic position of study huts [purple dots] and WGMS points, coloured through annual thickness change values [mm] (image source: QGIS, WGS84, EPSG: 4326)

5.3.5 WGMS points geographic distribution

One first analysis of this computation is related to the geographic position of the WGMS points, which are not equally distributed over the Alps and they are concentrated along the swiss border; this result would be a consistent expression of a specific study area analysis, but it appears much less precise for a more comprehensive evaluation of the glacier retreat on the Alps.

If the WGMS points had appeared more spatially homogenous, an interpolation over the alpine chain would had been more reliable and the thickness change values, associated with all the points of the alpine glaciers, would had been a more accurate result to associate to the glacier coordinates extracted by the PANGAEA data warehouse explained above. Nevertheless, the *annual thickness change* values are kept, due to the absence of more complete and consistent information for the whole Alps (as explained above).

5.3.6 Thickness change – elevation comparison

In order to better understand the *thickness change* values occurrence, a scatterplot is computed (figure *27*), evaluating the distribution of *thickness change* as the elevation of the glacier varies: the variability appears very high, even after the division of the *thickness change* values by the *delta years* to compute the *annual thickness change*.

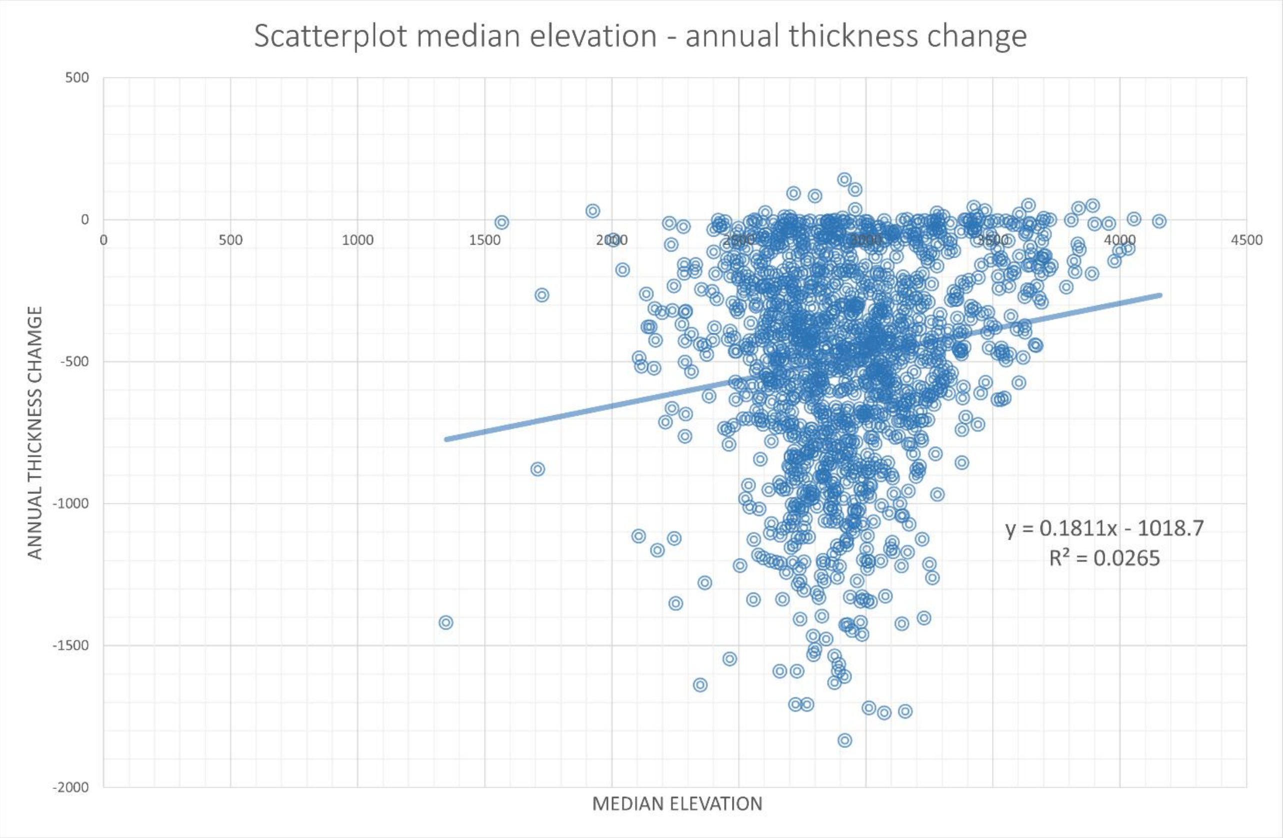


Figure 27 *scatterplot of annual thickness change variability over elevation*

Finally, a further selection is applied, regarding the values of *delta years*: *annual thickness change* values are more reliable if *delta years* are higher enough, because they are related to a longer period; therefore, the WGMS ID points with a *delta years* value lower than 30 years are neglected.

This high uncertainty, checking also the tendency line position and the R^2 indicator, is surely caused by the high heterogeneity of the surveys explained above; given this parameter distribution, it’s impossible to estimate an eventual relationship between the ice loss (expressed by the *annual thickness change*) and the elevation, which would have been extended to the glacier pixels where the WGMS points are not present and compute a continue expression of *thickness change* over the Alps surface.

Nevertheless, the raster is then computed using QGIS software and applying a IDW (inverse distance weighted) interpolation approach to *annual thickness change*, obtaining a raster which is shown below (figure 28) and then uploaded into Matlab software with the same matrix dimension of the PANGAEA glacier matrix.

Must be highlighted that the computed interpolated value has only a functional purpose, it doesn’t’ have any physical meaning, due to the issues explained above, but also because, even inside each raster cell, the ice loss and the associated thickness change value is extremely positional, it doesn’t describe the real ice coverage loss over a single glacier, even less for a larger spatial scale.

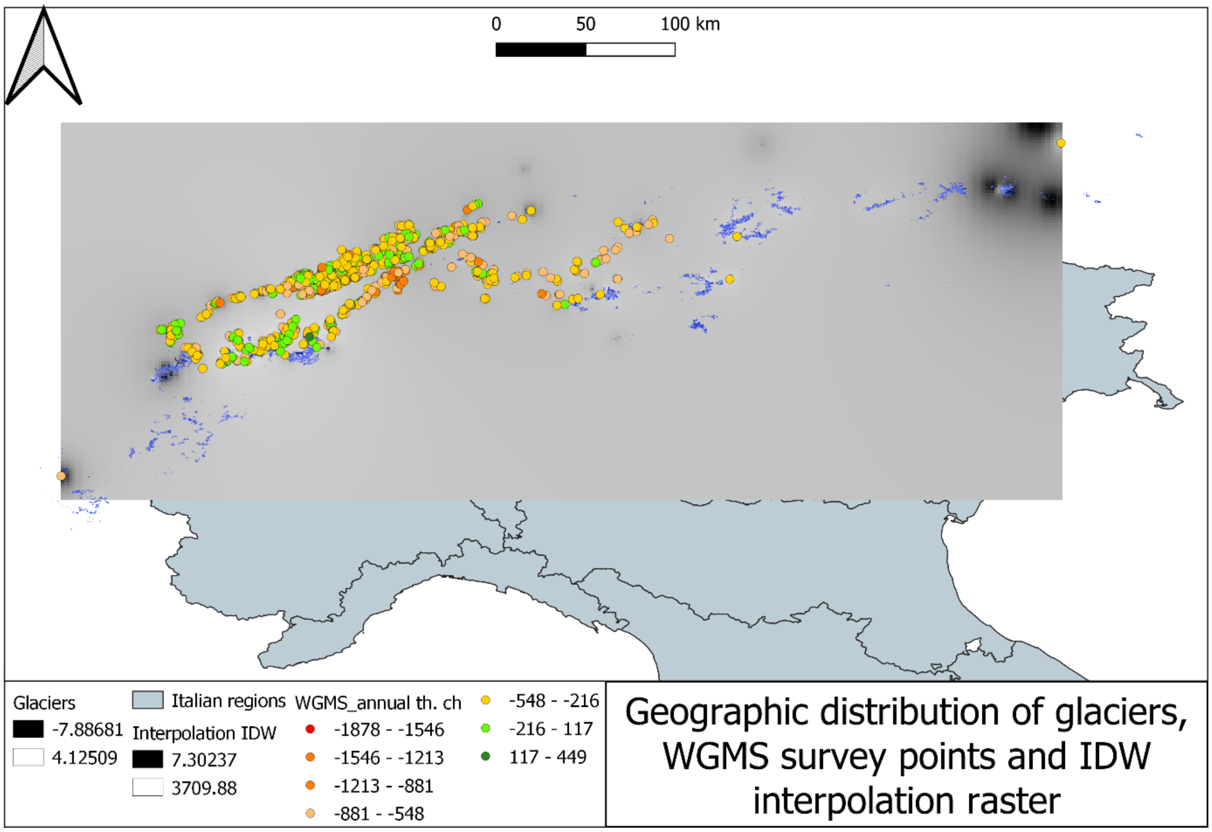


Figure 28 *Alps, geographic position of WGMS points and IDW interpolation raster (image source: QGIS, WGS84, EPSG: 4326)*

6 RISK ANALYSIS

Once the visualisation maps are generated, the following step of the analysis is to determine a risk index for the mountain huts located on the Italian Alps, above 2000 meters and with an available access to freshwater, evaluating the structures that, in this selection, are the most endangered by the glaciers retreat regarding how much their freshwater supply is affected.

For the risk analysis the paper 'Qualitative risk assessment and strategies for infrastructure on permafrost in the French Alps' (Duvillard et al., 2021) is considered, focusing on the Specific Risk computation about the structures built on permafrost over the French Alps area and evaluating the hazard characterisation and the structures vulnerabilities.

6.1 Risk parameters and indicators

For a correct risk analysis, some indicators must be introduced: first, the Hazard evaluation indicates how frequently a specific natural phenomenon is going to occur; the core process of this study is the ice loss caused by the paraglacial processes related to climate change effects, especially whether the glacial retreat affects the meltwater flow and therefore the mountain huts water supply.

The quantification of glaciers ice melting is, for this analysis, represented by the *annual thickness change* parameter which indicates the ice coverage loss trend for a specific area, therefore it's chosen as a numeric representation of the hazard for the risk analysis approach.

Typically, the hazard expresses a frequency of occurrence, in fact the risk analysis of the paper specify how to compute a hazard value considering passive and active factors related to the terrain instability (Duvillard et al., 2021); on the other hand, for this study, the hazard is chosen as an average annual loss of ice thickness, the measurement that better expresses the water supply difficulties related to glacier melting and retreat.

The second indicator is the Vulnerability of the structures that can be affected by the natural phenomena, regarding a description of the structures and infrastructures that could be affected and damaged by a natural phenomenon, considering two factors: the level of potential damage and the financial/operating values of the structure (Duvillard et al., 2021).

The level of potential damage, also generically named as 'Vulnerability' in several risk analysis approaches, is defined as an indicator which evaluates how much the natural phenomena, if occurred, affects the structure; for the purposes of this analysis the indicator can be expressed by the *minimum distance* between each mountain hut and the glaciers in the area because the closer a refuge is to a glacier, the higher is the possibility to be affected by the ice coverage loss, especially for increasing trends.

As explained before, a geographic and spatial distribution comparison among high-altitude structures and shrinking glaciers considers a comprehensive estimation of the effects of climate changes on the Alps and on the solid ice basins, on permafrost and on ice- and snow-covered areas, focusing on the touristic human activity and the freshwater access criticalities for mountain huts.

The *minimum distance* between each selected mountain hut ('CAI' and 'non-CAI') and the closest glacier has been computed using Matlab software and explained further.

Finally, as third indicator, the financial/operating values of the structures describes the values of the structures defining a classification of the affected buildings in terms of costs and losses, in the risk analysis approaches it is typically called 'Exposure'; the financial activity information of the selected mountain huts is not available, therefore this indicators and the computed risk index is not money-based, it's not going to express the risk in terms of financial losses, but instead a general risk related to the freshwater availability for high-altitude environments.

In order to better characterize the selected mountain huts and the associated vulnerability indicator, the *dimension* parameter can be used, which has been saved for each structure and expressed through the number of beds: it's directly proportional, as explained above, to the number of people that the structure is able to host at a time, therefore to the quantity of water that is necessary during a specific period of time, but also to the losses caused by an eventual freshwater unavailability; an higher number of beds means more involved people, a more complex structure, more offered services to the visitors and more financial criticalities for the hosts, the owners and the associations.

