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Deliverable D2.8: Landslides tools and methods. Validation report

A deliverable of WP 2: Tools to support the Early Warning for Landslides geohazard

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EXECUTIVE SUMMARY

This task consists in the validation of the product generated in the Tasks 2.3 “Landslide activity map” and 2.4 “Vulnerability elements at risk map generation”.

The products of these two tasks are: ADA (Active Deformation Areas) and VEAM (Vulnerable Elements Activity Maps). The first one represents a direct output of the interferometric analysis of multi-temporal Sentinel-1 images; the second one comprises the evaluation of landslide intensity and vulnerability/exposure of elements at risk starting from interferometric results.

Considering this different validation procedure have been defined to manage the different outputs of the project.

This deliverable will explain how these products are validated, presenting some practical examples and how uncertainties are evaluated.

The deliverable is based on the latest product produced by Task 2.3 (Deliverable 2.5 “Updated Active deformation areas map (ADA)” and Task 2.4 (Deliverable 2.7 “Updated Vulnerable elements at risk map generation (VEAM) – Final version”

The Activity 2.7 is led by UNIFI, supported by the Valle d’Aosta Region for the ancillary and validation data collection.

REFERENCE DOCUMENTS

N°	**Title**
RD1	DoW Part B

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1 INTRODUCTION

Validation is the last task to be performed after obtaining convincing and reliable results. The connection between models or remotely sensed data and the "ground truth" has to be established in order to avoid exaggerations or underestimations and to evaluate the uncertainty level of the work.

In this deliverable, the outputs produced by Tasks 2.3 "Landslide activity map" and 2.4 "Vulnerability elements at risk map generation" are validated.

The main outputs that will be evaluated are three:

1. PSI (Persistent Scatterers Interferometry) data obtained from Sentinel-1 images processing, i.e. deformation maps composed of thousand PS (Persistent Scatterers) points;
2. Active Deformation Areas (ADA), i.e. hot-spots of active motion above a certain threshold;
3. Vulnerable Element At risk Map (VEAM), i.e. the process to produce maps of potential impact and loss degree by starting from interferometric products.

These various outputs require different validation procedures to be implemented, based on ground data comparison or previously proposed approaches.

In summary:

1. PSI results are compared with GNSS (Global Navigation Satellite System) data;
2. the ADA database is matched with the landslide inventory of the Valle d'Aosta Region and with the local morphology;
3. the VEAM procedure is evaluated through a literature analysis of different vulnerability and exposure approaches proposed for landslide studies in similar contexts.

2 PSI VALIDATION

Considering the increasing use of PSI data for multiple monitoring purposes, validation became a relevant topic. Most of the PSI validation activities are based on the comparison of time series with independent estimations of the same quantities acquired by detailed-scale systems, e.g. levelling or GPS measurements. Some authors proposed validation approach based on the comparison between 2 different processing approaches applied to the same data stack (Crosetto et al. 2016).

In the Valle d'Aosta Region, some sites are currently or have been monitored using GNSS permanent or discontinuous stations. Of these, we selected the data referred to the Bosmatto landslide in the Gressoney Valley. We opted for this site because of the availability of a good density of PS points, the high "radar visibility" of the slope from the descending orbit (90% of the real component of motion is measurable from satellite) and for the presence of 5 GNSS stations.

The Bosmatto landslide is located in the Gressoney Saint Jean municipality and is classified as complex (Luino, 2005), being composed of two landslide bodies that involve both debris and bedrock. The western sector of the landslide is almost completely vegetated, whereas the eastern one presents a heterogeneous debris cover. In October 2000, a debris flows originated from the blocky sector of the Bosmatto landslide was triggered by intense rainfalls, running down the Letze Creek and destroying several private houses, depositing 2–3 m of debris with rock blocks of the maximum estimated volume equal to 103 m^3 (Luino, 2005).

A total of 102 PS points is found in the debris area from which the October 2000 debris flow was originated. Velocities varies between 5 and 42 mm/yr, away from the sensor and coherent with a motion along the WNW direction (Figure 1A).

