REGIONAL AVALANCHE RISK ANALYSIS IN PIEDMONT, ITALY

Lanteri Luca Maria[1,3], Solero Erika[1], Pispico Rocco[1], and Chiambretti Igor[2]

[1] Arpa Piemonte, Italy; [2]AINEVA, Trento, Italy; [3]Corresponding Author

ABSTRACT: This study develops a methodology for analysing avalanche risk at a regional level, adapting methods previously used for assessing other natural risks, such as floods and landslides. The methodology is based on applying the classic Buwel matrix method adapted to the avalanche context. The perimeters of the CLPV (Probable Avalanche Location Map) allow for the definition of different levels of danger (low, medium, high) based on the type, size, and frequency of avalanches. Risk elements were defined using data from various regional sources, foremost among them the BDTRE (Territorial Reference Database of Entities). Geographic analysis combines this information, determining a risk degree for each element on a scale from R1 to R4. The exposed population and the economic value of the buildings at risk were also estimated for residential and productive contexts. A significant aspect of this methodology concerns the organization and management of data and analysis algorithms within a PostgreSQL database. This technological choice ensures high flexibility and ease of updating analytical processes, allowing new information to be incorporated efficiently and promptly. This experimental study has been used to identify the phenomena at greatest risk, where it is a priority to conduct local in-depth analysis, as defined by the recent Directive of the President of the Council of Ministers dated 12th August 2019, and as support for defining alert scenarios at the regional level.

KEYWORDS: avalanche hazard assessment, roads, infrastructures.

1. INTRODUCTION

The Directive of the President of the Council of Ministers (DPCM) of 12th August 2019, "*Operational Guidelines for the Organisational and Functional Management of the National and Regional Warning System and territorial civil protection planning in the context of avalanche risk*", establishes the operational guidelines for the management of the national and regional warning system, with particular attention to civil protection planning in the event of avalanche risk. The directive aims to improve the organization and coordination between the different authorities involved in managing emergencies related to avalanche risk, defining procedures for alerting, information management and operational intervention. It also includes guidelines for drafting territorial civil protection plans to adapt to the avalanche risk's specificities and guarantee a timely and effective response. The directive requires that within two years from the publication of the DPCM, the Regions, based on the hazard studies, define, in connection with the municipalities, based on the information provided by them, an initial mapping of the areas subject to avalanche risk and issue the directives for alerting and the guidelines for provincial, municipal/inter-municipal or civil protection area planning, implementing the provisions of the DPCM itself.

In Piedmont, a region in the north-west of Italy (Fig.1), to provide a support tool for these activities, a "*Strategic project for the completion of avalanche cartography in the regional territory*" was started, which made it possible to complete the regional avalanche cartography for part of territory where data was lack, at least concerning the main anthropic areas affected in the region.

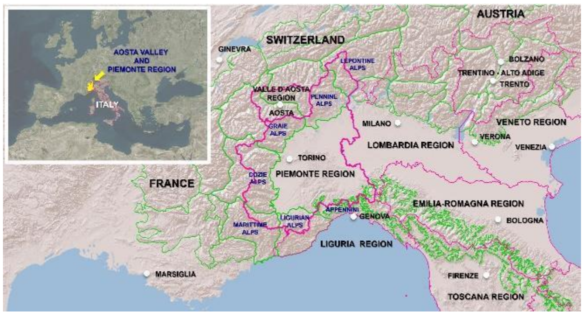


Fig. 1: Geographical outline of the area covered by this work

Given the tight time frame, the methodology used was expeditious, mainly using photo-interpretation and data deriving from the approved urban planning instruments (PRGC), validated at a later date with targeted inspections on the anthropized areas of particular interest and the analysis of archive information already available.

Although less in-depth and complete than the methodology commonly used for drafting maps of probable avalanche locations (CLPV), this methodology has made it possible to cover a vast portion of the regional territory in a limited time (Prola et al., 2021).