The Risk index can be computed multiplying the three indicators: Specific Risk = (Hazard) × (Vulnerability s.l.) (Duvillard et al., 2021), for this analysis the parameters are going to be:

Specific Risk = Hazard [*annual thickness change*] x Vulnerability [*minimum distance*] x Exposure [*dimension*]

6.2 Minimum Distance Computation

Among the three different parameters introduced above, the *minimum distance* shall be computed using Matlab software; first, the selected mountain huts data are uploaded and merged in a single matrix which collects, for all the 259 structures, the following parameters:

- Longitude
- Latitude
- Altitude
- Dimension [number of beds]
- ID

The glaciers position raster (PANGAEA) and the glacier *annual thickness change* raster (WGMS FoG 2021) are uploaded, with the same known georeferenced information and matrix dimension (10 000 x 5000), therefore the cells of the two matrices with the same indices correspond to the same geographical area, they can be superimposed.

Finally, the altitude of the glaciers position is obtained using a European DEM (Source: Copernicus) which has been exported to the same georeferenced information and matrix dimension using QGIS software.

Once the glaciers data are uploaded, a maximum distance threshold is set, in order not to save distances values if higher than 30 kilometres, then a for-cycle computes, for each mountain hut, the distance to the closest glacier cell, also saving the *annual thickness change* associated with that glacier cell.

A Distance Matrix is therefore generated, in which all the needed data and parameters are linked to the mountain huts:

- ID
- Name of the Hut
- Longitude
- Latitude
- Altitude
- Dimension
- Minimum distance to a glacier
- Annual thickness change of the glacier

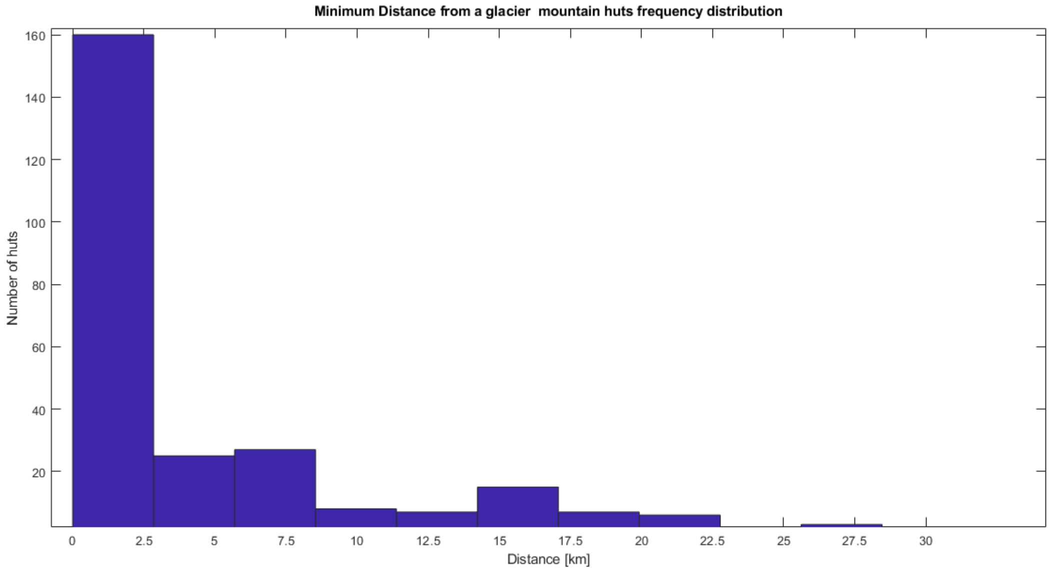


Figure 29 Minimum distance results _ values distribution [kilometres]

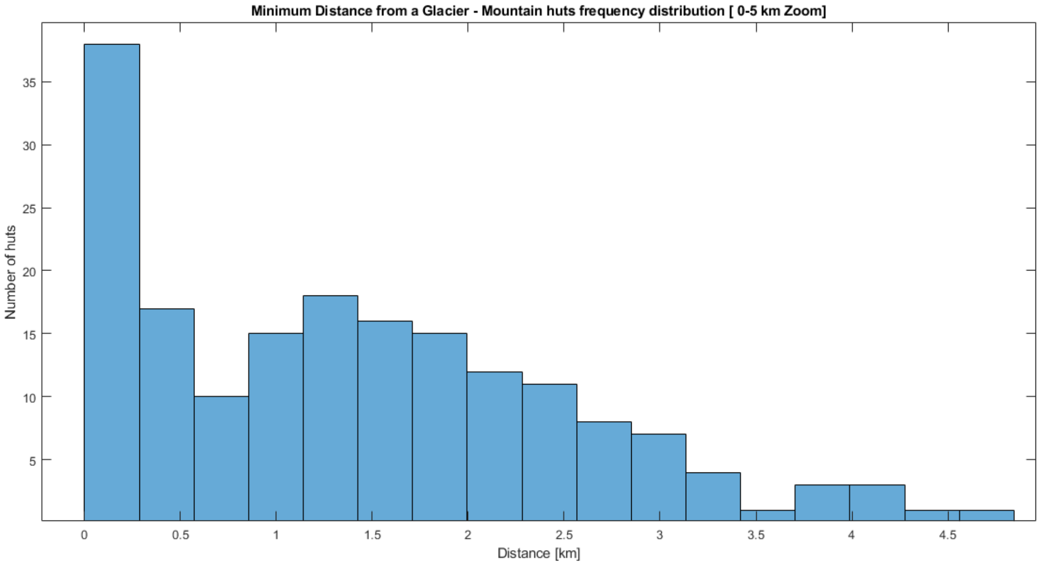


Figure 30 Minimum distance results _ values distribution [kilometres] (0-5 km Zoom)

A specific consideration must be brought regarding the mountain huts which are located just upon a glacierised area: in this case, in terms of data analysis, a further selection is immediate and associated to the end of the Matlab code, and, on the other hand, this highlights the physical meaning of the effects of glacial shrinking, which are much more evident if the building stability directly depends on the glacier underneath.

The Matlab code is asked to select the mountain huts which have a geographical position located inside a cell of the glacier position raster, therefore, with also a computed distance lower then the half of the dimension of the cell. Four structures are selected and shown below (figure *31, 32*)

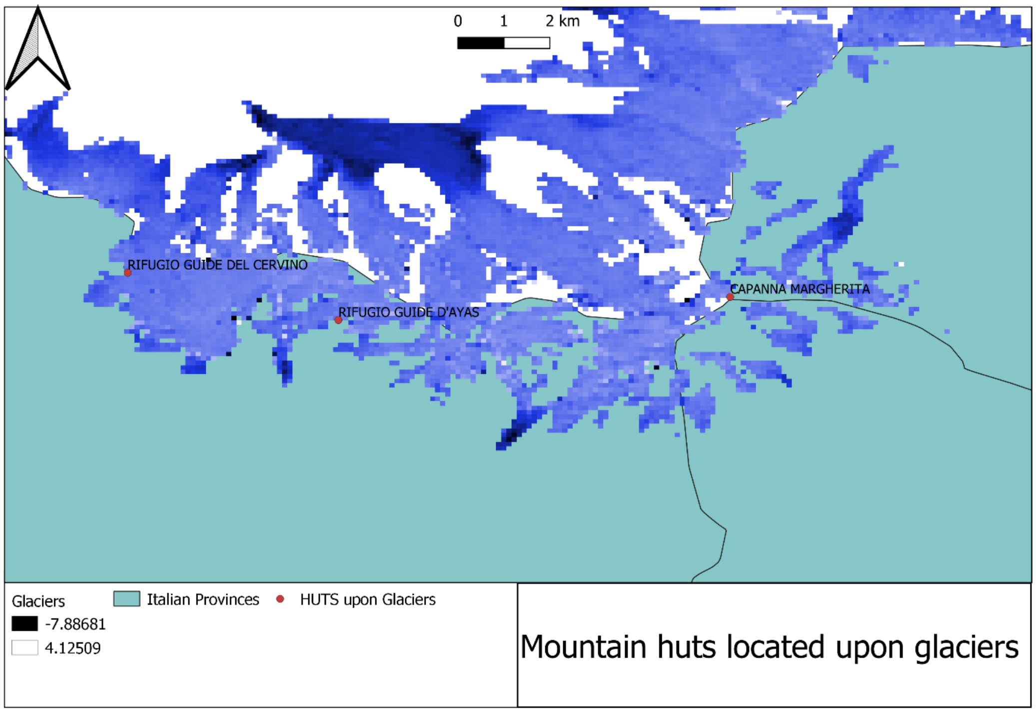


Figure 31 Geographical position of 3 mountain huts located upon a glacier (image source: QGIS, WGS84, EPSG: 4326)

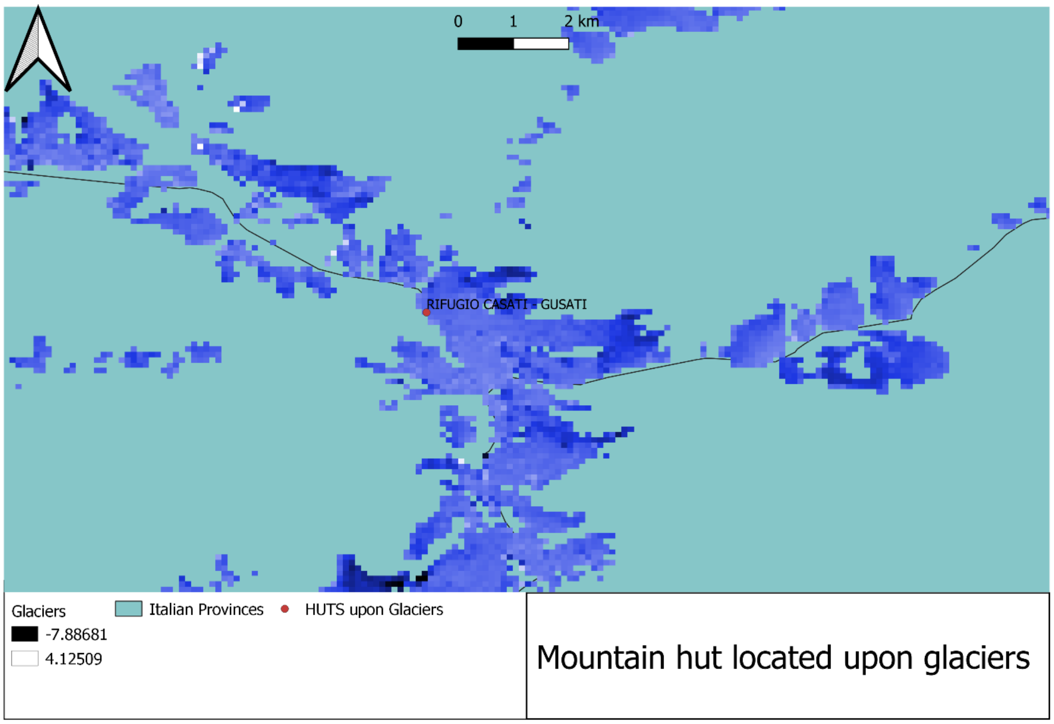


Figure 32 Geographical position of mountain hut located upon a glacier (image source: QGIS, WGS84, EPSG: 4326)

6.3 Parameters normalisation

The specific risk involving the difficulties of freshwater supply due to glaciers retreat in high-altitude environment can now be computed, the values of the three parameters are normalised to better represent the specific risk values.

Three approaches are considered:

- Use raw parameters values
- Define parameters classes (same length classes)
- Define parameters classes (equi-distributed classes in terms of frequency)
- Define parameters classes (logarithmic classes)
- Normalised values

The first approach is discarded because the results of raw values multiplying wouldn't take into account the different numerical variation among the parameters: for instance, an Exposure value of 100 (Dimension : *number of beds)* has a very different effect than a Vulnerability value of 100 (Minimum distance from a glacier: kilometres).

The classification of the parameters is evaluated but not considered, due to the loss information that would result from a limited number of classes of the parameters.

The normalisation is therefore applied applying the following formula:

$$X_{norm} = (X – X_{min}) / (X_{max} – X_{min})$$

Regarding the Vulnerability values, the inverse normalised value is computed, due to the fact that the risk associated to the distance increases when the distance decreases.

