Urban Climate 32 (2020) 100622

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com/locate/uclim

Toward a trans-regional vulnerability assessment for Alps. A methodological approach to land cover changes over alpine landscapes, supporting urban adaptation

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ARTICLE INFO

Keywords:
Urban planning 1
Transboundary governance 2
Remote sensing analysis 3
Climate change 4
Adaptation strategies 5
Alps monitoring 6

ABSTRACT

The contribution presents a possible assessment methodology for land cover change over ice and snow, between 1990 and 2018 in the Dolomites and the Alpi Giulie. The methodology aims to build surface atlas to assess the land cover changes. The tool is intended as a support for environmental management, forecasting and, as support for territorial government systems in climate-proof planning processes. In the "business as usual" global warming scenario, ice and snow resources will become one of the most affected subjects by Climate Change, with heavy consequences on ecosystems, urban environments and socioeconomic. Current monitoring and assessment systems are fragmented both by survey methodology and by local distribution. The methodology is developed in using GIS, following remote sensing (RS) processes and spatial analysis tools to manage multispectral satellite images. The process uses spectral signatures from satellite images to identify homogeneous areas in material and morphology. The process takes into account the actual systems of assessment and local socioeconomic exposures. The methodology takes a proactive approach to future hazards and impacts considering their management in alpine habitats to support local administrations. The project develops transboundary assessment techniques and aids the adaptation of planning strategies in the context of Climate Change.

1. Introduction

1.1. State of the art

The Alps are the most significant mountain system on the European continent in terms of elevation and contribution to water resources, in the form of snow deposits (Beniston et al., 2018; Teston and Bramanti, 2018a). The articulation of the mountain range covers eight national states: Italy, France, Switzerland, Liechtenstein, Germany, Austria, Slovenia, and Hungary. The mountain range is a permanent presence in the landscape for a population of 14 million people and, in Italy, it covers seven administrative regions: Liguria, Piemonte, Val d'Aosta, Lombardy, Trentino Alto Adige, Veneto, and Friuli - Venezia Giulia. This complex system, made by a fragile environment and heterogeneous socioeconomic context, is highly exposed to the effects of Climate Change; the dynamic conditions in high altitude territories increase climatic impacts on those downstream. (Agrawala and Organization for Economic Co-operation and Development., 2007; Allamano et al., 2009; Bavay et al., 2009; Brunetti et al., 2009; Gobiet et al., 2014; Marty et al.,

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https://doi.org/10.1016/j.uclim.2020.100622
Received 9 December 2019; Accepted 18 March 2020

2017).

There are a large number of studies concerning the climatic variability in the short, medium and long term, from the local to the global scale (Bartolini et al., 2009; Brunetti et al., 2009; Field et al., 2012). These studies generally tend to connect historical analyses, forecast estimates, and territorial anthropic systems which evaluate different investigative tools; implicitly they are the necessary structure on which to base possible strategies of action (Farinotti et al., 2012; Huss et al., 2014). Considering the economic importance of the Alpine mountain range, its sizable population, the forms of settlements and territorial infrastructures, it is necessary to investigate the relationship between trans-regional governance, local planning actions, and analysis methods. (Balbi et al., 2011; Giorgi and Mearns, 1991; Laghari et al., 2012).

These considerations are linked to the need to define a series of fixed coordinates around which strategies to protect and adapt the alpine system, and its peculiarities, can be developed. The uncertainty in definition of the most effective or generally correct adaptation methodologies lies in the correct interpretation of the given scenario and in the limited capacity of the monitoring tools to provide forecasts and complete cognitive frameworks. (Majone et al., 2016; Schmucki et al., 2017).

The main indicators that define the growing vulnerabilities and exposures of these territories are the water resources which, in this study, are defined in terms of square meters covered by ice and snow (Stefanicki et al., 1998; Steger et al., 2013). The morphology and availability of these resources are connected to the combined temperature and precipitation change (Bavay et al., 2009; Durand et al., 2009). The quantitative variation of the glaciated water surfaces can be measured using Remote Sensing techniques, developing a replicable methodology and testing its effectiveness on two specific study areas. Test results have been related to socio-economic changes in the territories to emphasize the connection between water resources and the human habitat in Alpine area. (Balbi et al., 2013; Bavay et al., 2009; European Environment Agency, 2009; Gilaberte-Búrdalo et al., 2014)

The variation in the presence of snow and ice over the period 1990–2018, referring to the vast scientific literature related to climate monitoring and land cover, suggests a substantial loss of icy surfaces and an increase in anthropized surfaces (Barthel et al., 2008; Marinucci et al., 1995). The summer periods have been compared to illustrate the connection between climatic hazard, economic activities (connected with seasonal tourism), habitat loss, the safety of human activities and impacts on economic productive sectors (agriculture and industry) (Elsasser and Bürki, 2002; Gilaberte-Búrdalo et al., 2017; Rogora et al., 2018). The summer deposits were identified and quantified, referring to international literature and national monitoring systems, and interpreted as a "Base Line" for the entire year (Field et al., 2012; François et al., 2014). The selection of summer satellite images brings two benefits: a lower presence of clouds at high altitudes and consequently a greater availability of information for analysis; a proximity to the periods of the year with greater frequency of climatic episodes of calamity (landslides, avalanches, wildfires, infestations of alien species, extreme meteorological phenomena, etc.) (Frey et al., 2010; Montesarchio et al., 2014).

The research was developed to take into account the ambitions, visions of governance and strategic integration developed by governmental and non-governmental institutions (Macchiavelli and Andrea, 2009; Stern, 2007). Two illustrative and representative cases were selected both for their territorial coverage, the relevance of the results and for the stated objectives, namely: CIPRA[1] (Köhler et al., 2003) and EUSALP[2] (Teston and Bramanti, 2018b). The "*Commission Internationale pour la Protection des Alpe"*(CIPRA) is an autonomous non-governmental and non-profit umbrella organization which has been committed to the protection of sustainable development since 1952. The EU Strategy for the Alpine region (EUSALF), was founded October 182,013. The latter is a key reference in the identification of threats to the Alpine context and for the definition of the objectives and potential opportunities for these territories. EUSALP connects 7 nations and 48 administrative regions of the Alpine region (including non-EU states) within a strategic agreement, with the aim of creating a coordinated approach to the challenges of economic globalization, demographic trends, climate change, energy. Furthermore, the assembly sets an important precedent for the project of cohesion; one of the objectives declared by the EUSALP Presidency 2019 was considered fundamental for the selection of the focus areas. With the awareness of the planning dynamics in Alpine coordination and the aspirations for growth of these territories, it is fundamental to implement the connection to the ongoing agreements aimed to merge local strategies into the legal framework of the Cohesion Policy 2021–2027.

The phases followed in the research process have followed parallel and interdisciplinary paths. It is possible to recognize three core strategies within the presented work. The first relates to the selection of the Remote Sensing methodology (Bhardwaj et al., 2015; Dewan and Yamaguchi, 2009; Hall et al., 1987) The second relates to the development of a site-specific analysis on Cortina D'Ampezzo and Tarvisio, in relation to climatic data and the specific morphologies of the territories (SOIUSA[3]). The third develops a quantitative and comparative analysis of water resources, urban development, and territorial governance. This last study was undertaken in relation to the local administration nature of these territorial systems and highlighted the need for a tool to analyse and monitor the effects of climate change in a trans-regional context, in order to allow for adaptation and the future mitigation of its effects. (Kim, 2011).