---

[3] *Corresponding author address:*
Luca Maria Lanteri, ARPA Piemonte, Via Pio VII 9, Torino (TO), Italy:

luca.lanteri@arpa.piemonte.it

To achieve an initial risk assessment at a regional scale, a methodology for risk assessment at a regional scale has been prepared, derived from that already applied by Arpa Piemonte (Regional Agency for the Protection of the Environment) in the context of other types of risk, in particular that for the implementation of the Basin Scale Flood Risk Management Plans (PGRA), as defined by the Legislative Decree 49/2010, in implementation of the European Commission Floods Directive 2007/60/E.C.

The risk analysis, among other things, is aimed at directing the in-depth activities that the municipalities (with the support of the Local Avalanche Commissions) will have to carry out to fulfill the provisions of the DPCM on 12th August 2019.

The developed methodology is a useful tool for territorial planning and the prevention and forecasting of avalanche risk on a broad scale. It can help direct any in-depth studies and focus on the available resources.

2. COLLECTION AND VALIDATION OF INFRASTRUCTURES INFORMATION

A fundamental requirement to move from avalanche maps to risk cartography is to have an accurate infrastructure database.

In Piedmont, the cartographic sector of the Piedmont Region takes care of implementing and updating of the Territorial Reference Database for Authorities (BDTRE), which represents the geographical reference database of the regional territory, with the contents of technical cartography, structured according to the national '*Technical rules for the definition of the content specifications of geo-topographical databases*' and primarily aimed at supporting planning, government and territorial protection activities.

The BDTRE makes available various information levels relating to infrastructures; the following information levels have been taken into consideration:

- landfills;
- buildings;
- electricity grid nodes;
- settlement units;
- assets according to Law 1497/1939;
- important elements of landscape;
- systems of villas, gardens and parks;
- roads and road elements;
- cable transport elements;
- railway elements;
- ski slopes.

This data was integrated with information from the 2012 edition of Piedmont Region's land use map, which divides the territory into 74 different land use classes according to a legend based on the CORINE LAND COVER project. The original raster coverage has been vectorized for easier cross-referencing with landslide areas. An attempt was made to use the most up-to-date land-use dataset, Corine Land Cover 2018 Level IV, but the data is not detailed enough for mountain areas.

Due to the lack of information in the roads layer, it was necessary to carry out a specific in-depth study in order to reclassify the roads based on any temporary winter closures or transit restrictions. In fact, the BDTRE contains the attributes of: location, level, and access restrictions for each road section (see Table 1), but in the case of mountain roads, they are often not valorized or have incorrect indications.

Without this specific in-depth study, there is a tendency to overestimate the risk on the road network because sections of roads that are not used during the winter period are taken into account. A similar problem was found with tunnels or viaducts, which in some cases were not correctly classified. To solve this problem, the entire mountain road network was verified and reclassified using information from photo-interpretation, direct knowledge, or contact persons on site or the contact persons of the Local Avalanche Commissions.

More than 96’000 road segments were analysed and verified, of which 4’786 were modified by correcting their attributes. The main corrections were made to the classification of access restrictions (Fig. 2), but, in several cases, the attributes relating to location and level (areas in tunnels or subways) were also modified.

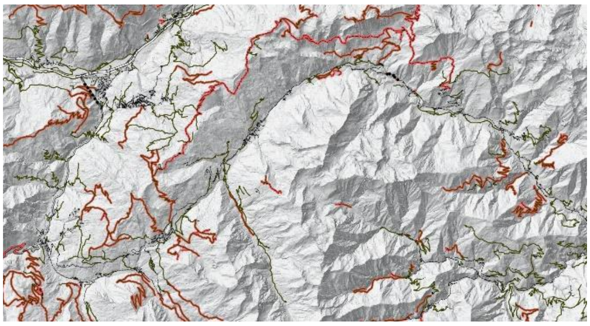


Fig. 2: Example of the road reclassification in Val Chisone and upper Val Susa: in red the BDTRE road without indication of closure status and reclassified by ARPA as "periodic restrictions" in the winter period or "no through traffic" after revision.

The updating methodology was shared with the cartographic sector of the Piedmont Region, putting in place several operational measures to reconcile the changes made with the original database. In this way, the revision work will be able to update the road layer of the BDTRE in the future.