The frequency distribution of the three parameters along the normalised values are shown below in Figure 33, 34, 35.

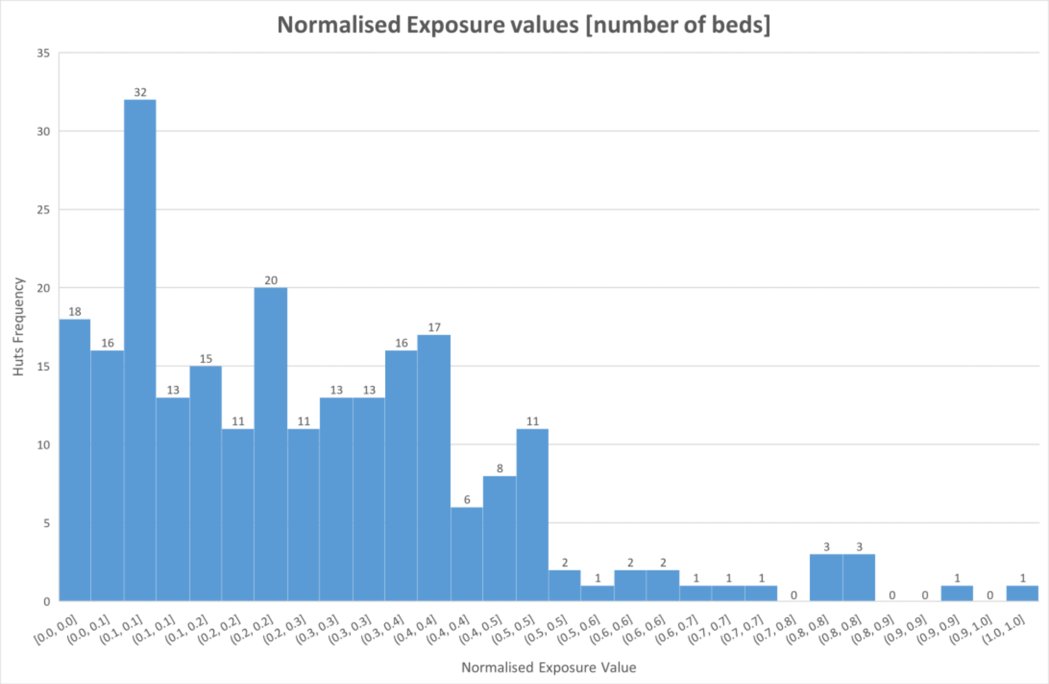


Figure 33 Frequency distribution of Exposure normalised value

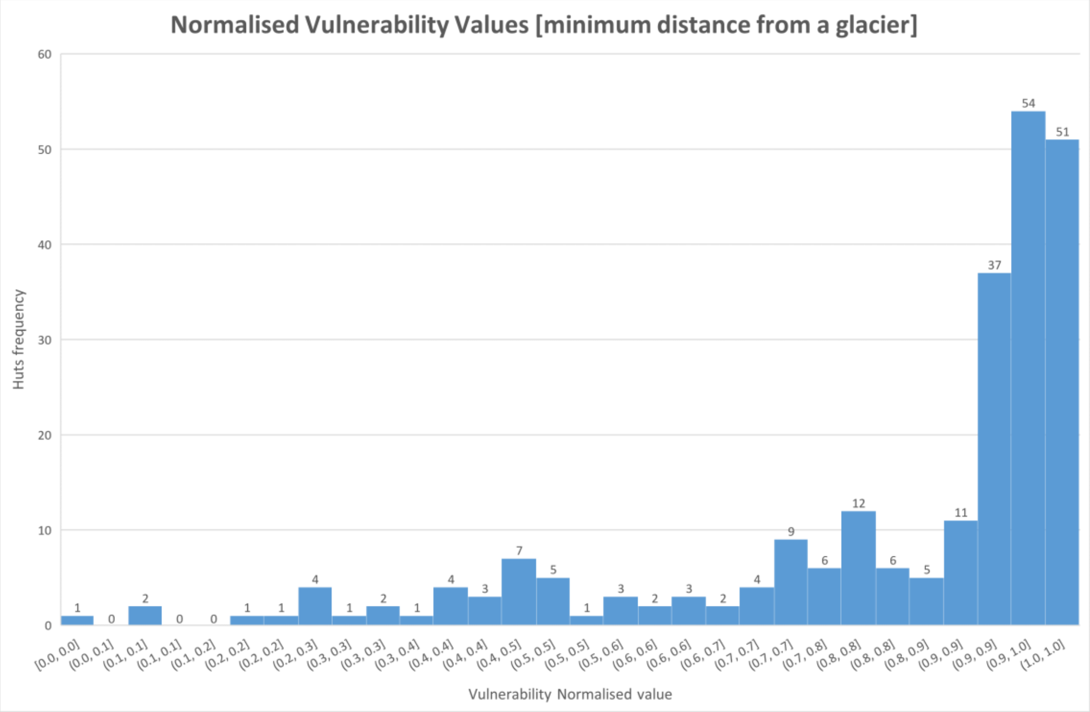


Figure 34 Frequency distribution of Vulnerability normalised value

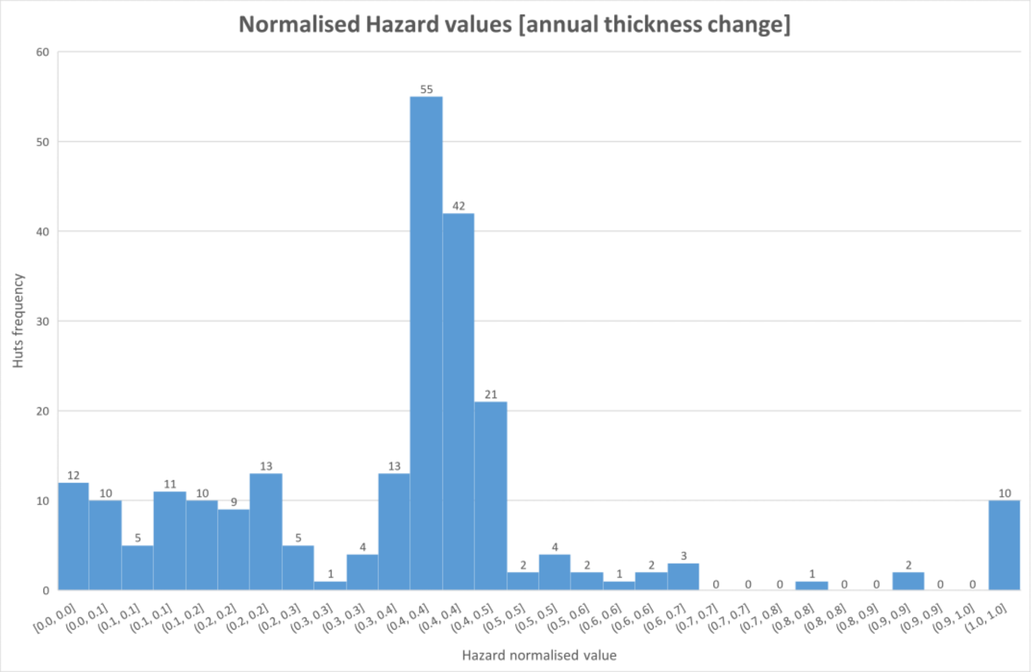


Figure 35 Frequency distribution of Hazard normalised value

The Specific risk results are finally generated, multiplying the normalised value of Hazard, Exposure and Vulnerability, obtaining a specific Risk Index associated to each mountain hut of the selection: the frequency distribution and the geographical distribution are shown below (Figure 36, 37).

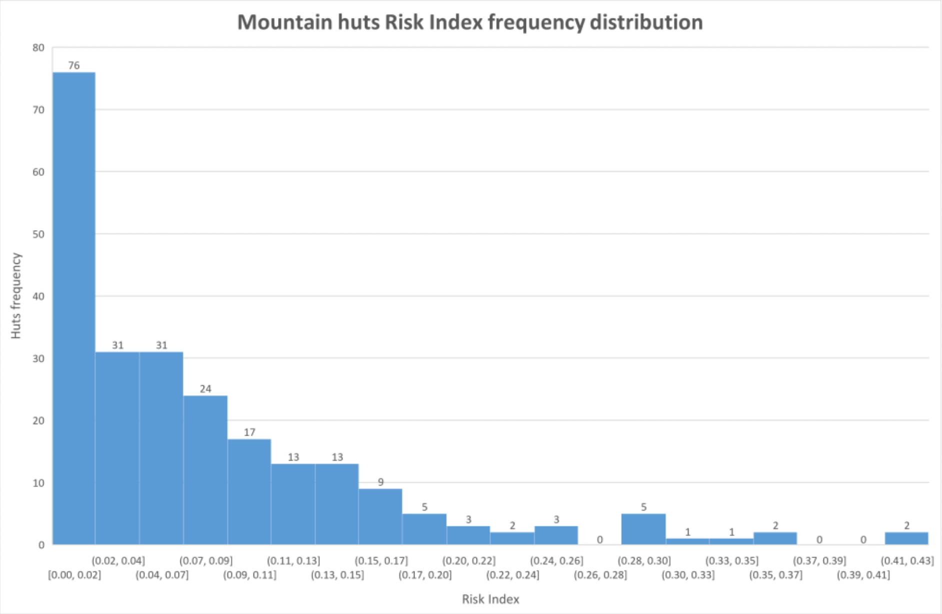


Figure 36 Frequency distribution of Risk values

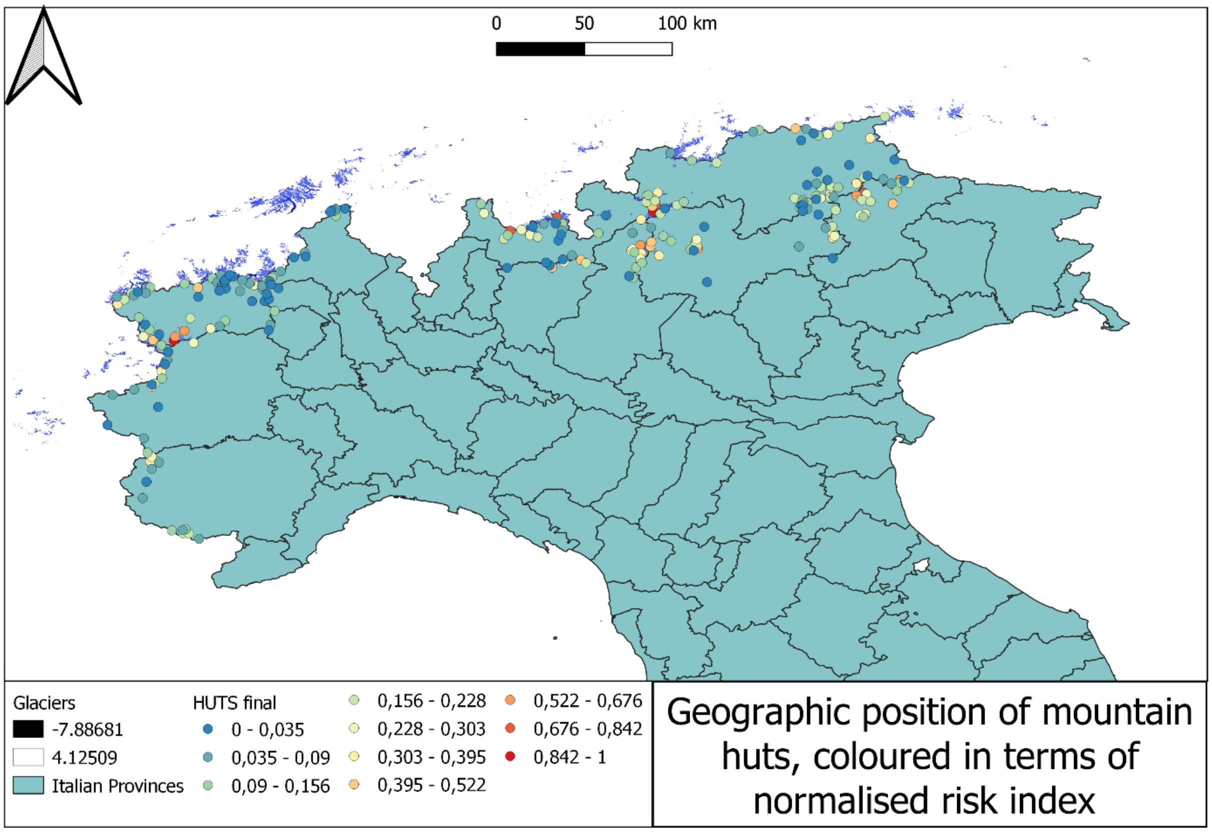


Figure 37 *Geographic position of mountain huts [238 structures], coloured in terms of normalised risk index (image source: QGIS, WGS84, EPSG: 4326)*

In order to better comprehend the distribution of the Risk index among the structures, the Risk index values are also normalised, obtaining a discrete distribution between 0 and 1.