1.2. Objectives

The project findings aim to support local authorities in their interpretation and governance of Alpine territories. Awareness and knowledge of current phenomena are considered as the *conditio* sine qua non to protect the alpine habitats. The objectives are

[1] https://www.cipra.org/en/about/mission.

[2] https://www.alpine-region.eu/eusalp-eu-strategy-alpine-region.

[3] SOIUSA is an acronym for Suddivisione Orografica Internazionale Unificata del Sistema Alpino - in English: International Standardized Mountain Subdivision of the Alps.

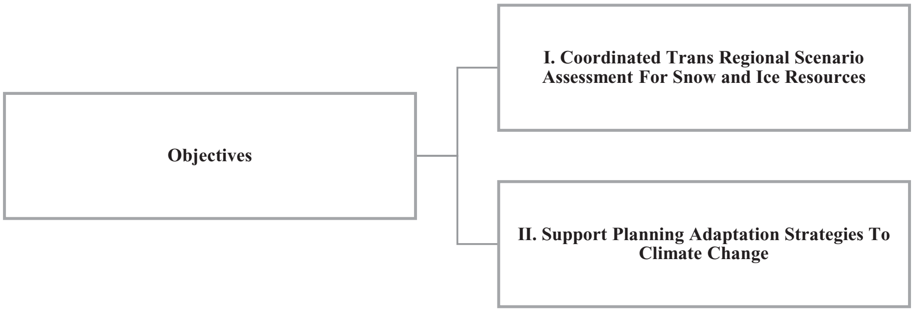

Fig. 1. Objectives of the study.

summarized in the figure below. The two objectives presented are both parallel and integrated. The purpose with which they are defined and described is to highlight the importance of each aspect of research. It is not possible to fully understand the territory without considering each of these aspects. The complex scenario of rapid change and the increase of the dangers for the Alps (both for natural environments and for human activities), defines a system of problems and solutions that must be investigated explicitly.

The specific objectives are summarized in the image below (Fig. 1):

Each objective takes into account the following considerations:

1.2.1. Coordinated trans regional scenario assessment for snow and ice resources

As stated in the Introduction, the Alpine territory involves different nations and regions with populations who have a particular relationship with the mountain environment. It has emerged, especially within the Italian areas of study, that there is discontinuity in the monitoring and administration of the territories at different levels, from the scale of the single municipalities to the territorial agencies for monitoring and environmental protection (ARPA).

Available data is extremely limited and localized on glaciers of significant collective interest and skiing infrastructure. There is also the problem of temporal continuity. Through the elaboration of this study, a discontinuity was found in the information provided by the detection devices, as they are switched off during the summer periods. The objective of this study is, therefore, to provide an analytical tool capable of representing a transnational and transregional aware framework, aimed to support the medium and long-term territorial governance and climate adaptation processes. This requires the possibility to assess the now and ice situation throught costruction of spatial information. This knowledge is fundamental for defining the causality between environmental change at high altitude and the related impact on downstream areas.

1.2.2. Support planning adaptation strategies to climate change

In reference to international climate agreements and the goals agreed by each nation, Italy has adopted two important documents at the national level: the National Adaptation Plan (PNAC), the National Adaptation Strategies (SNAC). A process is currently underway to upgrade regional and municipal planning structures and methods concerning mitigation and adaptation. The process promoted by the European Commission has references some examples of beneficial coordination between municipalities (eg. the Covenant of Mayors for Climate and Energy) and will become a strategic reality by 2030 with the Sustainable Energy and Climate Action Plan (SECAP). It is therefore necessary to have an integrated knowledge of the territories in order to be able to effectively manage their future transformation. Today, the primary knowledge resources available to local government structures are the traditional knowledge of spatial morphology and some specific studies related to dangers that are marginally aware of climate change. Given these considerations, it is a strategic objective to have an integrated system of geo-localized information that relates environmental transformations and the socio-economic evolution of the anthropized territories.

1.3. Study area

Study areas were selected due to their representative complexity and characteristics. In contrast to what was stated in the previous chapters, an evaluation was carried out throughout the Alpine area following the SOIUSA classification, giving priority to the Italian side. Focus areas were selected according to the transnational and transregional shape of the orographic system, the functional connection between the socio-economic fabric and the mountain environment, the availability of data, and the cultural value of the landscape and human activities (Pohl et al., 2019; Suklitsch et al., 2008). Among the seven Italian regions, Veneto, Trentino Alto Agide and Friuli Venezia Giulia were preferred. Specifically, two binomials were chosen, consisting of an orographic complex and a reference municipality, specifically: Dolomites - Cortina D'Ampezzo and the Julian Alps - Tarvisio. The two areas were evaluated according to the objectives defined in the previous chapter and with the expectation that the analysis conducted on this territory can be replicated in areas of similar complexity. To represent the complexity of the relationship between mountain and urban system, the extension of analysis includes all those administrative realities that intersect the selected mountain complex.

Specifically, the characteristics of each location are: (Fig. 2)