Five manual and 2 automatic GNSS station have been installed on the landslide by the Geological Service of the Valle d'Aosta Region, acquiring data continuously and discontinuously from October 2002 and October 2015. Manual stations are acquired every 6 months or one year. The automatic stations, installed on a 3m long pole, are the only able to acquire during winters.

Figure 1A and 1B show the average dip and azimuth direction of each GNSS station. Station A5 is representative for the motion in the crown area (320°N, 60° dip) whereas station A6 is a proxy

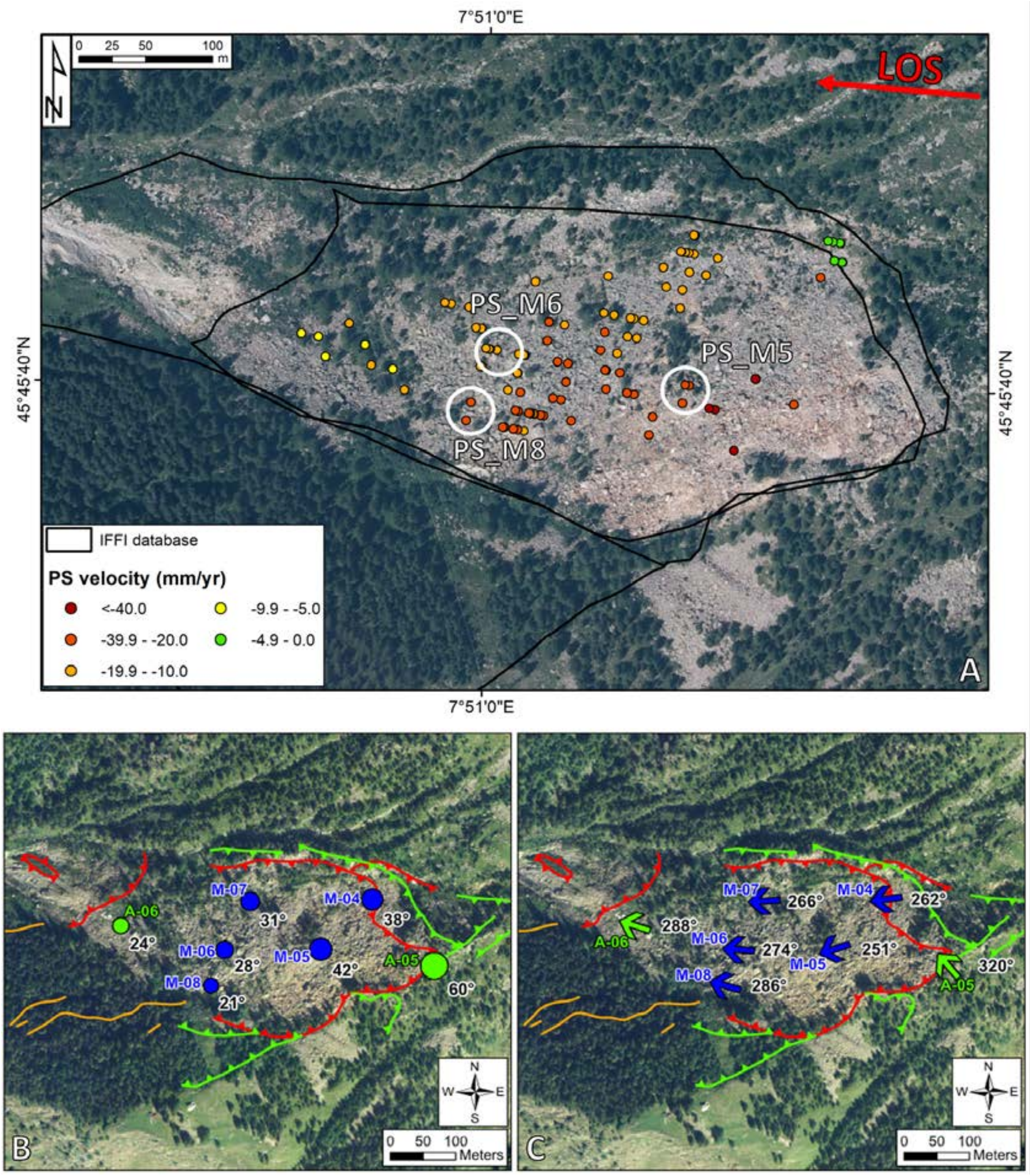

Figure 1 – PS and GNSS stations for the Bosmatto landslide. (A) PS distribution, the red arrow indicates the Line Of Sight of Sentinel-1 along the descending orbit. (B)Average dip angle of movement measured by automatic (prefix A-) and manual (prefix M-) GNSS stations. (C) Average azimuth direction of motion; modified after Carlà et al. 2019.