7 RESULTS ANALYSIS, INTERVIEWS

7.1 Risk Index results analysis _ The highest values

Evaluating the obtained results of the Risk Analysis involving the glaciers retreat in proximity of high-altitude mountain huts, the computed values of Specific Risk are considered and discussed, focusing on high values of the parameters.

ID	Name	Altitude	N. of beds	Min Dist.	Thick. Chng.	RISK index	Risk Norm	Locality/Mountain Range
24	RIFUGIO VITTORIO EMANUELE	2732	158	1.27	-365.5	0.435	1.00	Moncorvè, Gran Paradiso
61	RIFUGIO BRANCA-MARTINELLI	2493	102	1.05	-569.5	0.428	0.99	Lago delle Rosole, Stelvio, Forni Glacier
49	RIFUGIO GIANETTI	2534	90	2.15	-581.2	0.366	0.84	Val Porcellizzo
8	RIFUGIO CASATI - GUSATI	3254	192	0.05	-229.7	0.350	0.80	Passo del Cevedale, Stelvio
3	RIFUGIO MARCO E ROSA	3609	104	0.15	-412.3	0.327	0.75	Forcola di Cresta Guzza,Bernina,Lanzada
34	RIFUGIO GIUSSANI	2580	69	1.37	-655.6	0.316	0.73	Forcella Fontananegra, Dolomiti Tofane
47	RIFUGIO GARIBALDI	2548	96	1.60	-426.4	0.294	0.68	Lago Venerocolo, Adamello
33	RIFUGIO SELLA	2585	150	1.98	-262.4	0.287	0.66	Alpe Lauson, Cogne
219	RIFUGIO LAGAZUOI	2752	74	5.73	-655.6	0.287	0.66	Monte Lagazuoi, Dolomiti orientali di Badia
66	RIFUGIO LOCATELLI	2405	160	5.61	-282.2	0.286	0.66	Tre cime, Alta Pusteria
205	RIFUGIO FANES	2062	80	7.90	-655.6	0.283	0.65	Alpe Fanes piccolo
43	RIFUGIO TOSA E PEDROTTI	2491	155	2.85	-234.4	0.257	0.59	San Lorenzo in Banale, Brenta
206	RIFUGIO FEDERICO CHABOD	2710	85	0.88	-402.5	0.249	0.57	Valsavarenche, Alpi Graie
88	RIFUGIO TUCKETT E SELLA	2272	120	1.25	-278.0	0.247	0.57	Vedretta di Brenta inferiore
172	RIFUGIO AI CADUTI DELL'ADAMELLO	3040	120	0.12	-245.5	0.227	0.52	Passo della Lobbia Alta, Adamello
150	RIFUGIO FRATELLI CALVI	2015	78	3.02	-426.4	0.221	0.51	Val Brembana, Orobie
73	RIFUGIO CRETESE SECHES	2391	86	2.02	-357.4	0.215	0.49	Bionaz, Morion
183	RIFUGIO BARBELLINO	2131	60	1.79	-510.5	0.206	0.48	Barbellino Lake, Val Seriana
212	RIFUGIO GIAN FEDERICO BENEVOLO	2287	70	1.96	-426.7	0.204	0.47	Rhêmes-Notre-Dame
17	RIFUGIO PIZZINI	2706	96	0.60	-264.9	0.189	0.44	Cedèc, Cevedale
63	RIFUGIO MANDRON	2449	100	1.84	-264.6	0.189	0.43	Mandrone, Adamello
89	RIFUGIO AURONZO	2333	115	7.34	-282.2	0.186	0.43	Tre cime, Dolomiti
22	RIFUGIO EUROPA	2690	100	4.29	-286.6	0.186	0.43	Mount Kraxentrager
151	RIFUGIO CITTA' DI MESTRE	2018	99	1.03	-254.1	0.185	0.43	Col de la Puina

Table 6 Highest Risk index mountain huts (selection of highest values)

The complete information about the Risk Index computation are described into Attachment 1, nevertheless a further analysis is evaluated in this chapter, focusing on structures associated to high values of Risk Index (presented in Figure 38, 39, 40 using normalised risk index values).

It’s possible to underline that these structures are distributed in a heterogenous way over the Alpine chain, they are located in three main areas: the Gran Paradiso, the Lombardia-Trentino border area and the eastern Dolomites.

These mountain huts are located in different areas of the Alps, but they are associated with high values of Hazard, Vulnerability and Exposure: it means that they are built close to glaciers that are shrinking rapidly in the last years and they are characterised by a large number of beds available for the visitors.

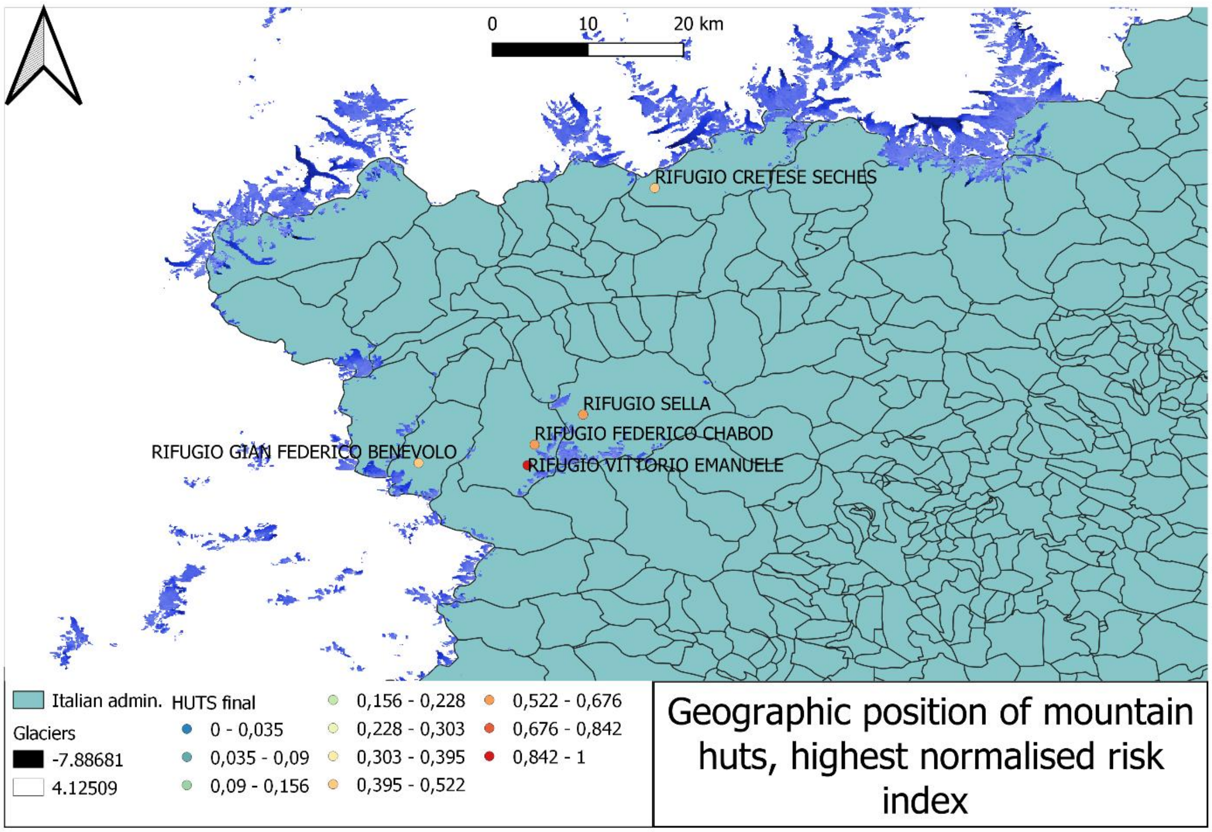


Figure 38 geographic position of highest normalised risk index
[Image Source: QGIS, WGS84, EPSG: 4326]

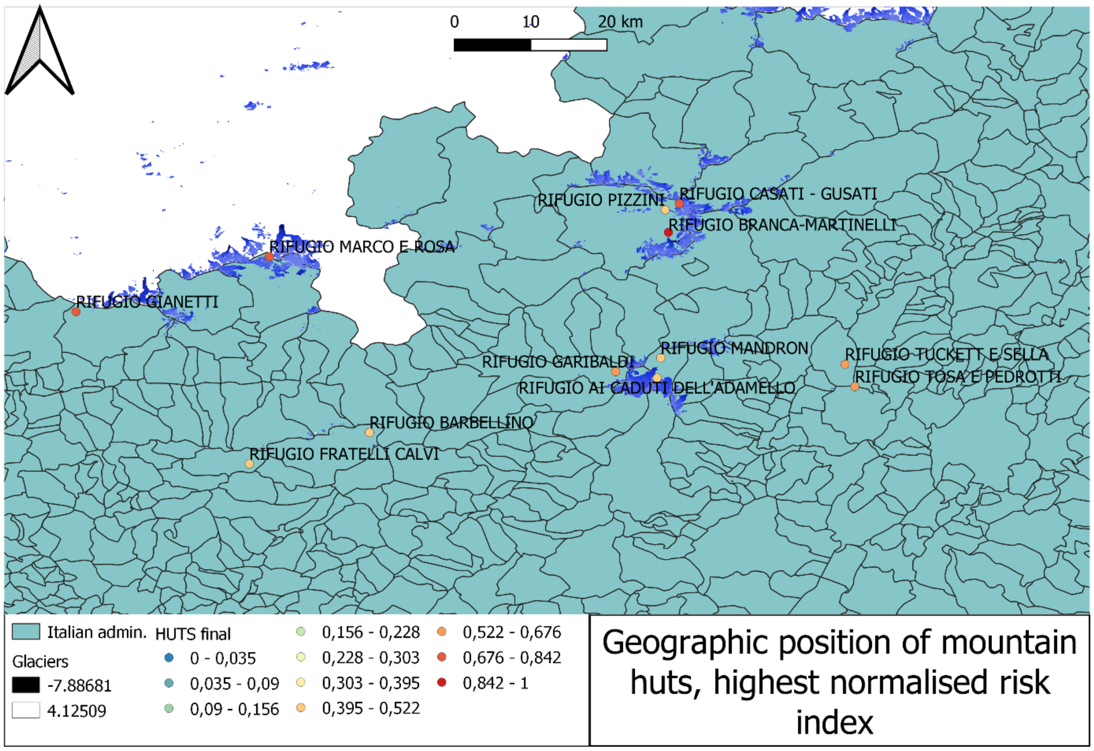


Figure 39 geographic position of geographic position of highest normalised risk index [Image Source: QGIS, WGS84, EPSG: 4326]

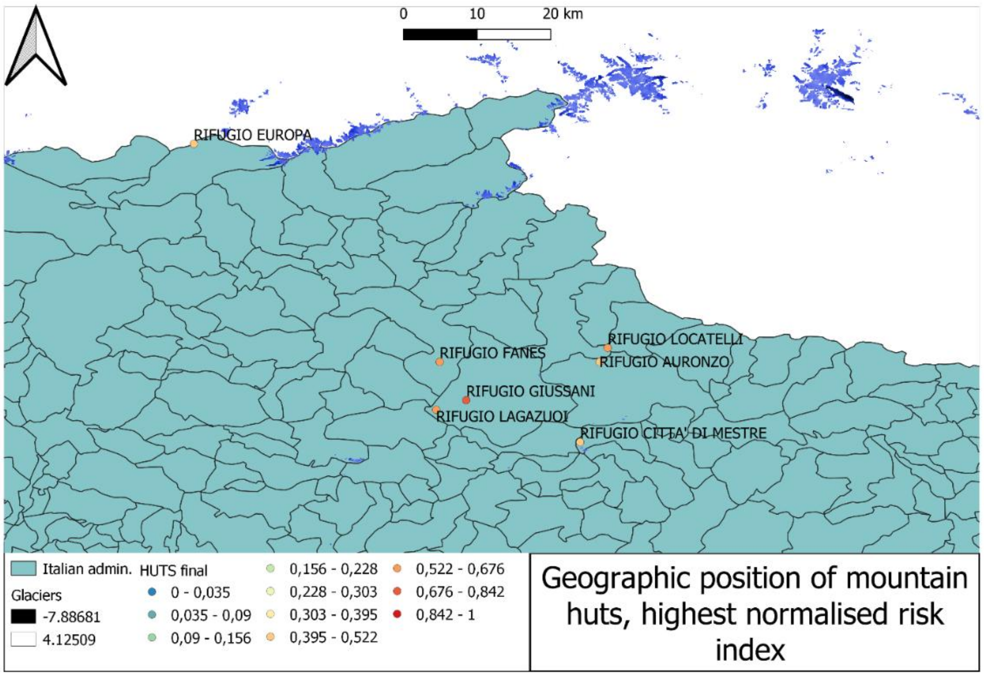


Figure 40 geographic position of highest normalised risk index

7.3 INTERVIEWS

7.3.1 SETTING

The analysis results show the geographical distribution of the mountain huts and their associated risk index in terms of water supply availability: the high value of Risk, obtained multiplying the values of Hazard (*annual thickness change*), the Vulnerability (*minimum distance from a glacier*) and the Exposure (*dimension* of the structure, expressed in terms of 'number of beds'), takes into account these parameters, but it's actually not sufficient to wholly express the freshwater access availability and the difficulties related to climate change effects, glaciers retreat and ice coverage loss, temperature increase and precipitations frequency variation.