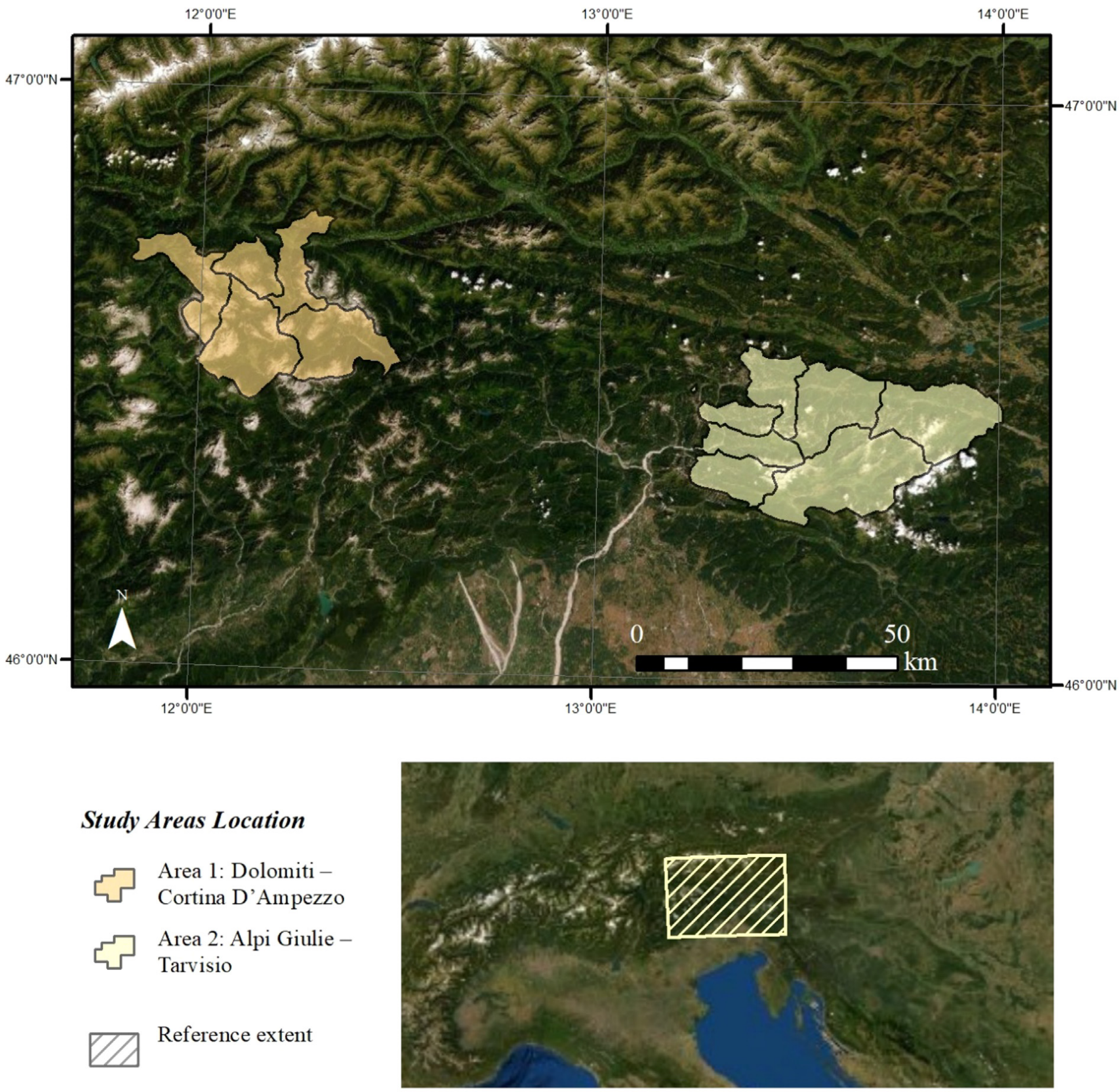

Fig. 2. Focus areas location.

1.3.1. Area 1: Dolomiti – Cortina D'Ampezzo

The first area, which covers 1.231,60 km^2, includes the Veneto region and the Friuli Venezia Giulia region, and five municipal units: Cortina d'Ampezzo, Auronzo di Cadore, Marebbe, Braies, and Dobbiaco. This area is a representative example for the relationship between mountains and tourism (both winter and summer); Cortina d'Ampezzo hosted in the 1956 Winter Olympics and - along with Milan - will host the games again in 2026 (CIO, 2019). In addition, the Dolomites complex has been a World Heritage Site since 2009 (UNESCO, 2016). These attributes have been judged to be fundamental to the complexity of the governmental structure of this territorial area.

1.3.2. Area 2: Alpi Giulie – Tarvisio

The second, slightly smaller, area covers 840,70 km^2 and includes the Friuli Venezia Giulia region and extends into the state of Slovenia. There are five municipal zones within the area: Tarvisio (Italy), Chiusaforte (Italy), Resia (Italy), Kranjska Gora (Gorenjska - Slovenia), Bovec (Goriška - Slovenia). In this case, the two most relevant socio-economic and cultural contexts are within the municipality of Tarvisio, which is the main ski centre of Friuli region, and Kranjska Gora, which is an annual FIS Alpine Ski World Cup event (FIS, 2019). The geomorphological and administrative characteristics of this context are judged to be illustrative both for the transnational distribution of the orographic system and the discontinuity of their governance. An experimental project was implemented in this area to coordinate the transnational adaptation strategies promoted by the European Community program (Interreg V-A Italy-Slovenia program 2014–2020, 2018).

The selection of the areas described above is functional to the elaboration of this study on two distinct and consequential levels: the first concerns the selection of the Remote Sensing method for the processing of satellite images and the second concerns the territorial analysis on the target areas. The first level is carried out on a sample portion of satellite images related to the territory of the Julian Alps - Tarvisio. This choice was made considering the objectives of the research and evaluating the opportunity to establish a relationship between the ongoing strategic transformation design processes and the development of the present study.

2. Material and methods

The territorial observation and analysis give the possibility, through a space-time evaluation, to recognize the changing happened in the past, to control the ongoing processes and to forecast possible trends. In this sense, the principal deployable tool is the nadiral observation which allows a homogeneous interpretation of those features by which the landscape is composed. One of the main parameters of the choice of the sources is the scale of resolution. To reconstruct the information of a specific area it is necessary to use the most appropriate tool of representation among the thousand possible ones. Generally, for detailed, precise and restricted spatial observation, an analysis “from the ground” is preferred, as in the case of a topographic survey. To solve and assess problems connected to the urban and territorial scale, a more extensive source is required. In some cases, aerial photogrammetric surveys can give the first response to some large-scale assessment, but remote sensing techniques can allow bypassing some problems like costs and transboundary governance issues. The bases of remotely sensed assessment are satellite data, which can be an “open” or “close” source as this information gives the possibility to geomorphologically assess the territories and the environmental quality. The application of image classification methods derives from the use of satellite-earth observation platforms with an optical-passive sensor, capable of returning a multispectral image for the bands of the visible and non-visible range. In the case of the present research, it has been selected a set of data available in open source and with the longest possible continuity over time. These two aspects are fundamental to develop a public based monitoring system as they allow a cyclical, free and accessible retrieval of information. The supervised-classification techniques developed and integrated into the tools for remote sensing processing are also widespread and available under an open-source license, another point in favor in terms of portability of operations. The processes followed in this methodology aim to automate analysis as much as possible. It is necessary to provide spatial analysis of the water resource in order to quantify the surface area that is exposed to climate change. This is possible through geoprocessing operations on remotely sensed data (Oerlemans, 1994; Wolf et al., 2012). The methodological structure is necessary to achieve an optimal classification method, and therefore accomplish the objectives in the introduction. Two macro processing phases were necessary to do this: the first phase with the choice of the most performing process in relation to the data objectives; the second one of replication and extension of the method validated in the first phase on the study areas with quantification and comparison of results with respect to a significant period of time.

2.1. Selection of remote sensing method

The general process (Fig. 3), is divided into three main steps that will be described indepth in this chapter, following the workflow diagram below.

The elaborations are performed using the functionalities of the GIS OpenSource client QGIS 3.4.8 -’Madeira’ with the support of a plug-in for the supervised classification of remote sensing images, Semi-Automatic Classification Plugin (SCP) (Congedo, 2017).