for landslide toe (288°N, 24° dip). Considering that Sentinel-1 in descending orbit acquires with a azimuth angle of 281° and an incidence angle of 43°, we obtain that almost the 90% of the real displacement vector is measurable from space. Accordingly, measured LOS velocities of Figure 1A are consistent and comparable with GNSS results.

GNSS and PSI time series cannot be directly overlapped because:

1. Different time coverage: GNSS data run from October 2002 to October 2015 whereas PSI data span between May 2015 and September 2018;
2. Impossibility of calculating E-W (approximation of horizontal) and vertical component of motion from PSI data since only one orbit is available. When ascending data will be available the comparison between PSI and GNSS data a more quantitative comparison could be done.

We compared GNSS and PSI product in a qualitative way, by the point of view of time series general trend and velocities registered. Figure 2 shows the derived time series.

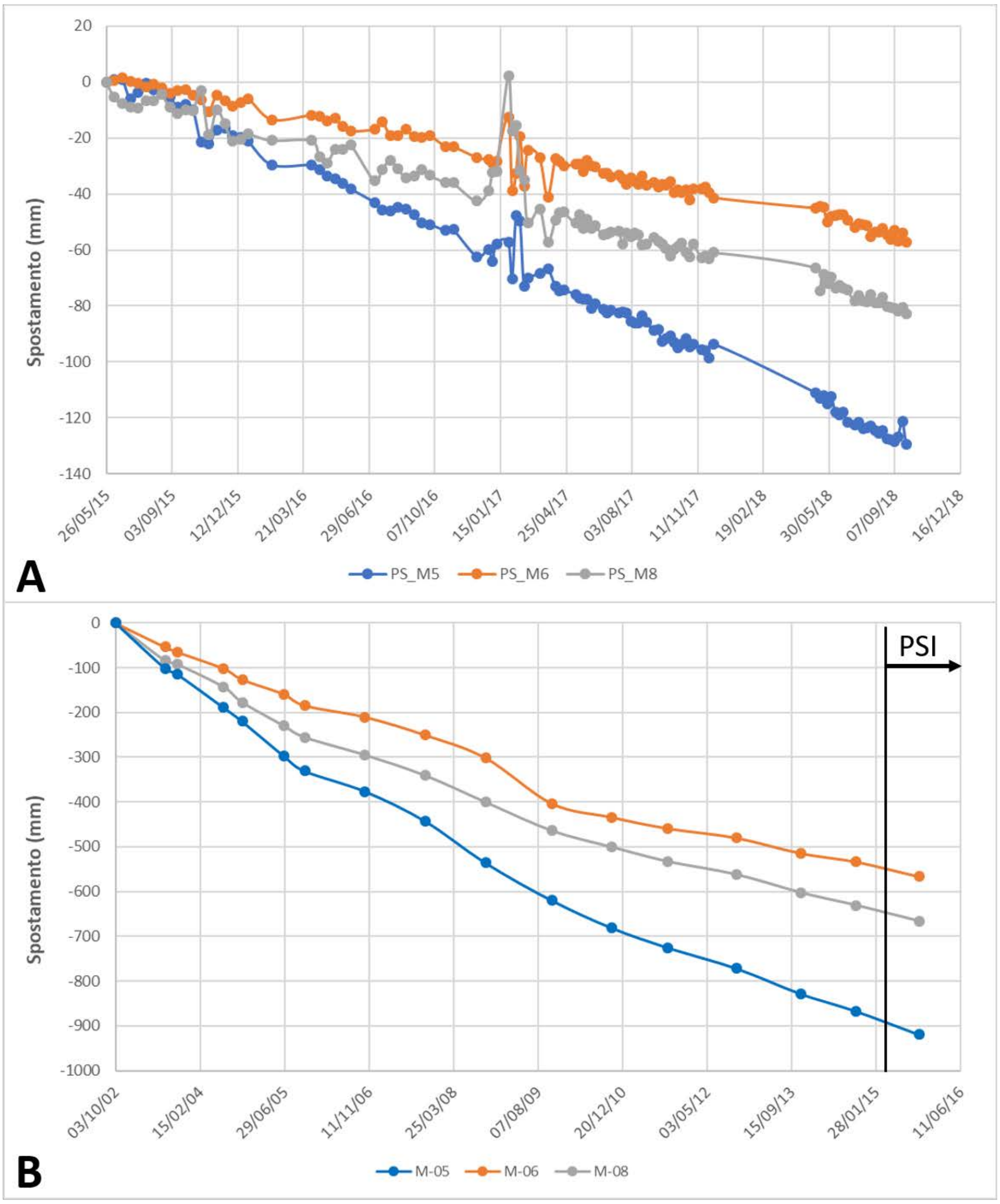

Figure 2 – Time series for the Sentinel-1 PSI products (A) and for the GNSS stations (B). PSI time series represent the average value of displacement obtained from a small neighbourhood of PS around each GNSS station. GNSS displacements are negative for a better visualization with respect to PSI time series.

Figure 2A shows time series derived from PS points around each GNSS station. The values of displacement are projected along the slope, i.e. representing the real motion component of the landslide downhill (Dlos is equal to 90% of the Dslope). The trend of all the time series is regular with some outliers due to snow coverage and same gaps due to the absence of winter images removed from the PSI processing. No relevant accelerations have been registered.

GNSS time series record a similar trend, with a small deceleration starting from June 2005. The time series represent the horizontal component of the motion, the most representative for the landslide motion and for the along-slope component of motion.

Table 1 shows the velocity values extracted from PSI and GNSS data for the 3 points of interest within the landslide body. PSI data testify how the crown portion of the landslides moves faster than the toe area and the main body can be subdivided into two sectors, the northern one, faster (velocities up to 30 mm/yr), and the southern one, slower (velocities below 20 mm/yr).

Table 1 – Velocity values extracted from PS and GNSS time series.