Moreover, it's not possible to find any relationship among the structures that are linked to a very high level of Risk: they are not located in the same region of the Alps, their altitude is not consistent and the environmental features and characteristics are not similar among them.

Therefore, in order to complete this study, a series of telephonic interviews have been set, approaching the mountain huts management staff with the highest risk index values and asking them the same questions about the water supply difficulties, the usage of water and the perception of the phenomena.

This final step has been chosen in order to confirm or disprove the obtained results, asking directly to the people which live and work on the territory that has been analysed, and especially to transfer the information of existing structures to the hosts and the staff, who are directly involved in climate change effects and who are experiencing the phenomena that have been described and evaluated in this analysis.

This last passage of the study is essential in order to combine a scientific research approach through literature review and data analysis with the direct experience of the structures managers and staff, enriching the evaluation of the climate change effects involving the high-altitude environment and connecting the two level of comprehension of the climatic variations on the alpine environment.

7.3.2 MOUNTAIN HUTS MANAGEMENT EXPERIENCE

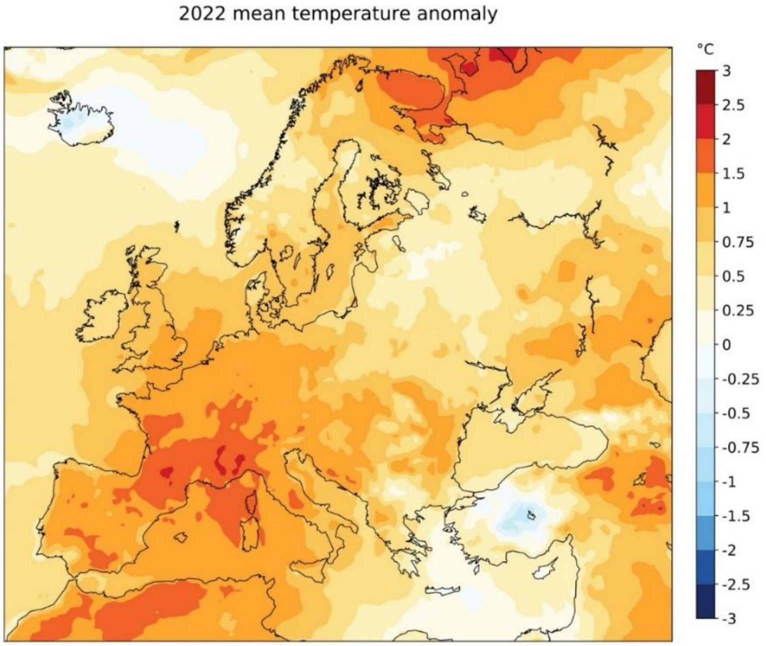
All the mountain huts managements shown above have been contacted via e-mail and five of them were available for a telephone call interview, during which the same question have been asked:

- the characteristics of the water access and water basins of the area (GW and surface)
- the eventuality of energy production
- the water supply difficulties in the last years
- any strategies considered and applied
- climate change effects perception

Firstly, the usage of the extracted water is considered, regarding the different structure necessities: besides the freshwater access for domestic purposes, such as the kitchen and the toilets, all the interviewed confirmed that the water extracted from the area is used also for electric energy production using turbines: for some of the structures the water level difference which is exploited for hydropower production derives from the same extraction sites of the potable water used inside the structure (for instance, Rifugio Gianetti), while for other huts the extraction site for the domestic use it's not the same related to the turbine.

The energy production is perceived as the most concerning issue related to water supply, four structures had experienced issues involving the turbine and three of them confirmed that during the summer of 2022 it was really difficult to keep a constant water flow and fuel-combustion energy generators were used to fill the energy loss.

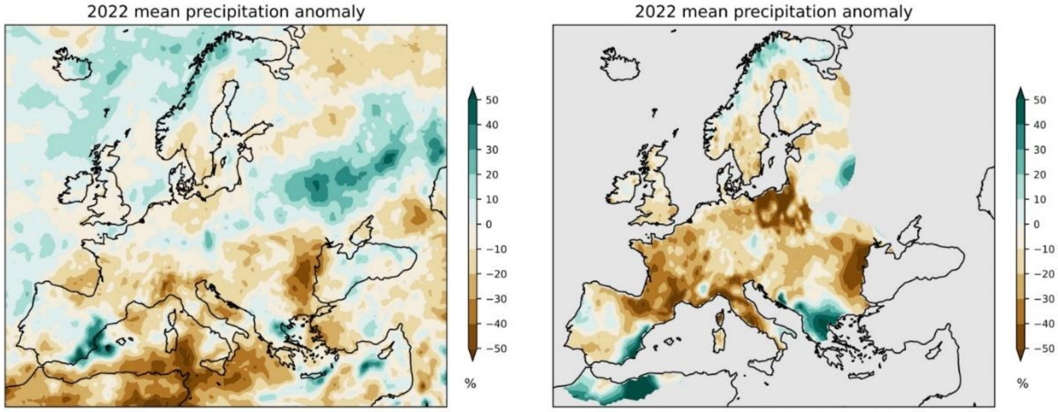
In fact during 2022 the climatic effects on the mountain chain were extremely effective, with very high recorded temperatures (both in terms of peaks and hot-periods durations) and a very low cumulative meteoric water, leading to a generalised freshwater scarcity on the whole Alps (see Figure 41, 42).



Reference period: 1991-2020, Data source: ERA5, Credit: C3S/ECMWF

Copernicus Climate Change Service European State of the Climate | 2022 PROGRAMME OF THE EUROPEAN UNION Copernicus ECMWF

Figure 41 2022 mean temperature anomaly, EU (Copernicus)



Data source: ERA5 Credit: C3S/ECMWF Reference Period: 1991-2020

Data source: E-OBS Credit: C3S/KNMI Reference Period: 1991-2020

Copernicus Climate Change Service European State of the Climate | 2022 PROGRAMME OF THE EUROPEAN UNION Copernicus ECMWF

Figure 42 2022 mean precipitation anomaly, EU (Copernicus)

The water supply can be directly affected by surface water variations, such as a lake water level: for Rifugio Barbellino, for instance, the potable freshwater is extracted from a spring, but the structure energy production is supplied by a turbine upstream the Barbellino lake and, according to the manager, during summer of 2022 the water level of the basin was so low that they had to shut the hydropower production down, until the next precipitation events.

"The month of July of last year was harsh, we didn't stop our hut activity, but we were at the limit. Luckly, after some rainy days in August, the level of the lake rose and we were able to re-active the turbine." (M. Albricci, Rifugio Barbellino, 22/06/23).

A very similar issue has been experienced by the staff of Rifugio Gianetti, who was forced to stop using the turbine due to water scarcity, otherwise they wouldn't had had enough waterflow for the potable use.

Figure 43 Rifugio Barbellino

A critical year in terms of climatic effects can affect the hut management also through other factors than water scarcity, for instance related to dissolved minerals and deposits in the glaciers meltwater: the Rifugio Vittorio Emanuele manager assured that the water scarcity wasn't affecting them, but a greater ice coverage loss and ice melting caused a more concentration of transported solid material in the waterflow used for hydropower production, causing a malfunctioning of the turbine.

"We didn't experience potable water scarcity, but the control unit of the turbine was damaged by the dissolved silt inside the meltwater coming from the glaciers, our settling tanks were not sufficient because in the flow the presence of solid material and sand was too high." (P. Pellisie, Rifugio Vittorio Emanuele, 23/06/23).

Figure 44 Rifugio Vittorio Emanuele

Regarding the possible strategies to face the increasing trends in this sensitive environment, especially relating to freshwater scarcity, a possible solution has been chosen by the staff of Rifugio Branca, who decided to apply an adaptation strategy taking advantage of a CAI public call and build a bigger water storage system.

“Luckly we didn’t’ have issues during the summer of 2022, thanks to the characteristics of the ground of the area, but we know that several other huts were forced to closed and to stop the activity due to water availability loss. In order to prevent any future issue, we applied for a CAI public call and we now have a water storage able to collect up to 6000 liters.” (S. Confortova, Rifugio Branca, 23/03/2023).

This choice supports a convenient evaluation of the crisis of the area and a prevision of the future which is part of a reasonable strategy of adaptation of climate change effects in high-altitude environment.

Figure 45 Rifugio Branca

Besides the water availability among the mountain huts and the issued experienced by the management staff, the perception of the climate change is consistent with the data information and the description provided by the climate agencies such as Copernicus, WGMS and CGI: all the interviewed managers assured that they are clearly aware of the variations in the surrounding area, the increasing temperature and the temporal changes in seasonal flourishes, the precipitation frequency irregularity and the ice - and snow – coverage areas disappearing.

They describe the water basins that are no longer frozen during wintertime, the mountain peaks that are not snow-covered during the whole year and, in general, the solid precipitation and accumulation are more rare and shorter in terms of time duration.

“The next years will be harder for sure. We are aware of how fast everything changes, especially for the people who attend this place. During this year the situation is better [2023], but if another year like 2022 happened again, everything can occur: the landscape, the territory, the water, everything changes, it’s difficult to predict how it’ll be.” (P. Pellisie, Rifugio Vittorio Emanuele, 23/06/23).

The climate change perception is consistent among the structures and it reflects the concerning uncertainty of the future, a complex scenario which involves an environmental and human activity system, but also the working activities of people which are directly experiencing the climate change effects in one of the most sensitive environments.

Figure 46 Rifugio Benevolo

Figure 47 Rifugio Gianetti

8. CONCLUSIONS

Collecting all the information and the experiences provided by the mountain huts management staff during the interviews and comparing them with the glacier and huts analysis of this study, it’s possible to evaluate some final considerations.

The Alpine glaciers retreat is a critical climate issue for the countries which are part of the mountain chain (Italy, France, Austria, Switzerland, Slovenia), the ice coverage loss and permafrost degradation affects several sectors such as the hydropower production net, the touristic sector, the residential one and the environment, reducing the water availability, increasing the frequency of natural hazards and terrain instability, affecting the surface and underground water basins and forcing flora and fauna to move their natural habitats.

The high-altitude mountain huts are located in an altitude layer where these effects and the paraglacial processes are enforced, leading to terrain instability, itineraries variations, rockfall and detachments occurrence, droughts and extreme precipitation events and freshwater availability uncertainty.

A first step of evaluation of how much the glaciers shrinking are going to affect the structures is a geographical comparison distance-related, therefore a geographical distribution of high-altitude mountain huts and glaciers are generated: connecting the data about the distance and the annual ice loss provided a useful information about how much the glacier retreat can affect the mountain hut management.

On the other hand, the telephonic interviews which are set at the end of the study give fundamental information about the real effects of glaciers retreat on the freshwater access availability: in fact, none of the managers confirmed the water scarcity assumed at the end of the analysis regarding the different classes of Risk computed combining Hazard, Vulnerability and Exposure, while instead some of them assured a stable access to water.