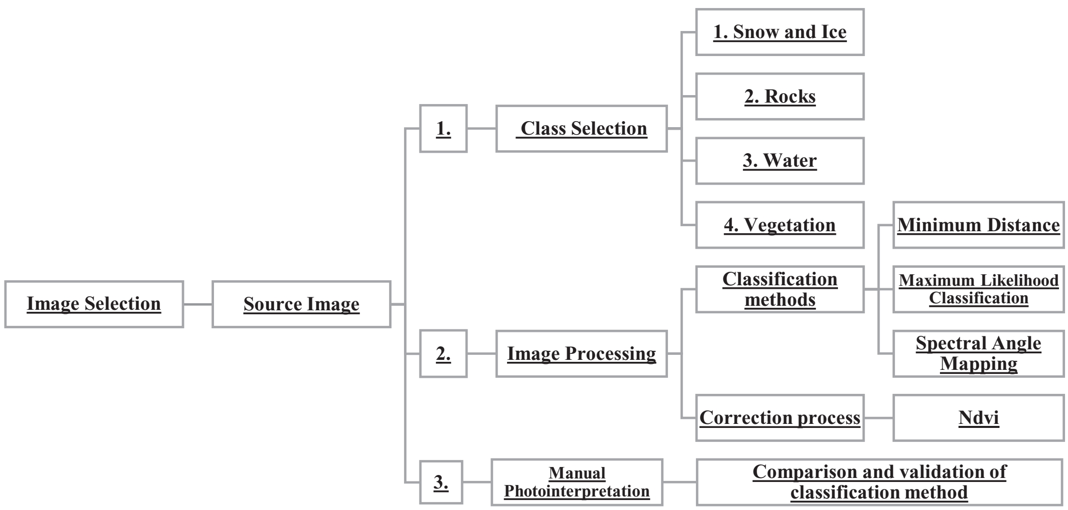

Fig. 3. Geoprocessing workflow for method validation.

2.2. Class selection

Class selection is necessary to define the target of the remote sensing assessment (Valt and Cianfarra, 2014). The proposed classes enclose and synthesize the set of homogeneous conformations of surfaces that can be found on the territory, so from this point the distribution and the variation of them. Concerning the objectives to be achieved through the application of this methodology, it's necessary to elaborate an interpretative tool of the mountain territorial context, structuring a surface atlas based on natural morphological aspects (Kääb et al., 1997; Shukla and Ali, 2016). The classes identified within this atlas dedicate a specific observation to the following typological surfaces: 1) Glaciers/Snow, 2) Rocks, 3) Water, 4) Vegetation. In this sense, the macro-classes represents a set of land covers and land uses. For land use is meant the ground material typology, such as soil, vegetation, water, asphalt, etc. (Fisher and Unwin, 2005). Selected classes namely contain: 1) Glaciers/Snow: surfaces with presence of ice and snow deposits; 2) Rock: mountainous walls, bare rock, quarries, surface no longer covered by snow; 3) Water: bodies and watercourses of inland waters, rivers, lakes, streams; 4) Vegetation: permeable natural soils, forests, woodlands, grasslands, land for agricultural use. To distinguish these differences a Region of Interests (ROI) assessment was elaborated assuming as class-representative the portion of pixels of the satellite image contained in the polygon designed to sample each specific type of surface. Then, ROIs are used to establish the Training Inputs for the classification algorithm representing each class, and on a second level, by grouping these elements in material representative macro-classes. The Regions of Interest, from which spectral signatures are calculated for the application of the classification algorithms (Congedo, 2017), are determined with the operator intervention in comparison to the source image. In this sense, the classification method used is called supervised.

3. Theory and calculation

3.1. Data acquisition and preparation

In the first phase, with awareness of the potential and the limits of the satellite products (Kuenzer et al., 2014), an image acquired from the Landsat 8 platform was used (Hall et al., 1987; Menenti et al., 2015). Once the bands were imported, the product was preprocessed by applying atmospheric correction and using the pansharpening technique to improve its geometric resolution. In accordance with the objectives, images are elaborated taking into account the geographical relevance of the focus areas. The process was developed through the evaluation of accessible sources linked to the availability of formal local data and researching the best meteorological condition (in terms of the presence of clouds and image quality). This last factor may affect the quality of the obtainable result with the applied remote sensing technology.

The most recent images are available through the Landsat 8 platform, so the image selected to use for the first phase comes from a recent satellite scene from this platform, focused in the easternmost area of Alpi Giulie group (Table 1). (See Table 2.)

A sample area of this image was used to test the algorithms. This sample area depicts a location near Tarvisio and Slovenia Goriniska (46° 26′7.30″ N, 13° 41′30.04″ E) and is defined by a 480 *m* square, equal to 23 ha; centered on the target point. This portion is used in the comparison and validation phase, through manual photointerpretation operation on the last high-resolution imagery (0.5 m) provided by CNES/Airbus via Google Earth, 2019 Google Map data.

3.2. Semiautomatic classification

Classification allows the initial data to define a discrete datum across the mapped the surfaces, or rather for the surfaces to be analysed as composites of distinguishable elements, identified and declared in the macro-classes that reflect each land cover. The project tested a set of three algorithms refine the methodology according to the stated objectives.

The first algorithm tested is Maximum Likelihood. MLH calculates the probability distributions of the classes, as defined by Bayes' theorem, and estimates if a pixel belongs to a land cover class. (Richards, 2013). The second algorithm tested is Minimum Distance (MD). This algorithm calculates the Euclidean distance between spectral signatures of image pixels and training spectral signatures. (Richards, 2013). The final algorithm is Spectral Angle Mapping (SAM); this calculates the spectral angle between spectral signatures of image pixels and training spectral signatures (Kruse et al., 1993).

3.2.1. NDVI correction

To improve the accuracy of the surface estimation, a correction operation is performed using remote sensing indexes. Specifically, this means Normalized Difference Vegetation Index (NDVI) (Rouse, 1974), calculated both on Red and Near-Infrared bands values, is used to improve vegetation estimation.

The results of the semi-automatic classification, obtained through the applications of available algorithms, are reported in the

Table 1
Satellite metadata extracted from the source.

Year	WRS2 Path/row	Satellite	Landsat scene ID	Landsat product ID	Date acquired	Cloud cover scene (%)	Cloud cover land (%)
2017	191/28	Landsat 8	LC81910282017187LGN00	LC08_L1TP_191028_20170706_20170716_01_T1	2017-07-06	0.85	0.99

Table 2
NDVI's thresholds applied for the correction process.

NDVI'S thresholds applied for correction				
Area target	Alpi Giulie – Tarvisio		Dolomiti – Cortina d'Ampezzo	
Year	1990	2017	1990	2017
Value	> 0.5	> 0.6	> 0.5	> 0.5

tables below (Table 3, Table 4, Table 5). Each algorithm is compared with the Manual Photo Interpretation process, which is described in the following paragraph. (See Table 6.)

3.2.2. Maximum likelihood
See Table 3.

3.2.3. Minimum distance
See Table 4.

3.2.4. Spectral angle mapping
See Table 5.

3.3. General results of the process

The results obtained from the processes are presented to show the particular distribution of each identified class. (Fig. 4).

The final results on the sample area show a different spatial distribution depending on the algorithm applied in the classification process. Overall, the most visible heterogenous is found on the water. The results were used to make a comparison between the surfaces identified by the algorithms and the reality of the *status quo*.

3.4. Manual photo interpretation

The effectiveness of the classification and the validation of the classification algorithm were assessed by comparing the automated results to a manual interpretation of a source image for the same sample area. In this way, it was possible to evaluate the performance of the tested algorithms and to then make an informed choice as to which was the best suited to represent the various surface typologies which characterize the specified area of the mountain.