	PS velocity (mm/yr)	GNSS velocity (mm/yr) – All period	GNSS velocity (mm/yr) – Oct. 14 to Oct. 15
M-5	34.6	70.0	52.0
M-6	17.0	43.0	32.8
M-8	25.0	51.0	35.2

The comparison between PSI and GNSS data have shown how the general trend of time series and the spatial distribution of velocity value are coherent. A more quantitative comparison between the results could be performed by using the double satellite geometry which allow deriving the E-W and vertical components of motion. Considering that the LOS of the sensor is parallel to the GNSS average azimuth direction, the E-W component would be considered as the horizontal component.

The Bosmatto landslide is intended as an example of local validation. A whole PSI dataset validation would require a regional-scale GNSS network which is not available in the Valle d'Aosta Region. Some efforts in this sense have been made in the Emilia Romagna and Veneto Regions for subsidence monitoring through PSI data (i.e. Baldi et al. 2009; Bitelli et al. 2015). Landslide monitoring is a way more difficult task, thus regional scale strategies based on GNSS-PSI cross-correlation are not simple to implement.

3 ADA VALIDATION

ADA maps can be qualitatively validated by comparing them with available landslide catalogues. It is not possible to gather ground information for each of the ADA produced in a reasonable time and with few economical resources, considering the location of some of the ADA. Landslide damage reports are not available for the entire area as well.

For these reasons, the comparison between landslide catalogues and ADA results can be a good way to evaluate if the PSI results are coherent with the reality or not.

Some considerations should be done:

A. if an ADA overlaps with a known landslide it is highly probable that the motion is real and not effect by some kind of artefact (condition A). The sign and vector of velocities should be considered anyway;
B. if an ADA does not intersect with a known landslide, we can suppose that:
    1. the motion is real (i.e. the velocity vector is coherent with slope orientation and local morphology) and we have found a new unstable area (condition B1);
    2. the motion is not real (i.e. the velocity vector is not coherent with slope orientation and the morphology is not landslide prone) and something went wrong in the PSI/ADA processing of data (condition B2). The presence of velocities with different signs within a cluster is another proxy for the definition of a "not real" motion.