Rifugio Barbellino manager, as said above, described how their water availability directly depends on the lake Barbellino, some meters upstream the hut, while Rifugio Branca staff didn’t experience water scarcity during 2022 thanks to the characteristics of the terrain, associated to a lower hydraulic conductivity value and therefore to a higher water storage capacity, even if the glaciers close to the structures are shrinking at a higher trend.

This consideration can lead to a more comprehensive description of the factors that can affect the water scarcity of a high-altitude building and touristic structure, which are not only related to the distance to a glacier and how fast that glacier is melting, but it depends also from the presence of surface basins (Rifugio Barbellino), the characteristics of the terrain (Rifugio Branca) and several other site-specific characteristics.

The ice melting of the glaciers, increasing over the Alps in the current climatic period, causes an abundance of melting water, with higher surface flows and higher groundwater levels, therefore the alpine touristic activities haven’t experienced any glacier-related water scarcity yet.

This study considers the present situation around the Alps, but the ice coverage loss and permafrost degradation must be considered in a long-term period, evaluating how the glaciers retreat would lead, in the next future, to critical water scarcity, therefore the current melting flows will eventually end up to become water scarcity.

The computed risk index shall be considered as a long-term risk evaluation highlighting how the water supply issues are going to evolve in the next years for the single mountain huts, considering their dimension, their distance from the surrounding glaciers and how much the ice is shrinking in the area.

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I would finally thank all the people who helped me during these years, the professors, the colleagues, my friends, my therapist and virtual rooms web channels participants.

ATTACHMENTS

ATTACHMENT 1: RISK ANALYSIS RESULTS TABLE _ Risk index sorted (descendent)

Long.	Lat.	Altitude	Dimension	Exp. Norm	ID	Glacier Dist.	Vuln. Norm	Thick. Chng.	Hazard Norm	Name	RISK	RISK NORM
7,229	45,513	2732	158	0,82	24	1,27	0,96	-365,48	0,56	RIFUGIO VITTORIO EMANUELE	0,435	1,000
10,584	46,415	2493	102	0,51	61	1,05	0,96	-569,45	0,87	RIFUGIO BRANCA-MARTINELLI	0,428	0,985
9,584	46,281	2534	90	0,45	49	2,15	0,93	-581,23	0,89	RIFUGIO GIANETTI	0,366	0,842
10,602	46,463	3254	192	1,00	8	0,05	1,00	-229,68	0,35	RIFUGIO CASATI - GUSATI	0,350	0,805
9,911	46,374	3609	104	0,52	3	0,15	1,00	-412,26	0,63	RIFUGIO MARCO E ROSA	0,327	0,752
12,061	46,545	2580	69	0,33	34	1,37	0,95	-655,63	1,00	RIFUGIO GIUSSANI	0,316	0,728
10,495	46,179	2548	96	0,48	47	1,60	0,95	-426,36	0,65	RIFUGIO GARIBALDI	0,294	0,676
7,303	45,580	2585	150	0,77	33	1,98	0,93	-262,41	0,40	RIFUGIO SELLA	0,287	0,662
12,008	46,528	2752	74	0,36	219	5,73	0,80	-655,63	1,00	RIFUGIO LAGAZUOI	0,287	0,660
12,311	46,637	2405	160	0,83	66	5,61	0,80	-282,22	0,43	RIFUGIO LOCATELLI	0,286	0,657
12,014	46,612	2062	80	0,39	205	7,90	0,72	-655,63	1,00	RIFUGIO FANES	0,283	0,652
10,899	46,154	2491	155	0,80	43	2,85	0,90	-234,37	0,36	RIFUGIO TOSA E PEDROTTI	0,257	0,591
7,239	45,540	2710	85	0,42	206	0,88	0,97	-402,45	0,61	RIFUGIO FEDERICO CHABOD	0,249	0,574
10,882	46,192	2272	120	0,61	88	1,25	0,96	-277,99	0,42	RIFUGIO TUCKETT E SELLA	0,247	0,568
10,565	46,169	3040	120	0,61	172	0,12	1,00	-245,50	0,37	RIFUGIO AI CADUTI DELL'ADAMELLO	0,227	0,522
9,877	46,024	2015	78	0,38	150	3,02	0,90	-426,36	0,65	RIFUGIO FRATELLI CALVI	0,221	0,510
7,399	45,882	2391	86	0,42	73	2,02	0,93	-357,36	0,54	RIFUGIO CRETESE SECHES	0,215	0,494
10,080	46,076	2131	60	0,28	183	1,79	0,94	-510,49	0,78	RIFUGIO BARBELLINO	0,206	0,475
7,084	45,516	2287	70	0,34	212	1,96	0,93	-426,71	0,65	RIFUGIO GIAN FEDERICO BENEVOLO	0,204	0,470
10,579	46,453	2706	96	0,48	17	0,60	0,98	-264,93	0,40	RIFUGIO PIZZINI	0,189	0,436
10,571	46,203	2449	100	0,50	63	1,84	0,94	-264,59	0,40	RIFUGIO MANDRON	0,189	0,435
12,296	46,612	2333	115	0,58	89	7,34	0,74	-282,22	0,43	RIFUGIO AURONZO	0,186	0,428

11,581	46,997	2690	100	0,50	22	4,29	0,85	-286,62	0,44	RIFUGIO EUROPA	0,186	0,427
12,262	46,471	2018	99	0,49	151	1,03	0,97	-254,09	0,39	RIFUGIO CITTA' DI MESTRE	0,185	0,425
12,103	46,929	2274	90	0,45	243	1,63	0,94	-267,57	0,41	RIFUGIO ROMA ALLE VEDRETTE DI RIES	0,172	0,395
7,110	44,666	2640	94	0,47	28	1,55	0,95	-254,09	0,39	RIFUGIO QUINTINO SELLA (MONVISO)	0,171	0,394
7,850	45,900	3611	176	0,91	6	0,06	1,00	-118,75	0,18	CAPANNA GNIFETTI	0,165	0,379
10,626	46,108	2450	85	0,42	46	1,02	0,97	-263,73	0,40	RIFUGIO CARE' ALTO	0,162	0,374
10,502	46,124	2235	69	0,33	96	2,08	0,93	-345,04	0,53	RIFUGIO PRUDENZINI	0,162	0,372
10,892	46,174	2580	94	0,47	175	1,28	0,96	-234,37	0,36	RIFUGIO ANGELO ALIMONTA	0,160	0,367
7,143	45,298	2659	99	0,49	20	1,38	0,95	-219,28	0,33	RIFUGIO GASTALDI	0,157	0,362
12,358	46,629	2224	80	0,39	259	2,33	0,92	-282,22	0,43	RIFUGIO ZSIGMONDY-COMICI	0,155	0,356
10,432	46,141	2281	90	0,45	182	3,09	0,89	-254,09	0,39	RIFUGIO BAITONE	0,154	0,354
10,618	46,547	2721	65	0,31	173	1,30	0,96	-322,70	0,49	RIFUGIO ALFREDO SERRISTORI	0,146	0,335
10,543	46,528	3029	75	0,36	233	0,78	0,97	-269,17	0,41	RIFUGIO JULIUS PAYER	0,145	0,335
6,837	45,767	2195	77	0,38	108	0,96	0,97	-262,64	0,40	RIFUGIO ELISABETTA SOLDINI	0,145	0,334
7,065	44,666	2450	80	0,39	55	1,28	0,96	-254,09	0,39	RIFUGIO VALLANTA	0,145	0,333
7,793	45,901	3585	142	0,73	4	0,14	1,00	-131,27	0,20	RIFUGIO SELLA (AL FELIK)	0,145	0,333
11,843	46,231	2333	78	0,38	91	3,22	0,89	-281,22	0,43	RIFUGIO VELO DELLA MADONNA	0,145	0,333
12,069	46,399	2132	86	0,42	127	5,82	0,80	-279,49	0,43	RIFUGIO COLDAI	0,144	0,331
12,007	46,611	2042	45	0,20	222	8,14	0,71	-655,63	1,00	RIFUGIO LAVARELLA	0,144	0,331
11,822	46,536	2587	111	0,56	32	9,83	0,66	-254,09	0,39	RIFUGIO CAVAZZA	0,142	0,327
12,041	46,499	2413	41	0,18	180	6,52	0,77	-655,63	1,00	RIFUGIO AVERAU	0,138	0,319
11,839	46,267	2578	80	0,39	35	2,78	0,90	-254,09	0,39	RIFUGIO ROSETTA	0,137	0,315
10,500	46,359	2541	71	0,34	45	1,41	0,95	-269,17	0,41	RIFUGIO BERNI	0,134	0,308
10,583	46,502	2661	70	0,34	199	0,53	0,98	-261,15	0,40	RIFUGIO DEL COSTON	0,132	0,303
7,018	45,541	2284	80	0,39	224	1,51	0,95	-229,68	0,35	RIFUGIO MARIO BEZZI	0,130	0,299
7,488	45,596	2526	74	0,36	252	3,11	0,89	-	0,40	RIFUGIO SOGNO	0,129	0,296

								263,87		DU BERDZE' AL PERADZA		
9,960	46,062	2295	64	0,30	86	1,19	0,96	-286,62	0,44	RIFUGIO BRUNONE	0,128	0,294
11,854	46,244	2278	65	0,31	100	1,66	0,94	-281,22	0,43	RIFUGIO PRADIDALI	0,125	0,288
10,497	46,083	2020	80	0,39	147	6,21	0,78	-261,85	0,40	RIFUGIO LISSONE	0,122	0,281
7,369	45,496	2217	70	0,34	238	2,83	0,90	-261,53	0,40	RIFUGIO PONTESE	0,121	0,279
11,633	46,459	2243	130	0,66	105	15,15	0,47	-254,09	0,39	RIFUGIO VAJOLET	0,120	0,277
9,664	46,288	2385	70	0,34	75	1,19	0,96	-234,37	0,36	RIFUGIO ALLIEVI	0,115	0,266
11,757	46,509	2180	86	0,42	102	8,80	0,69	-254,09	0,39	RIFUGIO PASSO SELLA	0,114	0,261
10,876	46,175	2180	98	0,49	115	1,85	0,94	-161,17	0,25	RIFUGIO MARIA E ALBERTO	0,112	0,258
12,078	46,536	2303	30	0,12	237	2,02	0,93	-655,63	1,00	RIFUGIO POMEDES	0,111	0,256
10,440	46,150	2450	65	0,31	60	2,25	0,92	-254,09	0,39	RIFUGIO TONOLINI	0,111	0,255
12,033	46,388	2250	77	0,38	84	8,80	0,69	-279,49	0,43	RIFUGIO TISSI	0,110	0,254
9,402	46,403	2044	73	0,35	143	1,87	0,94	-214,50	0,33	RIFUGIO CHIAVENNA	0,108	0,248
7,075	45,191	2854	60	0,28	190	1,67	0,94	-265,62	0,40	RIFUGIO CA' D'ASTI	0,108	0,248
10,889	46,220	2261	70	0,34	90	3,21	0,89	-234,37	0,36	RIFUGIO GRAFFER	0,107	0,246
9,723	46,251	2559	56	0,26	44	1,07	0,96	-267,11	0,41	RIFUGIO PONTI	0,102	0,235
11,809	46,957	2420	60	0,28	213	2,44	0,92	-257,46	0,39	RIFUGIO GIOVANNI PORRO	0,102	0,234
7,076	44,697	2741	60	0,28	21	2,20	0,92	-254,09	0,39	RIFUGIO GIACOLETTI	0,101	0,233
12,206	47,080	2441	56	0,26	189	0,96	0,97	-257,78	0,39	RIFUGIO BRIGATA TRIDENTINA	0,099	0,228
7,346	45,668	2507	66	0,32	177	3,71	0,87	-234,70	0,36	RIFUGIO ARBOLLE	0,098	0,226
12,374	46,615	2297	54	0,25	72	2,75	0,90	-282,22	0,43	RIFUGIO CARDUCCI	0,097	0,224
6,934	45,844	3375	150	0,77	7	0,16	1,00	-83,03	0,13	RIFUGIO TORINO	0,097	0,223
11,824	46,515	2873	69	0,33	9	7,42	0,74	-254,09	0,39	RIFUGIO BOE'	0,095	0,219
11,863	46,425	2074	50	0,23	136	1,55	0,95	-282,22	0,43	RIFUGIO FALIER	0,093	0,214
10,538	46,482	2878	50	0,23	14	0,30	0,99	-267,11	0,41	RIFUGIO QUINTO ALPINI	0,092	0,212
11,886	47,013	3026	50	0,23	247	0,12	1,00	-264,46	0,40	RIFUGIO AL SASSO NERO (VITTORIO VENETO)	0,092	0,211
11,829	46,590	2475	94	0,47	57	15,77	0,45	-287,52	0,44	RIFUGIO PUEZ	0,091	0,210
10,597	46,491	2581	55	0,26	195	0,50	0,98	-	0,35	RIFUGIO CITTA'	0,089	0,204