3.5. Comparative selection

The comparison examines the sample portion and the spatial relevance of each homogeneous area. The table below (Table 7) illustrates the extension of each homogeneous area and the percentage proportion.

The difference between the various automated results and the MPI is significant in terms of quantity (Table 7) and spatial distribution (Fig. 4). The MLH results show minimal deviations between the classification results and the MPI: the water class (1%) is close to the 0% of water existing in reality; even the vegetation detected (17%) is very close to manually recorded (14%), with a minimum deviation of 3%. The MD and SAM algorithms have an equal amount of ice, although the image (Fig. 5) does not correspond with the current state. For these reasons, the analysis was conducted using the MLH algorithm.

4. Results

This section presents the results achieved by applying the methodology described in the previous chapter. The results concern the two study areas and conclusions related to the processed data.

Table 3
ML results.

Class	# pixel	Area (m^2)	Area (km^2)	LC Percentage (%)
Ice	315	70875	0.071	7%
Rock	3250	731250	0.731	75%
Water	50	11250	0.011	1%
Vegetation	741	166725	0.167	17%
Total		980100.00	0.980	100%

Table 4
MD results.

Class	# pixel	Area (m^2)	Area (km^2)	LC Percentage (%)
Ice	170	38250	0.038	4%
Rock	2995	673875	0.674	69%
Water	141	31725	0.032	3%
Vegetation	1050	236250	0.236	24%
Total		980100.00	0.980	100%

Table 5
SAM results.

Class	# pixel	Area (m^2)	Area (km^2)	LC Percentage (%)
Ice	194	43650	0.044	4%
Rock	3038	683550	0.684	70%
Water	74	16650	0.017	2%
Vegetation	1050	236250	0.236	24%
Total		980100.00	0.980	100%

Table 6
MP results.

Class	Area (m^2)	Area (km^2)	Percentage (%)
Ice	37,290.29	0.037	4%
Rock	804,317.48	0.804	82%
Water	–	–	0%
Vegetation	138,929.68	0.139	14%
Total	980,537.45	0.981	100%

4.1. Image selection

The images selected to analyse the two case studies were taken in the summer period over two dates for comparison. The selection criteria was based on weather conditions and images availability. Images were selected on dates as close as possible to each other to try to analyse the study areas in a homogeneous condition. A comparison was made with the climatic information provided by the regional monitoring centres with respect to the air temperature and the possible presence of snow. In the absence of snowfall, the potential sample across several years of the summer season was considered. Climate data for this range was collected by reference stations in the site areas from 1986; at this time the Landsat 5 platform was already operational. The best scenes - in terms of image quality for the remote sensing applications and the reduced presence of clouds - were identified, in line with the availability of data, from 1986 onward and 2018 backward. Following this process, 1990 and 2017 were selected as the sample years (Table 8).

4.2. Image elaboration

The testing process for the case study results followed the phases presented below:

1. Selection of the survey extension in relation to the municipal boundaries defined in the Area Selection chapter;
2. Analysis through the process defined in Methodology;
3. Site specific correction in relation to land cover through known data – Corine Land Cover. These corrections were lead with the aim to link environmental and anthropic evolution on a specific area. To enforce the result of this step, in the paragraph Driving Forces Effectes, is integrated to socioeconomic evolutions between 1990 and 2018.

4.3. Focus area 1: Dolomiti – Cortina D'Ampezzo

The data collected shows a reduction, from 1990 to 2017, of the water resource classified as both glaciers (with a reduction of −34%) and for bodies of water (−89%). The vegetation class also shows a slight contraction (−2%). The rock class, on the other hand, is the only increase (+ 21%), demonstrating that the bare areas (i.e. without vegetation) are expanding. (Fig. 6; Table 9).

4.4. Focus area 2: Alpi Giulie – Tarvisio

For 1990 it was used Landsat 5 which operates with the Thematic Mapper (TM) sensor, while for 2018 it was used Landsat 8 which operates with the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). This aspect can affect the results

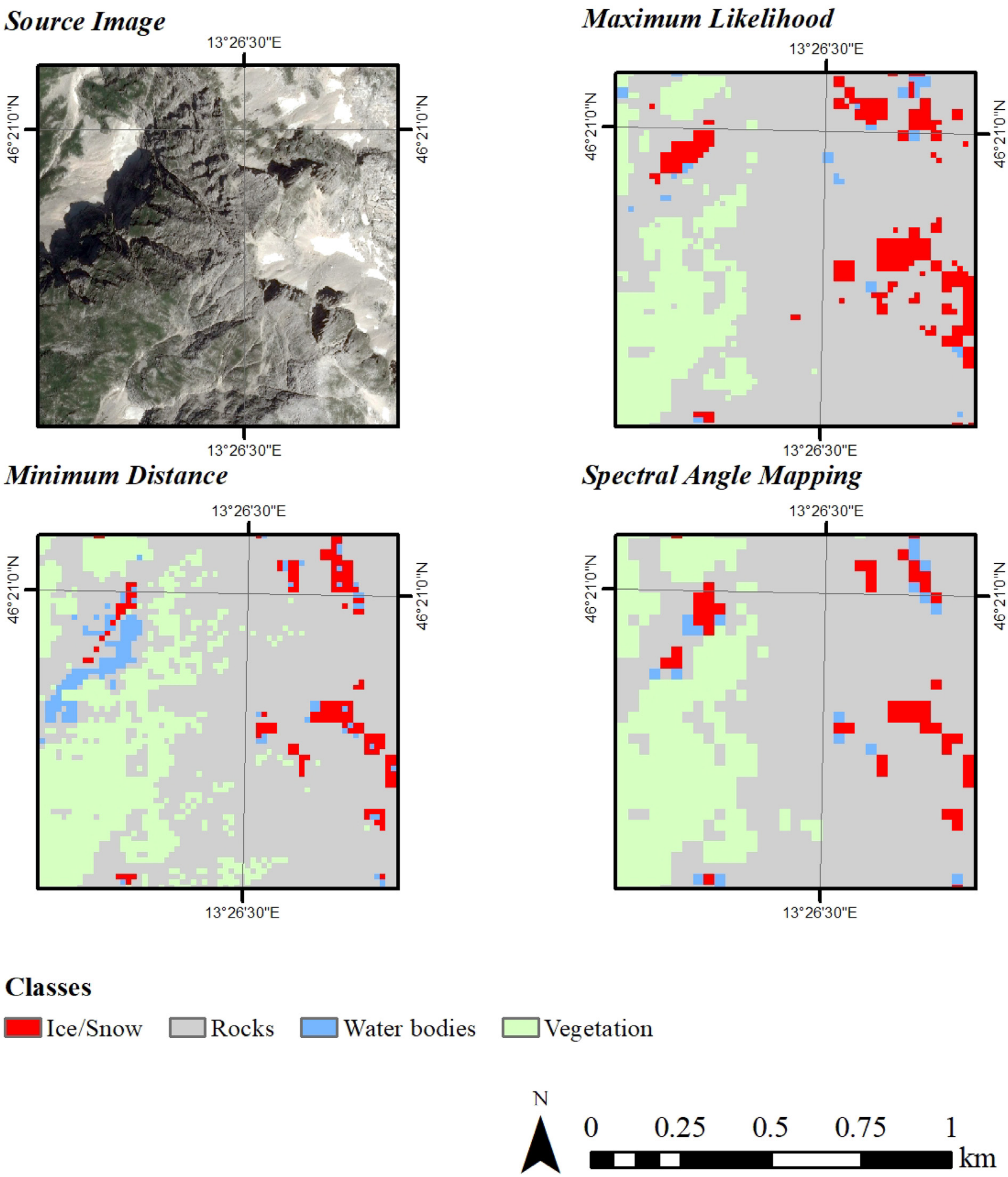

Fig. 4. Results comparison.