3. RISK ANALYSIS ON A REGIONAL SCALE

In the last few years, ARPA and the Piemonte Region have developed a flood risk analysis methodology at a regional scale, used for the realisation of the hazard and risk maps related to the European Commission Floods Directive 2007/60/C.E., now in its second cycle. This methodology is based on the classic matrix approach (so-called Swiss method) widely used classically in areas such as the definition of landslide hazard and developed by the Bundesamt für Umwelt, Wald und Landschaft (BUWAL) of the Swiss Confederation, suitably modified (BUWAL, 1998).

This methodology has been reused at the regional level with good results in other areas, such as for fire risk, alluvial fan risk zone and recently for landslide risk.

As a first step, tree level hazard was defined (low/medium/high), based on the available data for each avalanche type. Thus, when necessary, the hazard picture was cross-referenced with anthropogenic structures, using data derived from the BDTRE supplemented with other data sources (see previous section). From the geographical intersection between hazard and exposed elements, a risk grade ("R1", "R2", "R3", and "R4") was derived for each exposed element, using a matrix approach derived from the methodology of the "*Floods Directive*". In addition, for the residential and productive contexts, an estimate was made of the population potentially affected by each phenomenon, as well as of the economic value of the buildings "at risk", using the Real Estate Market Observatory (O.M.I.) database and National Institute of Statistics (ISTAT) data as a basis.

3.1 Hazard Definition

The base map to define the hazard was SIVA, a Regional Information Avalanche System based on the CLPV approach (Probable Avalanche Location Map). We had to use different approaches depending on the type of information available for each prone avalanche area, because not all areas have the same level of in-depth knowledge. In facts, the SIVA avalanche cartography provides the following information layers:

a) Documented avalanche sites: avalanche sites surveyed according to the CLPV or Cadastre methodology, to which a detailed description sheet is associated, such as morphometric parameter and frequency;

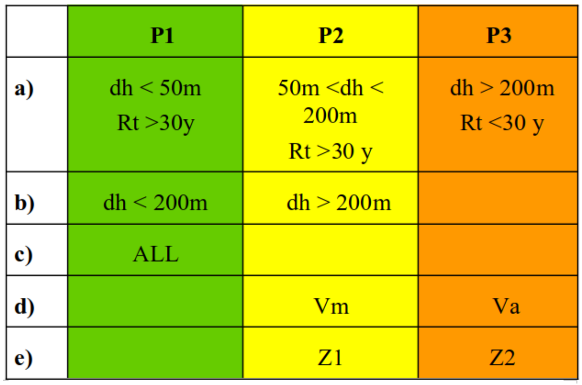
b) Linear avalanches sites: smaller avalanches that cannot be mapped as polygons;

c) Danger zones: areas subject to possible release or smaller avalanches that cannot be mapped as avalanche sites;

d) P.A.I. avalanches: Avalanche sites derived from the expeditious review of data from the Master Plans updated to Basin plans for hydrogeological risk (P.A.I.), to which a detailed descriptive sheet is not associated;

e) Data from model: Avalanche sites derived from applying a specific mathematical model.

Using the matrix in Fig. 3 it's possible to classify avalanche sites in 3 different hazard levels (P1, P2, P3). For documented avalanche sites (type a), it's possible to use both morphological data and frequency data together, so the hazard level is quite well-defined; instead for other typology, where frequency is not defined we have to use another approach. For linear avalanches sites (type b), generally not of large dimensions, only the height difference was used; for danger zones (type c) that are defined as prone only to small avalanches the hazard level was assigned to P1. For the avalanches derived from the P.A.I. (type d), a preliminary hazard classification is already available (Vm: Medium Dangerousness, Va: High Dangerousness); the already available classification (Z1, Z2) was also used for avalanches from the model.



	P1	**P2**	**P3**
a)	dh < 50m Rt >30y	50m <dh < 200m Rt >30 y	dh > 200m Rt <30 y
b)	dh < 200m	dh > 200m	
c)	ALL		
d)		Vm	Va
e)		Z1	Z2

Fig. 3: the matrix defines the hazard level (P1, P2, P3) for each type of avalanche (a, b, c, d and e).