The evaluation of conditions B1 and B2 is done using a 10m DEM-derived aspect map in which it is easy to define the main slope orientation to be compared with the PS LOS velocity vector.

In summary, we have 2 situations in which an ADA is considered as a "true positive", although not ground validated – A and B1, and one situation in which an ADA is a "false positive", condition B2. Of course, this is a qualitative and expeditious approach that will be improved in the future.

A total of 220 ADA was generated in the second iteration of the PSI processing over north-eastern Valle d'Aosta. We removed all the ADA in flat areas, not representative for landslide motions (20 in total). These ADA are not validated with an external source since no maps or database about subsidence/uplift motions in Valle d'Aosta are available. It is worth recalling that all these ADA are quite small and coincide with one or few buildings, defining some local motions of single structures.

For the validation work we used two landslide databases:

- IFFI (Inventario Fenomeni Franosi Italiano – Italian landslide inventory; Trigila et al. 2010), available for the whole area and composed of 2383 landslides of different typologies (flows, complex, rotational, etc…) collected after meteorological events or derived from ortophotographic investigations and site data;
- DSGSD (Deep Seated Gravitational Slope Deformation) database of the area, derived from ancillary information cross-correlated with ERS 1/2 and Envisat PSI products (Broccolato & Paganone, 2012).

Applying the methodology, we obtained that:

- 71 ADA fall into the contour of IFFI landslides or DSGSD and their LOS velocities are coherent with the slope orientation (class A);
- 83 ADA were recognized to be coherent with the ground morphology and slope orientation (class B1);
- 46 ADA were recognized to be potential false positives (class B2).

In summary, 80% of the ADA can be reasonably considered as true positives whereas 20% of the ADA are potential false positives. The spatial distribution of the validation classes is presented in Figure 3.

Figure 4 shows the distribution of validation classes for three different ADA sizes in terms of number of PS points. As expected, the highest number of false positives (class B2) coincide with the smaller ADA size. In fact, it is more likely that a small cluster of points is related to some topographic or atmospheric artefact not solved or to a processing problem in general. On the contrary, ADA connected to mapped landslides (A class) are most represented by medium and large size ADA, confirming the activity of these phenomena.