derived from a multi-band image classification application due to the different acquisition platforms, each one with different band's intervals. For example to control the anomalies in water variation, caused by difference in sensors, it can be calculated throu a remote sensing index, the water ratio (WRI) (Shen and Li, 2010; Rokni et al., 2014). The strong variation between 1990 and 2017 in the Water Class is therefore connected to a different sensibility between the sensors used in the source satellites. (Fig. 7)

The data also shows a reduction in the snow presence on the ground for this complex, from 1990 to 2017, equal to −90%. It is important to note, however, that this difference is overestimated due to the limitations of the image because it was not always possible to find a scene of the same period without clouds. In fact, one of the limits is that the detectable spectral signature above the

Table 7
Classification comparison.

Class	Maximum likelihood	Minimum distance	Spectral angle mapping	Manual photo interpretation
Ice	7%	4%	4%	4%
Rock	75%	69%	70%	82%
Water	1%	3%	2%	0%
Vegetation	17%	24%	24%	14%
Total	100%	100%	100%	100%

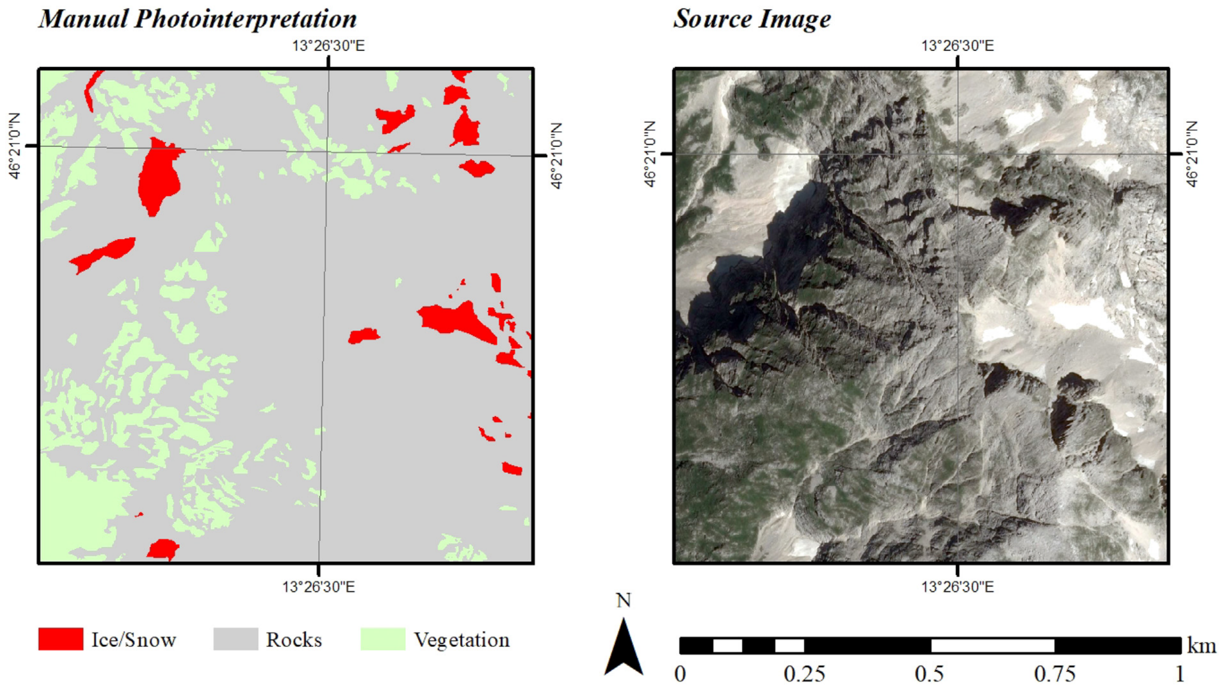

Fig. 5. MP and SI comparison.

Table 8
Satellite metadata extracted from the source.

Year	WRS2 Path/row	Satellite	Landsat scene ID	Landsat product ID	Date acquired	Cloud cover scene (%)	Cloud cover land (%)
2017	191/28	Landsat 8	LC81910282017187LGN00	LC08_L1TP_191028_20170706_20170716_01_T1	2017-07-06	0.85	0.99
	192/28	Landsat 8	LC81920282017162LGN00	LC08_L1TP_192028_20170611_20170627_01_T1	2017-06-11	3.97	4.41
1990	191/28	Landsat 5	LT51910281990193FUI00	LT05_L1TP_191028_19900712_20180214_01_T1	1990-07-12	2.00	2.00
	192/28	Landsat 5	LT51920281990200FUI00	LT05_L1TP_192028_19900719_20180214_01_T1	1990-07-19	6.00	6.00

clouds conflicts with the spectral signature of the ice. This generates an error, as can be seen in the 1990 image above the mountain groups of the Slovene part of the Mangart Group, Jalovec-Bavški Grintavec Group, Škrlatica Group. (See Table 10).

The surfaces with ice decreased by −90%, the rocky surfaces increased slightly (9%), while the water bodies are increasing (375%), the vegetated surfaces are almost unchanged, experiencing a slight increase (3%).

5. Discussion

The previous chapter presents the results of the survey methodology on the two focus areas. In summary, what emerges is a marked decrease in the ice-class for both territories. This result illustrates the impacts of rising global temperatures, and of Climate Change more generally, in the Alps.

The result isn't "only" a statistical result of changing, but trough the spatial information is possible to understand "where" territories are changing. Identifying where the land cover varied allows to assess which adaptation strategies can be deployed to cope with specific impacts.