It's important to remember that the perimeters of avalanche sites represent the envelope of the maximum extent ever reached by all known avalanche events (deduced from historical or morphological information). In fact, at our scale of analysis it's not possible to have information about all single events, in order to map zones with different return time frequencies and intensity.

3.2 Classification of Elements at Risk

For the classification of the elements at risk, we referred in the first instance to the classification proposed by Barbolini et al. (2004) and to that proposed in the 'flood directive' method; the classifications were suitably modified to adapt to the information available on the infrastructures and to the specific context.

All the point, linear and polygonal elements described in the previous paragraph were classified according to the proposed classification to arrive at four damage classes in relative value (D1, D2, D3 and D4).

This methodology does not consider the intrinsic vulnerability of the exposed objects, which is currently too complex and unreliable at the regional analysis scale used. Vulnerability was therefore regarded as equal to one for all infrastructures.

3.3 Hazard Matrix

Spatially cross-referencing the infrastructure, classified in four damage classes, with avalanche sites classified in the three hazard classes, according to the matrix in Fig. 4 yields it possible to reach the four relative risk classes, increasing from R1 to R4.

Damage

Hazard	D1	D2	D3	D4
P1	R1	R1	R2	R3
P2	R1	R2	R3	R4
P3	R1	R2	R3	R4

Fig. 4: the matrix puts together information about hazard and danger level in order to get a 4 class risk classification of classification elements at risk.

The analysis allows obtaining three different information layers (point, linear and polygonal) that define the risk classes for the various infrastructures in the area.

Furthermore, for residential and productive contexts, an estimate was made of the population potentially affected by each phenomenon, as well as the economic value of the "at risk" buildings, using the O.M.I. Database as a basis (Real Estate Market Observatory) and the *"Population and housing census"* carried out by ISTAT (National Institute of Statistics) in 2011 (ISTAT, 2011).

The SIVA database currently contains information on more than 4'500 documented avalanche sites, about 9'000 localised hazards and 4'400 danger zones. The database shows that for 1'220 sites, some interference with anthropogenic activities has been reported from the XVII century to the present day.

The risk analysis allows identifying and classifying a great number of anthropogenic elements interfering with avalanche sites or other avalanche dangers that were not previously detected. About 9'000 polygonal infrastructures, 2'500 linear stretches (generally road sections) and 195 point elements interfering in some way with the SIVA areas were identified and classified.

Fig. 5 and Fig. 6 show some examples of the results obtained respectively for an area in Formazza Valley (in north part of Piedmont) and Upper Susa Valley (in west part of Piedmont).

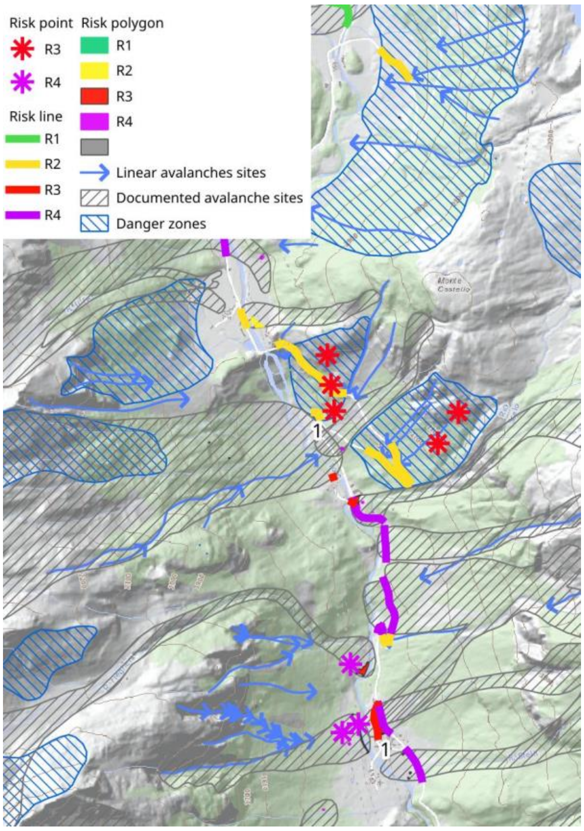


Fig. 5: Example of risk classification of infrastructures in the Formazza Valley.