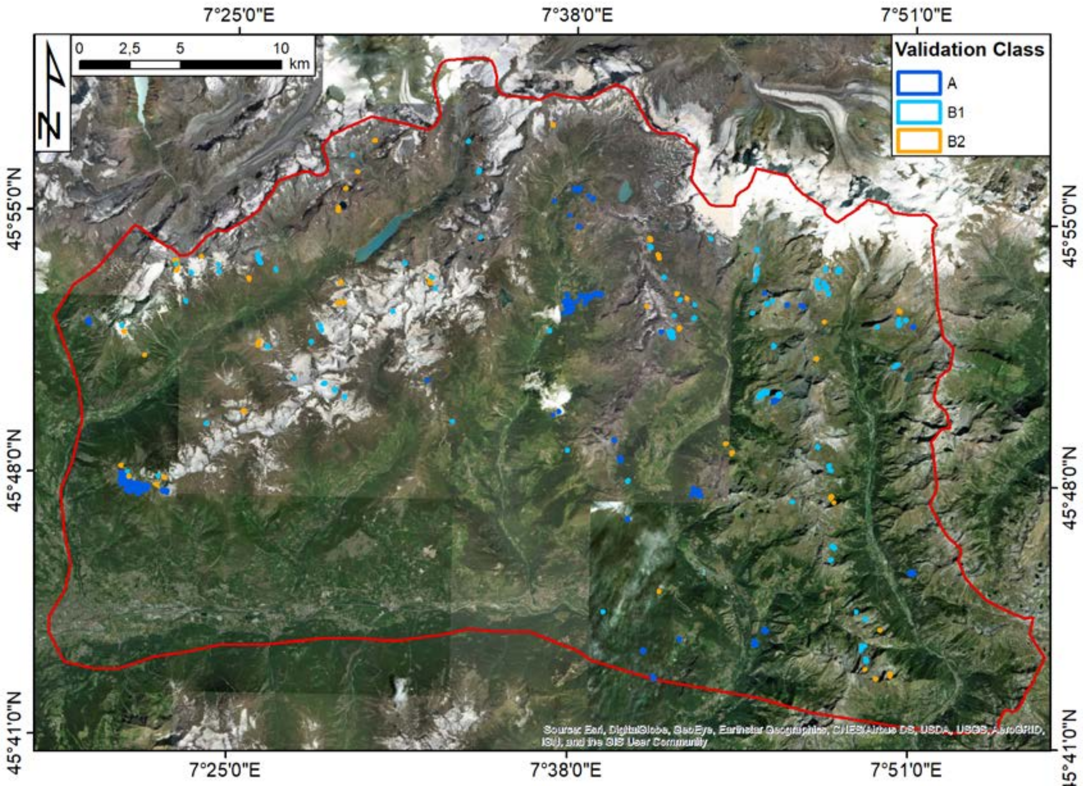

Figure 3 – Spatial distribution of validation classes.

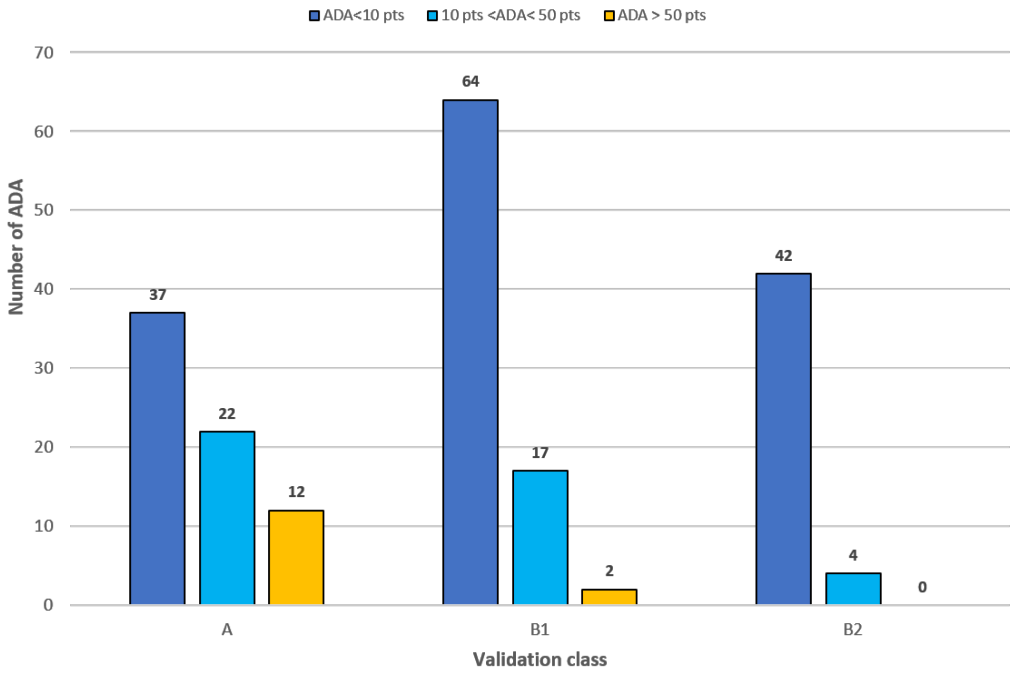

Figure 4 – Validation classes for ADA size in terms of number of points.

4 VEAM VALIDATION

Validating the approach used to pass from interferometric products to landslide intensity information and potential damage assessment is not an easy task, even more when working at regional scale. Detailed damage information, including expected or recorded economic losses, are required. This kind of information is unfortunately unavailable here; commonly, it is not something simple to have over large areas and for multiple events. Sometimes it is possible to obtain such data for single municipalities or for single events.

Considering this, we tried to validate our approach by the point of view of the methodology itself and not by the point of view of the results obtained. The only approach to follow in this case is to compare all the different steps of the methodology with other works of this kind.

Following the concept of the methodology, the bibliographic validation was performed on exposure definition and vulnerability estimation.