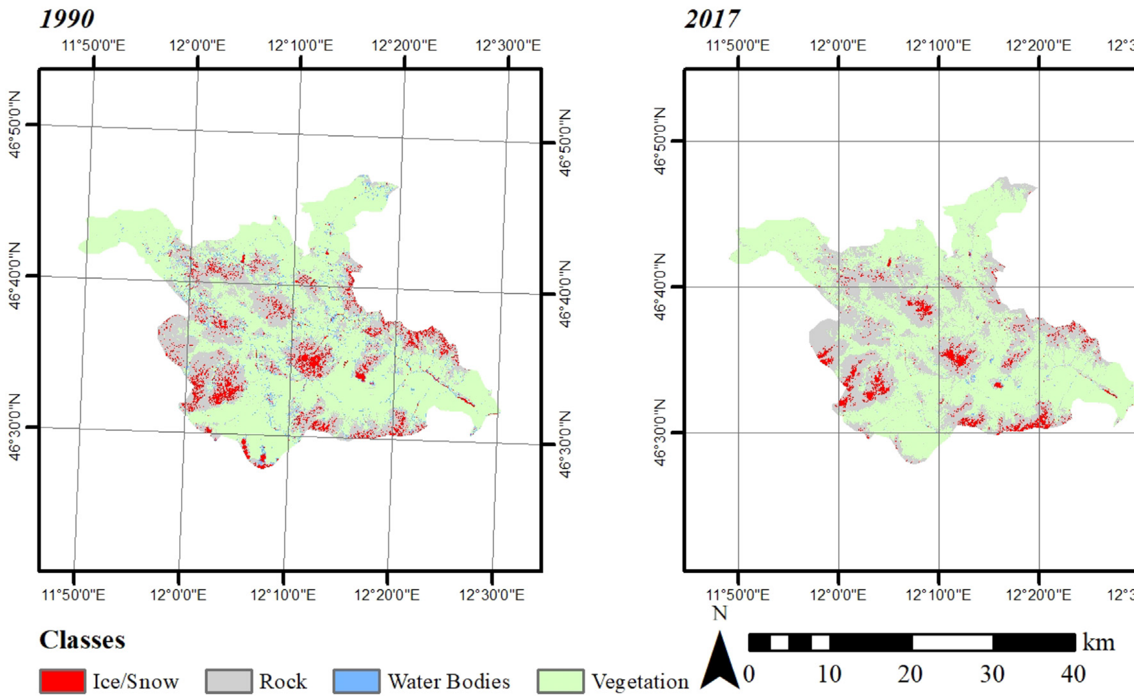

Fig. 6. Area 1 classification results.

Table 9
Area 1 classification results.

Class	1990			2017			Variation (%)
	Area (m^2)	Area (km^2)	Percentage (%)	Area (m^2)	Area (km^2)	Percentage (%)	
Ice	53.648.100,00	53,65	6%	35.467.875,00	35,47	4%	−34%
Rock	250.676.100,00	250,68	30%	303.049.800,00	303,05	36%	21%
Water	26.826.300,00	26,83	3%	2.831.850,00	2,83	0%	−89%
Vegetation	511.497.000,00	511,50	61%	499.342.500,00	499,34	59%	−2%

The results underline how the reduction of surfaces covered by ice and snow is related to the general territorial context. What emerges is a reduction of that resource that turns out to be strategic both from ecosystemic and from the economic point of view. It is possible to hypothesize, in the light of the information obtained, that economic activities connected to tourism could contract in the medium term due to the lack of resources. Both focus areas are renowned ski resorts, where continuous public and private investments have been made in recent decades.

The case of Cortina D'Ampezzo is particularly representative of the relationship between the presence of ice and snow deposits and winter tourism infrastructure. In Fig. 8 are relates the land-cover changes over the presence of perennial snow between the two decades, with the current ski areas and accommodation facilities localization. The map highlights how these human activities are exposed to the phenomenon of snow and ice melting. These information are a structural support for planning activities as they can forecast the progressive exposure of economic activities in a perspective of loss of the resource. The proposed methodology is consequently oriented to present a framework of risk and vulnerability to support the planning of the territory in the function of adaptation to climate change, in this case to the impact of a loss of a structural resource. Economic investment models have been based on the continuous availability of ice and snow over time. The reduction of this resource amounts to −90% in Tarvisio and − 34% in Cortina D'Ampezzo, while it is appreciable the expansion of urban settlements in the same period of time. The results do not aim to present a reduction in snowfall or a microclimatic modification, but rather they are aimed at providing a survey tool related to human activities in the area and to provide the cognitive basis for adaptation strategies to an ongoing phenomenon.

The limits recognized during the research process are mainly related to the availability of images and socio-economic and climatic data.

As reported in the previous chapters, the following limitations were found in the image processing methods:

1. the use of satellite images is necessary to address the gaps in territorial monitoring systems, but there is a limited availability of images with good geometric resolution and suitable atmospheric conditions;

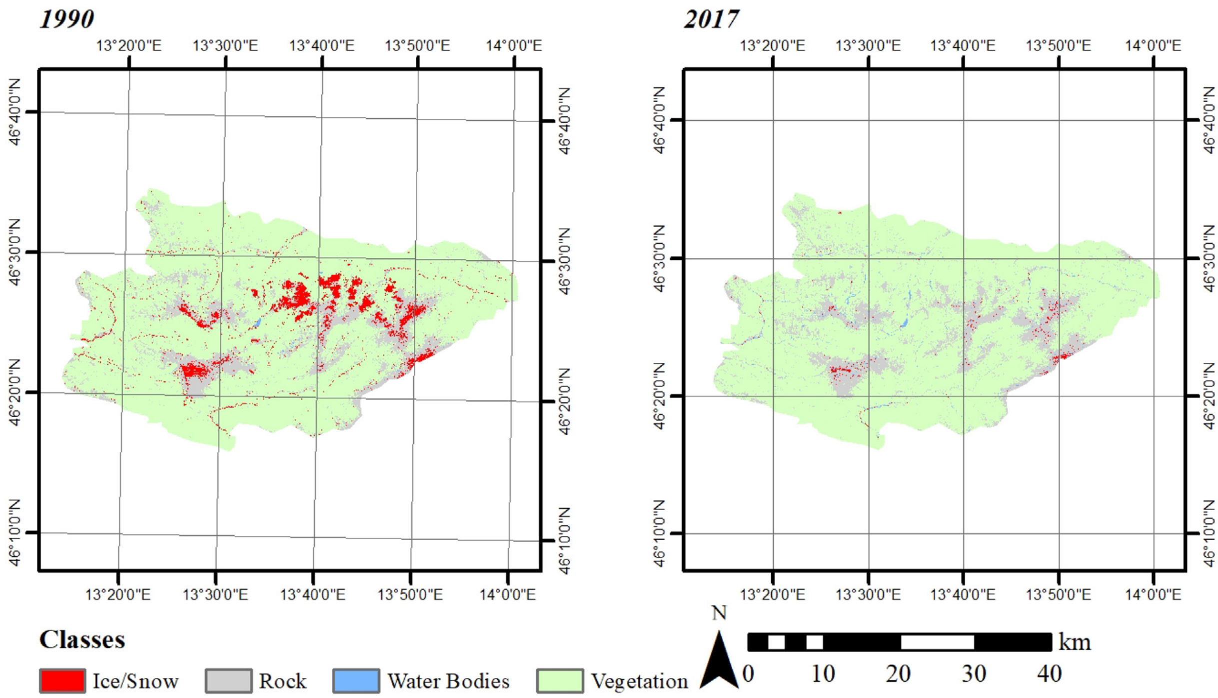

Fig. 7. Area 2 classification results.

Table 10
Area 2 classification results.