After this first phase of analysis, a careful verification of the identified interfering anthropic elements is needed, to validate the results and correct any errors related to the inaccuracy of the starting databases. The main problems identified are: elements present in the BDTRE that no longer exist (e.g. old ruins); elements wrongly classified (e.g., sections of road classified as always open that are closed in winter; section of road with missing indication of presence of tunnels or viaducts); element with inconsistent classifications or perimeters; missing elements.

As previously described, in the first phase the verification was made directly by ARPA Piemonte. At the end of analysis, all data were shared with the CLV (Local Avalanche Commission) in order to allow an in-depth verification. The CLV are advisory collegial bodies established in mountain areas at risk of avalanches, aiming to monitor, prevent and manage avalanche hazards in support of the local civil protection authorities. These commissions are generally composed of local experts, technicians and representatives of local and regional authorities.

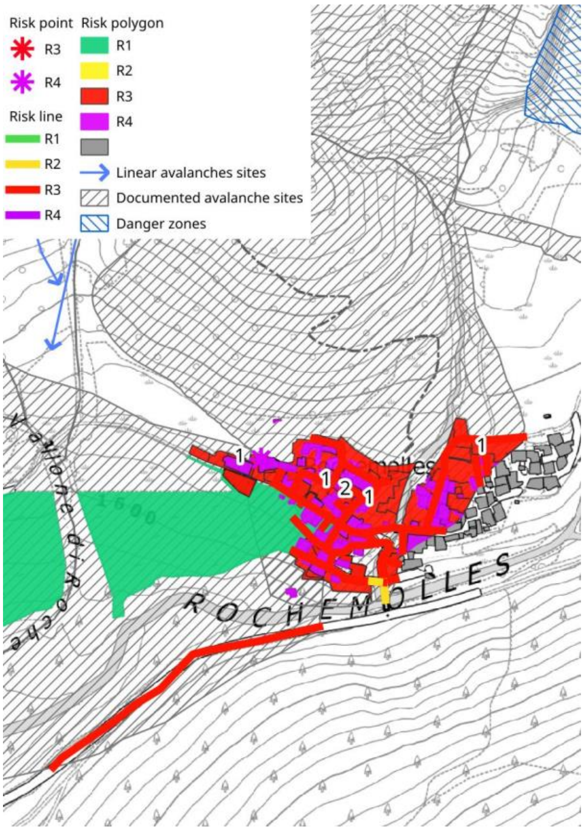


Fig. 6: Example of risk classification of infrastructures in the Upper Susa Valley. In this case, the algorithm also tries to estimate the number of inhabitants for each building using the OMI data (black numbers with white borders).

Data was also progressively shared with other authorities at regional and provincial level. Sharing data has the double purpose of allowing the verification and integration of information about infrastructures by the local expert that knows very well their territory, but also to make available the result of risk analysis to authorities to subsequent insights, as requested by National Directives.

4. TOOLS USED

All the analysis process and data were fully transferred to the ARPA Piemonte geodatabases managed on PostgreSQL/PostGIS technology in order to o benefit from various advantages. It

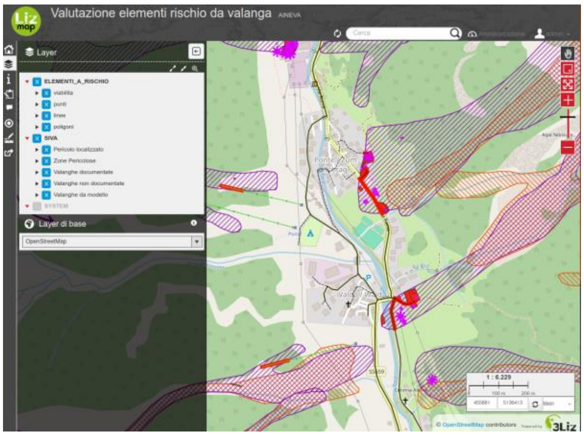
- allowing multi-user editing in the correction phases;
- automatise the risk analysis;
- integrate the results into the regional geological information system.