								231,75		DI MILANO		
12,045	46,496	2574	29	0,11	36	6,79	0,76	-655,63	1,00	RIFUGIO GIUSSANI	0,087	0,200
11,838	46,311	2571	51	0,23	39	2,55	0,91	-266,36	0,41	RIFUGIO MULAZ	0,086	0,199
10,752	46,461	2436	77	0,38	58	1,93	0,93	-159,76	0,24	RIFUGIO DORIGONI	0,085	0,196
9,777	46,237	2086	50	0,23	110	2,47	0,91	-265,62	0,40	RIFUGIO BOSIO-GALLI	0,084	0,194
11,575	46,507	2450	136	0,70	69	20,61	0,28	-287,52	0,44	RIFUGIO BOLZANO	0,084	0,194
11,758	46,588	2037	90	0,45	207	16,43	0,42	-287,52	0,44	RIFUGIO FIRENZE	0,083	0,190
7,296	44,163	2430	46	0,21	65	2,87	0,90	-289,02	0,44	RIFUGIO REMONDINO	0,082	0,188
9,541	46,224	2212	24	0,09	98	1,87	0,94	-655,63	1,00	CAPANNA VOLTA	0,081	0,187
11,029	46,757	2875	80	0,39	208	0,42	0,99	-137,01	0,21	RIFUGIO FRANCESCO PETRARCA	0,080	0,185
7,334	44,161	2015	50	0,23	144	4,11	0,86	-266,36	0,41	RIFUGIO GENOVA - FIGARI	0,079	0,183
6,884	45,800	2590	55	0,26	226	0,36	0,99	-200,75	0,31	RIFUGIO MONZINO	0,077	0,178
7,767	45,921	3420	80	0,39	216	0,08	1,00	-129,76	0,20	RIFUGIO GUIDE D'AYAS	0,077	0,177
11,724	46,520	2256	69	0,33	257	11,39	0,60	-254,09	0,39	RIFUGIO VICENZA	0,077	0,177
12,106	46,487	2046	52	0,24	137	7,15	0,75	-281,22	0,43	RIFUGIO CRODA DA LAGO	0,077	0,177
12,059	46,654	2126	60	0,28	250	11,15	0,61	-290,19	0,44	RIFUGIO SENNES	0,076	0,175
10,115	46,055	2328	35	0,15	81	1,66	0,94	-345,04	0,53	RIFUGIO TAGLIAFERRI NANI	0,073	0,168
10,636	46,399	3535	66	0,32	5	0,15	1,00	-151,01	0,23	RIFUGIO VIOZ	0,072	0,166
7,097	45,210	2642	42	0,18	27	1,63	0,94	-265,62	0,40	RIFUGIO TAZZETTI	0,071	0,162
10,799	46,483	2561	65	0,31	41	1,69	0,94	-152,62	0,23	RIFUGIO CANZIANI	0,068	0,156
10,551	46,530	2556	40	0,17	253	0,50	0,98	-257,32	0,39	RIFUGIO TABARETTA	0,067	0,154
11,633	46,497	2440	72	0,35	174	16,04	0,44	-287,52	0,44	RIFUGIO ALPE DI TIRES	0,067	0,153
7,143	45,480	2604	35	0,15	193	2,50	0,91	-322,70	0,49	RIFUGIO CITTA' DI CHIVASSO	0,066	0,152
7,060	45,589	2370	80	0,39	192	2,02	0,93	-118,55	0,18	RIFUGIO CHALET DE L'EPEE	0,066	0,151
11,630	46,485	2134	70	0,34	186	15,86	0,44	-287,52	0,44	RIFUGIO BERGAMO AL PRINCIPE	0,065	0,151
7,045	44,728	2377	48	0,22	54	6,43	0,78	-254,09	0,39	RIFUGIO GRANERO	0,065	0,150
10,847	46,151	2489	38	0,16	53	0,91	0,97	-269,84	0,41	RIFUGIO XII APOSTOLI	0,065	0,150
7,313	44,191	2350	38	0,16	85	1,02	0,97	-	0,41	RIFUGIO	0,064	0,147

								266,36		MORELLI BUZZI		
11,664	46,477	2496	64	0,30	56	13,10	0,54	-254,09	0,39	RIFUGIO ANTERMOIA	0,064	0,147
7,588	45,649	2132	40	0,17	184	8,94	0,69	-345,04	0,53	RIFUGIO BARBUSTEL	0,063	0,145
7,936	45,719	2150	58	0,27	122	12,48	0,56	-267,33	0,41	RIFUGIO RIVETTI	0,062	0,143
10,454	46,131	2166	38	0,16	117	3,16	0,89	-281,22	0,43	RIFUGIO GNUTTI	0,062	0,143
7,305	45,910	2779	37	0,16	16	0,82	0,97	-261,15	0,40	RIFUGIO CHIARELLA	0,061	0,140
7,918	45,953	2065	58	0,27	135	0,35	0,99	-148,34	0,23	RIFUGIO ZAMBONI-ZAPPA	0,061	0,140
7,147	45,247	2616	42	0,18	30	1,47	0,95	-225,35	0,34	RIFUGIO CIBRARIO	0,060	0,139
10,655	46,243	2298	78	0,38	93	0,92	0,97	-105,00	0,16	RIFUGIO DENZA	0,059	0,135
11,326	46,986	2368	44	0,20	77	2,71	0,91	-214,82	0,33	RIFUGIO TRIBULAUN	0,058	0,133
10,465	46,024	2577	47	0,21	38	8,77	0,69	-254,95	0,39	RIFUGIO MARIA E FRANCO	0,057	0,131
7,066	45,885	2062	115	0,58	203	0,95	0,97	-66,47	0,10	RIFUGIO ELENA	0,057	0,130
10,443	45,953	2367	60	0,28	254	14,43	0,49	-263,19	0,40	RIFUGIO TITA SECCHI	0,056	0,129
10,711	46,209	2373	54	0,25	71	1,95	0,93	-146,10	0,22	RIFUGIO SEGANTINI	0,052	0,119
7,216	44,183	2388	36	0,15	204	6,67	0,77	-289,02	0,44	RIFUGIO EMILIO QUESTA	0,051	0,118
6,986	45,675	2498	89	0,44	50	1,18	0,96	-80,18	0,12	RIFUGIO DEFFEYES	0,051	0,118
12,287	46,585	2359	40	0,17	80	7,36	0,74	-254,09	0,39	RIFUGIO FONDA SAVIO	0,050	0,115
9,568	46,249	2100	40	0,17	140	2,45	0,92	-206,00	0,31	RIFUGIO OMIO	0,050	0,115
11,630	46,420	2283	60	0,28	95	15,62	0,45	-254,09	0,39	RIFUGIO RODA DI VAEL	0,049	0,114
7,877	45,927	4554	82	0,40	1	0,11	1,00	-80,26	0,12	CAPANNA MARGHERITA	0,049	0,112
10,855	46,772	3019	50	0,23	251	0,13	1,00	-137,57	0,21	RIFUGIO SIMILAUN	0,048	0,110
11,739	46,947	2545	30	0,12	229	1,27	0,96	-272,85	0,42	RIFUGIO PASSO PONTE DI GHIACCIO	0,048	0,109
12,291	46,562	2110	34	0,14	128	6,49	0,77	-283,45	0,43	RIFUGIO CITTA' DI CARPI	0,047	0,109
9,379	46,469	2175	24	0,09	116	2,58	0,91	-388,85	0,59	RIFUGIO BERTACCHI	0,047	0,108
10,507	46,057	2060	34	0,14	138	5,15	0,82	-261,85	0,40	MALGA ERVINA	0,046	0,106
7,501	45,948	2818	74	0,36	19	1,13	0,96	-87,97	0,13	RIFUGIO NACAMULI	0,046	0,106
8,365	46,385	2194	50	0,23	114	1,84	0,94	-140,02	0,21	RIFUGIO MARGAROLI	0,046	0,105
11,612	46,443	2337	60	0,28	209	16,71	0,41	-254,09	0,39	RIFUGIO FRONZA ALEARDO ALLE CORONELLE	0,045	0,104
9,950	46,329	2385	60	0,28	83	1,70	0,94	-	0,17	RIFUGIO	0,044	0,102

								110,05		BIGNAMI		
12,057	46,379	2984	34	0,14	11	7,92	0,72	-279,49	0,43	RIFUGIO TORRANI	0,044	0,100
11,880	46,585	2050	25	0,09	210	15,15	0,47	-655,63	1,00	RIFUGIO GARDENACIA	0,043	0,100
12,312	46,618	2344	30	0,12	221	5,96	0,79	-282,22	0,43	RIFUGIO LAVAREDO	0,041	0,094
10,202	46,264	2079	41	0,18	248	12,29	0,57	-261,43	0,40	RIFUGIO ALPE SCHIAZZERA	0,041	0,094
11,623	46,459	2621	50	0,23	242	15,90	0,44	-254,09	0,39	RIFUGIO RE ALBERTO	0,039	0,090
11,849	46,519	2536	33	0,14	48	7,96	0,72	-254,09	0,39	RIFUGIO KOSTNER	0,038	0,087
7,293	44,185	2453	24	0,09	59	0,65	0,98	-289,02	0,44	RIFUGIO BOZANO	0,037	0,086
6,832	45,819	3072	24	0,09	15	0,20	0,99	-252,78	0,39	RIFUGIO GONELLA	0,033	0,077
8,363	46,434	2480	52	0,24	52	1,55	0,95	-96,06	0,15	RIFUGIO CITTA' DI BUSTO	0,033	0,076
10,705	46,826	2557	48	0,22	236	0,77	0,97	-102,33	0,16	RIFUGIO PIO XI	0,033	0,076
7,020	44,828	2583	48	0,22	37	17,37	0,39	-254,09	0,39	RIFUGIO SEVERINO BESSONE	0,033	0,076
7,551	45,612	2192	25	0,09	201	4,24	0,85	-273,11	0,42	RIFUGIO DONDENA	0,033	0,075
9,820	46,330	2450	25	0,09	62	2,09	0,93	-248,41	0,38	RIFUGIO LONGONI	0,032	0,075
6,952	45,171	2578	24	0,09	179	2,31	0,92	-261,15	0,40	RIFUGIO AVANZA'	0,032	0,073
11,284	46,974	2423	62	0,29	67	1,24	0,96	-72,04	0,11	RIFUGIO CREMONA	0,031	0,071
7,126	44,659	2268	24	0,09	99	2,82	0,90	-254,09	0,39	RIFUGIO ALPETTO	0,030	0,070
11,604	46,170	2473	56	0,26	64	21,30	0,25	-289,02	0,44	RIFUGIO CIMA D'ASTA	0,029	0,067
6,802	45,133	2160	24	0,09	118	2,67	0,91	-240,66	0,37	RIFUGIO SCARFIOTTI	0,029	0,067
7,184	45,376	2280	22	0,08	76	1,46	0,95	-257,02	0,39	RIFUGIO DAVISO	0,028	0,065
7,850	45,874	2625	35	0,15	170	1,78	0,94	-134,98	0,21	ORESTES HUTTE	0,028	0,065
11,658	46,992	2276	30	0,12	228	2,50	0,91	-166,22	0,25	RIFUGIO PASSO DI VIZZE	0,028	0,064
7,848	45,895	3498	80	0,39	194	0,21	0,99	-46,92	0,07	RIFUGIO CITTA' DI MANTOVA	0,028	0,063
10,569	46,303	2478	24	0,09	51	6,42	0,78	-261,24	0,40	RIFUGIO BOZZI	0,027	0,062
9,948	46,284	2287	30	0,12	197	2,17	0,93	-158,45	0,24	RIFUGIO CRISTINA	0,027	0,061
7,012	44,409	2335	48	0,22	79	19,47	0,32	-254,09	0,39	RIFUGIO GARDETTA	0,027	0,061
8,147	46,128	2039	27	0,10	157	6,57	0,77	-219,28	0,33	RIFUGIO ALPE IL LAGHETTO	0,027	0,061
7,533	45,921	2005	50	0,23	239	1,72	0,94	-79,47	0,12	RIFUGIO PRARAYER	0,026	0,060
9,905	46,345	2813	159	0,82	10	0,64	0,98	-20,94	0,03	RIFUGIO MARINELLI-BOMBARDIERI	0,025	0,058