Class	1990			2017			Variation (%)
	Area (m^2)	Area (km^2)	Percentage (%)	Area (m^2)	Area (km^2)	Percentage (%)	
Ice	60.742.800,00	60,74	5%	6.218.550,00	6,22	1%	−90%*
Rock	195.259.500,00	195,26	16%	212.717.925,00	212,72	17%	9%
Water	1.462.500,00	1,46	0%	6.943.725,00	6,94	1%	375%*
Vegetation	978.817.500,00	978,82	79%	1.005.722.100,00	1.005,72	82%	3%

2. the lack of a continuous set of satellite images can make the assessment of territorial micro-variation unprecise;
3. There is a shortage of sources – both from the climatic and the imagines point of view - capable to provide, from medium to long periods of time, the necessary data for effective statistical processing.

Despite the described limitations in the sources used for this study, it illustrates the potential to define a baseline which combines natural, environmental factors and anthropogenic trends in the Alps; an Atlas which monitors the variation in surface materials over time, in relation to climatic factors. In future, this tool could be integrated with new technologies; for this reason it has been designed with continuous implementation in mind. For example, Big Data could provide the necessary socio-economic data; this could permit a live stream of the various territorial dynamics, from CO2 emissions to the emergency management of extreme events. In addition, open-source access to high resolution satellite images with more frequent orbits would be highly beneficial for public administration and transboundary government agencies.

6. Conclusion

Local administrations will be increasingly committed to dealing with the impacts of climate change which, due to their nature and size, are difficult to locate and predict with precision. While international symposia usually define mitigation efforts, adaptation aims to solve local needs. These needs must, therefore, be identified for specific territorial areas as climate-related impacts differ according to each territory's geography and socio-economic function.

The Alpine territories, a popular location for winter tourism, exhibit local economies that are highly dependent on the presence of snow in the winter period. In addition, the reduction of the layer of snow and ice deplete water reserves, increase the warming effect and degrade the regions' biodiversity.

From this perspective, it is essential that local administrations have access to shared, holistic frameworks so they can develop

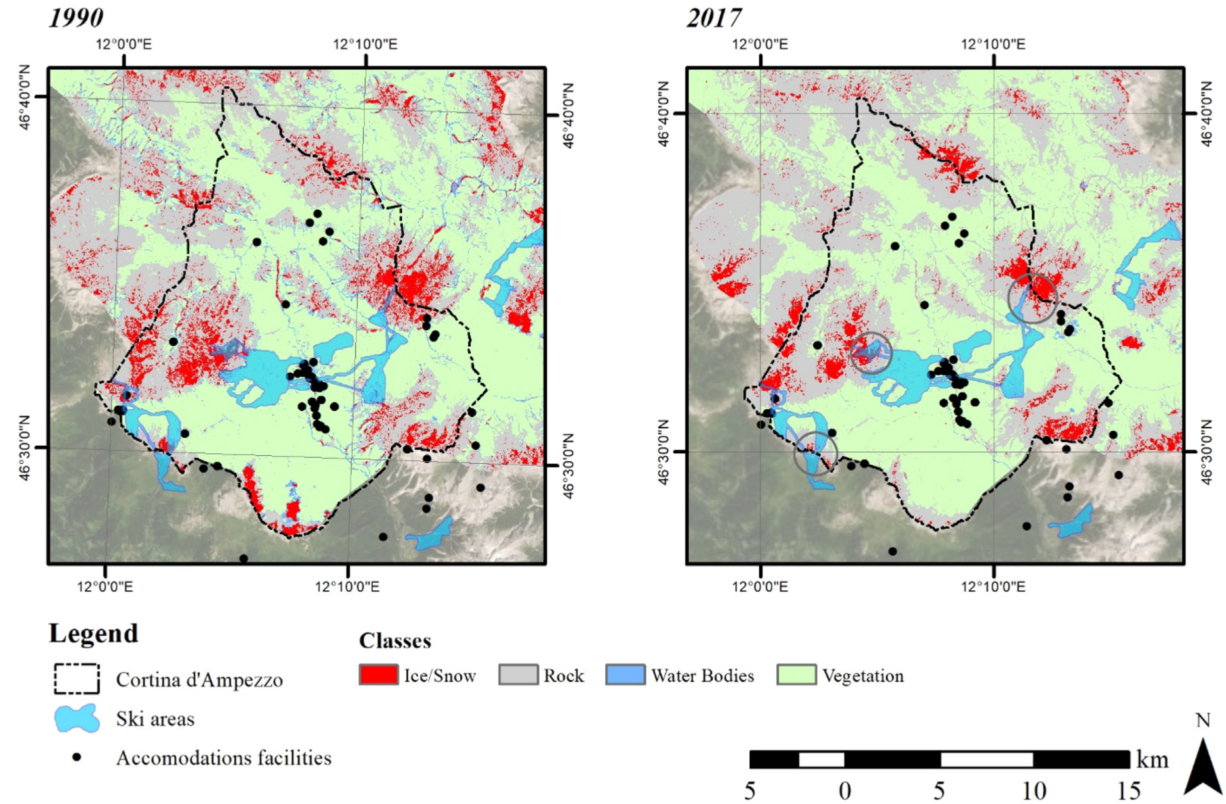

Fig. 8. Ski economy distribution.

adaptive policies and management strategies for the future climate.

In summary, what emerges is a marked decrease in the ice-class for both territories. This result helps to understand what are the impacts of the phenomenon of rising temperatures, and generally of Climate Change, concerning the environments of the Alps. Nevertheless, this variation only partially describes the organic relationship that exists between the natural environment and the anthropic system. To obtain this complete vision and achieve the objectives set out in the Introduction, it is also necessary to consider the factor of urban and socio-economic evolution.

This study aims to define a tool which can support collaborative strategies between different municipal and national bodies, by addressing the discontinuity of available data caused by administrative limits.

This paper has focused on a case study examining the Italian-Slovenian border, but its findings could be applied elsewhere. Implicitly, project aims to support territories in transitioning to alternative, sustainable forms of tourism and developing models for urban growth which reduce environmental fragility. The results define the extent of the impact of the climate on the reduction of ice and snow.

The reduction is not homogeneous and depends on the exposure of the Alpine slope. To account for this, the developed methodology does not just quantify the variation but constantly recalculates the permanent snow baseline. This factor is related to the socio-economic variations of the target territories and suggests that is necessary to develop an integrated and holistic approach, functional to the dynamics, of planning and governance. To define territorial adaptation strategies, it is therefore necessary to confront the actual vulnerabilities and the present and future risks of the territories. The current dynamics of urban planning and urban design are encouraged at European level through national, regional and local funding. These design dynamics network scientific research with local government agencies. This research is therefore oriented toward its pragmatic and paradigmatic use, with the aim of being a replicable methodology in the European Alpine area.

Foundings

The project is founded by the EU project "SECAP Supporting energy and climate adaptation policies", – Interreg Italia – Slovenja. [https://www.ita-slo.eu/en/secap]

Declaration of Competing Interest

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript

The following authors have affiliations with organizations with direct or indirect financial interest in the subject matter discussed in the manuscript:

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