In fact, the databases are mainly accessible by intranet network through the open-source G.I.S. software QGIS; ARPA Piemonte takes care of managing user administration, backups and integration with all the entire shared heritage.

Data processing was carried out employing specific SQL queries that allow the serialisation of calculation processes. In definition of risk analysis calculation method, particular attention was paid to the optimisation of the calculation processes and the parameterisation of the input data and classification matrices used, with a twofold advantage:

- it has been possible to reduce calculation times significantly: it is now possible to perform the analysis on the entire database in less than two hours, whereas previously many hours of processing were required;
- It is possible to update the internal process exceptionally easily and quickly, following changes to the databases, such as the annual update of the BDTRE and the anthropogenic elements involved or the perimeters of instabilities, and following changes to the tables and calculation matrices.

To easily share data with CLV and other authorities, a web GIS system was created based on the open source software Lizmap. This software allows viewing and also editing geographic and alphanumeric data directly using a common browser such as Firefox or Chrome, without the need to install additional software on your PC or smartphone (Fig. 7).



Valutazione elementi rischio da valanga

Fig. 7: The Lizmap webGIS allows viewing and also edit geographic and alphanumeric data directly using a common browser.

5. SUMMARY

This work tries to define a methodology for avalanche analysing risk at a regional level, using an easy and well-known approach previously used with success for assessing other natural risks. The approach tries to minimise the information needed because it's generally very hard to have deep and complete information on the whole territory.

A lot of time has been spent to find, organise and correct information about human infrastructure. It's mandatory to have a well-organised and updated database of infrastructure, so it's important that all data collected from local export or by other kind of analysis was used to update the original dataset, in a collaborative way.

Using a geo-databases to organise with integration of the analysis script has a lot of advantages: first, it is possible to keep up-to-date the information and share it with other stakeholders also via web; second, it's possible to easily replicate the analysis when some data is changed or updated.

The approach is based on a "maximum impact" scenario: the perimeters of avalanche sites represent the envelope of the maximum extent ever reached by all known avalanche events (deduced from historical or morphological information). It must be remembered that this analysis is not directly usable at the local scale for managing avalanche risk, where it is necessary to use more detailed tools such as PZEVs (Avalanche Zone Plans) or other more detailed analyses. It will then be in charge of individual municipalities to "reshape" the maximum risk envelopes based on the targets under consideration/interest in their respective territories. These detailed recalibrations may subsequently be subject to further in-depth statistical analysis concerning the local criticalities detected, with a view to defining the priorities of interventions.

Nevertheless, this risk assessment approach represents a primary tool for spatial planning and the prevention and forecasting of avalanche risk at the regional scale. It can help direct any in-depth studies and focus on available resources.

6. ACKNOWLEDGEMENT

We want to thank all local experts who work in avalanche management. A special thanks to Cristina Prola for her fundamental work on implementing and keeping up-to-date the SIVA.

7. REFERENCES

Barbolini M., Natale L., Tecilla G., Cordola M., 2004, Linee guida metodologiche per la perimetrazione delle aree esposte al pericolo di Valanghe: AINEVA, 2004. http://hdl.handle.net/11571/132893

BUWAL, 1998, Methoden zur Analyse und Bewertung von Naturgefahren. Umweltmaterialien nr. 85.

ISTAT. 15° Censimento della popolazione e delle abitazioni, 2011 https://www.istat.it/statistiche-per-temi/censimenti/censimenti-storici/popolazione-e-abitazioni/popolazione-2011/

Prola M.C., Lanteri L., Solero E., 2021, 20 anni di SIVA I passi per il completamento della cartografia valanghe in Piemonte: AINEVA, Neve e Valanghe n. 95, 2021.