7,561	45,970	2788	36	0,15	18	0,34	0,99	-101,31	0,15	RIFUGIO AOSTA	0,023	0,053
10,440	46,266	2080	22	0,08	133	5,51	0,81	-240,18	0,37	CAPANNA SOCIALE CASE DI BLES	0,022	0,052
7,759	45,914	3004	30	0,12	13	0,43	0,99	-124,21	0,19	RIFUGIO MEZZALAMA	0,022	0,051
11,793	46,301	2084	18	0,05	191	2,49	0,91	-287,52	0,44	RIFUGIO CAPANNA CERVINO	0,022	0,050
7,406	44,124	2650	24	0,09	25	11,07	0,61	-266,36	0,41	RIFUGIO PAGARI'	0,022	0,050
7,907	45,622	2280	50	0,23	97	22,44	0,21	-287,52	0,44	RIFUGIO PLAN DE CORONES	0,021	0,049
8,353	46,421	2561	26	0,10	40	1,00	0,97	-146,56	0,22	RIFUGIO SOMMA LOMBARDO	0,021	0,048
6,949	45,829	2173	25	0,09	232	1,59	0,95	-155,99	0,24	RIFUGIO PAVILLON	0,021	0,048
12,251	46,611	2205	20	0,07	176	5,29	0,82	-254,09	0,39	RIFUGIO ANGELO BOSI	0,021	0,047
7,076	44,613	2017	20	0,07	181	5,53	0,81	-254,09	0,39	RIFUGIO BAGNOUR	0,020	0,047
10,016	46,108	2004	18	0,05	153	1,84	0,94	-261,43	0,40	BAITA PESCIOLA	0,020	0,047
7,033	45,847	2025	75	0,36	258	2,87	0,90	-40,92	0,06	RIFUGIO WALTER BONATTI	0,020	0,046
12,196	46,642	2040	20	0,07	256	5,91	0,79	-254,09	0,39	RIFUGIO VALLANDRO	0,020	0,046
11,664	46,434	1998	25	0,09	149	12,80	0,55	-254,09	0,39	RIFUGIO CIAMPEDIE'	0,020	0,045
7,694	45,859	2535	45	0,20	215	5,78	0,80	-76,75	0,12	RIFUGIO GRAND TOURNALIN	0,019	0,043
11,639	46,474	2601	25	0,09	230	14,91	0,48	-254,09	0,39	RIFUGIO PASSO PRINCIPE	0,017	0,039
7,979	45,997	2796	24	0,09	12	0,79	0,97	-130,24	0,20	RIFUGIO OBERTO-MAROLI	0,017	0,039
7,567	45,904	2909	30	0,12	234	1,28	0,96	-96,06	0,15	RIFUGIO PERUCCA-VUILLERMOZ	0,017	0,038
11,727	46,610	2045	30	0,12	223	19,64	0,31	-287,52	0,44	RIFUGIO MALGA BROGLES	0,016	0,037
7,708	45,934	3480	36	0,15	217	0,04	1,00	-69,50	0,11	RIFUGIO GUIDE DEL CERVINO	0,016	0,037
10,416	45,963	2087	23	0,08	142	15,24	0,47	-263,61	0,40	RIFUGIO GHEZA	0,015	0,035
7,077	45,203	3538	15	0,04	246	0,34	0,99	-265,34	0,40	RIFUGIO SANTA MARIA	0,015	0,035
11,662	46,600	2164	33	0,14	241	21,24	0,25	-287,52	0,44	RIFUGIO RASCIESA	0,015	0,035
6,978	45,853	2803	20	0,07	23	0,14	1,00	-147,89	0,22	RIFUGIO BOCCALATTE	0,015	0,034
7,401	45,818	2422	18	0,05	163	8,11	0,72	-244,46	0,37	BIVACCO LA LLIE'E	0,014	0,033
12,341	46,632	2528	15	0,04	235	3,37	0,88	-282,22	0,43	RIFUGIO PIAN DI CENGIA	0,014	0,033
11,805	46,636	2306	30	0,12	211	20,91	0,27	-	0,44	RIFUGIO	0,014	0,032

								287,52		GENOVA		
7,962	45,878	2264	24	0,09	103	4,78	0,83	-123,03	0,19	RIFUGIO FERIOLI	0,014	0,031
7,777	45,787	2446	100	0,50	178	7,54	0,74	-24,30	0,04	RIFUGIO ARP	0,013	0,031
11,843	46,089	1993	25	0,09	134	18,23	0,36	-254,09	0,39	RIFUGIO DAL PIAZ	0,013	0,030
7,030	45,625	2916	52	0,24	198	0,46	0,99	-36,15	0,05	RIFUGIO DEGLI ANGELI AL MORION	0,013	0,029
11,740	46,395	2046	16	0,04	139	8,34	0,71	-254,09	0,39	RIFUGIO TARAMELLI	0,012	0,027
8,428	46,435	2160	72	0,35	121	2,55	0,91	-24,92	0,04	RIFUGIO MARIA LUISA	0,012	0,027
9,862	46,040	2026	23	0,08	141	2,30	0,92	-102,33	0,16	RIFUGIO FRATELLI LONGO	0,012	0,027
10,870	46,143	2410	60	0,28	70	1,16	0,96	-25,24	0,04	RIFUGIO AGOSTINI	0,010	0,024
11,725	46,502	2300	15	0,04	244	10,04	0,65	-254,09	0,39	RIFUGIO SANDRO PERTINI	0,010	0,022
11,957	46,741	2231	20	0,07	94	17,90	0,37	-254,09	0,39	RIFUGIO PLAN DE CORONES	0,009	0,022
7,866	45,789	2480	21	0,07	227	3,74	0,87	-96,06	0,15	RFUGIO OSPIZIO SOTTILE	0,009	0,021
12,085	46,666	2327	46	0,21	187	11,63	0,59	-48,17	0,07	RIFUGIO BIELLA	0,009	0,020
7,168	45,346	2620	14	0,03	156	1,28	0,96	-178,50	0,27	RIFUGIO SOARDI	0,008	0,020
11,620	46,913	2307	40	0,17	188	8,42	0,71	-45,48	0,07	RIFUGIO BRESSANONE	0,008	0,019
6,766	44,921	2035	23	0,08	119	20,91	0,27	-254,09	0,39	BAITA GIMONT	0,008	0,019
8,153	46,100	2114	12	0,02	160	7,67	0,73	-290,79	0,44	BIVACCO AMBROGIO FOGAR	0,007	0,016
9,902	46,331	2636	50	0,23	26	0,80	0,97	-20,94	0,03	RIFUGIO CARATE BRIANZA	0,007	0,016
11,618	46,456	2734	15	0,04	231	16,23	0,43	-254,09	0,39	RIFUGIO PASSO SANTNER	0,006	0,015
9,953	46,080	2004	24	0,09	146	1,84	0,94	-48,17	0,07	RIFUGIO MAMBRETTI	0,006	0,014
8,335	46,424	2960	90	0,45	171	0,16	1,00	-8,81	0,01	RIFUGIO 3A	0,006	0,013
9,562	46,021	2222	20	0,07	109	22,96	0,19	-287,52	0,44	RIFUGIO BENIGNI	0,006	0,013
12,275	46,778	2340	25	0,09	168	17,55	0,38	-102,33	0,16	BONNER HUTTE	0,006	0,013
7,559	45,878	2890	12	0,02	167	0,93	0,97	-152,13	0,23	BIVACCO RENZO RIVOLTA	0,005	0,011
7,120	45,048	2035	40	0,17	249	17,95	0,37	-48,17	0,07	RIFUGIO SELLERIES	0,005	0,011
7,901	45,926	3624	16	0,04	2	0,28	0,99	-70,55	0,11	CAPANNA RESEGOTTI	0,005	0,011
9,742	46,309	2580	10	0,01	29	0,81	0,97	-267,11	0,41	RIFUGIO DEL GRANDE-CAMERINI	0,004	0,010
10,962	45,921	2012	27	0,10	152	25,96	0,09	-289,02	0,44	RIFUGIO STIVO	0,004	0,009
8,325	46,415	2710	90	0,45	196	0,40	0,99	-6,44	0,01	RIFUGIO	0,004	0,009

										CLAUDIO E BRUNO		
7,910	45,903	2247	12	0,02	92	1,30	0,96	-115,65	0,18	RIFUGIO BARBA FERRERO	0,004	0,008
7,190	45,434	2250	25	0,09	87	2,13	0,93	-25,27	0,04	RIFUGIO JERVIS	0,003	0,007
7,894	45,585	2312	25	0,09	225	26,44	0,07	-287,52	0,44	RIFUGIO MOMBARONE	0,003	0,007
7,593	45,877	2169	24	0,09	185	3,62	0,87	-24,92	0,04	RIFUGIO BARMASSE	0,003	0,007
8,070	46,095	2061	70	0,34	148	2,20	0,92	-6,44	0,01	RIFUGIO ANDOLLA	0,003	0,006
7,127	45,555	2142	12	0,02	200	3,03	0,89	-86,96	0,13	RIFUGIO DELLE MARMOTTE	0,003	0,006
7,896	45,803	2201	24	0,09	112	2,65	0,91	-18,27	0,03	RIFUGIO CARESTIA	0,002	0,005
7,038	44,523	2020	10	0,01	155	14,10	0,51	-254,09	0,39	CAPANNA SOCIALE FRANCO ELLENA	0,002	0,005
11,632	46,458	2243	10	0,01	240	15,16	0,47	-254,09	0,39	RIFUGIO PREUSS	0,002	0,005
9,921	46,213	2137	16	0,04	126	3,86	0,87	-23,63	0,04	RIFUGIO GUGIATTI-SERTORELLI	0,001	0,003
7,881	45,837	2503	12	0,02	42	1,06	0,96	-39,80	0,06	BIVACCO RAVELLI	0,001	0,003
7,613	45,957	3325	9	0,01	161	0,52	0,98	-150,55	0,23	BIVACCO CAMILLOTTO PELLISSIER	0,001	0,003
7,549	45,861	2459	9	0,01	164	2,23	0,92	-149,30	0,23	BIVACCO LAGO TZAN	0,001	0,003
7,585	45,920	3320	9	0,01	165	0,32	0,99	-87,97	0,13	BIVACCO LAURA FLORIO	0,001	0,002
7,586	45,935	3572	9	0,01	166	0,56	0,98	-67,34	0,10	BIVACCO PAULUCCIO	0,001	0,001
9,941	46,253	2119	10	0,01	106	1,85	0,94	-35,26	0,05	RIFUGIO DE DOSSO	0,001	0,001
7,644	45,959	2802	22	0,08	202	0,84	0,97	-4,09	0,01	RIFUGIO DUCA DEGLI ABRUZZI ALL'ORIONDE'	0,000	0,001
10,666	46,437	2607	80	0,39	31	1,20	0,96	-1,03	0,00	RIFUGIO CEVEDALE	0,000	0,001
7,621	45,972	3708	9	0,01	162	0,52	0,98	-11,71	0,02	BIVACCO GIORGIO E RENZO NOVELLA	0,000	0,000
11,733	46,695	2447	66	0,32	74	28,46	0,00	-655,63	1,00	RIFUGIO PLOSE	0,000	0,000
11,709	46,962	2710	90	0,45	214	0,43	0,99	-0,56	0,00	RIFUGIO GRAN PILASTRO	0,000	0,000
10,255	46,389	2005	28	0,11	154	1,68	0,94	-0,56	0,00	RIFUGIO FALCK	0,000	0,000
9,835	46,059	2118	14	0,03	130	4,23	0,85	-0,56	0,00	RIFUGIO CAPRARI	0,000	0,000
11,631	46,420	2275	8	0,00	159	15,58	0,45	-254,09	0,39	BAITA MARINO PEDERIVA	0,000	0,000
10,942	46,309	2087	8	0,00	169	7,74	0,73	-345,04	0,53	MALGA TASSULLA	0,000	0,000