Both intensity approaches are based on well-established data. On one side, ADA-related intensity is obtained from the same ADA validated in the previous section (classes A and B1). Moreover, PSI data are classically used for this type of analysis and several examples can be found in literature. On the other side, model-related intensity is based on a robust vulnerability-intensity relation proposed in a very similar alpine context (see Deliverable 2.7 “Updated Vulnerable elements at risk map generation (VEAM) – Final version”).

4.1 Exposure approach assessment

Exposure is assumed to be a characteristic of the element at risk (person or structure) and it is referred to its location and economic value. This definition anticipates something difficult to estimate over large areas, depending on the “characteristics of a single object”.

In our approach, exposure is referred to the economic value of the object and is estimated separately in different ways for each building class. In general, we use a mixed approach based on market and construction values. The methodology does not include the costs associated with indirect and intangible consequences

Exposure for private houses is determined by following the market value, as defined in the OMI (Osservatorio del Mercato Immobiliare – Real estate market observatory) database. This is a certified source of information coming directly from the Italian central government and it is based on real estate market information collected every year for every Italian municipality subdivided into sub-zones.

This database has already been used by other researchers and it can be considered a reliable dataset for scientific usage. Peduto et al. (2018) used the OMI database as “most likely market value” for a quantitative analysis of masonry buildings response to landslide in a small town of Calabria (Southern Italy). This solution is based on the work of Lari et al. (2012) who calculated the minimum and maximum market value for each census parcel of the city of Brescia (Northern Italy) to calculate exposure to floods, earthquakes and industrial accidents. In his review work, Sterlacchini et al. (2018) explained how OMI-derived market value are suited for medium scale estimations (1:25000-1:50000), with the main advantage of well distinguishing between areas of higher economic importance and economically marginal areas (relevant information for risk management issues). From this point of view, construction costs are sometimes not representative of the reality, depending only on the type of structure and not on its location (in terms of market merit). On the other side, the market value is not fixed and suffers from market oscillations.

Considering these examples and our working scale, we believe that the use of OMI-derived market value for those building categories contained into the catalogue (private houses, commercial buildings, offices, sheds) is the right choice. It is in fact the most detailed information we can use at regional scale without the need of on field information sometimes impossible to gather in short times and with low human efforts. Moreover, the market value better describes the actual distribution of economic activities and prices over large areas.

For those buildings for which the market value is not fixed or tabled, we select the construction cost derived from engineers or architect associations within Valle d’Aosta or in similar mountain environments. The construction cost is a good trade-off solution to be used when the market value cannot be used. This solution has been used by Peduto et al. (2018) by multiplying the construction cost for the footprint area, the number of the floors, and the height of each store of the building (applying also an actualization cost if the construction estimation is not recent). In our work we use the construction cost multiplied by 10 in order to follow a similar concept but without using single buildings characteristic; this assumption is valid considering the regional working scale.

Pellicani et al. (2014) derived for each municipality of an Apennine portion of Apulia region (southern Italy), the maximum, minimum and medium economic values of 25 types of assets, including industries and agricultural terrains. For each municipality the maximum value is given by the market value (OMI database) and the minimum by the construction cost in euros/sqm or the agricultural unit in euros/hectare. Our approach well fits in the one proposed by Pellicani et al. (2014) considering the similar area extension and data availability.

Vranken et al. (2013) estimated both direct and indirect damage due to landslides in the Flanders (Belgium) using the repair and prevention costs for infrastructures and private houses; only for the latter, the estimated loss as well. This is certainly a more detailed way to estimate exposure, even at sub-regional scale. It is worth nothing that the number of landslides is way lower than what we can register in an alpine environment; thus, it is simpler to collect data for single events/involved buildings. Although its scientific soundness, this type of approach cannot be followed in areas/regions with limited information and it cannot be applied in our context.

In summary, the estimation of exposure within the VEAM methodology fits well into the available literature, using a well-established database (OMI) and an appropriate balance between working scale and detail of information.

4.2 Vulnerability approach assessment

Vulnerability is probably one of the most difficult parameters to assess in landslide risk evaluation, assuming many different connotations depending on the research orientation, overview and educational background. Vulnerability is a term encompassing five main dimensions: (i) physical, i.e. how much a structure can suffer from a hazardous event; (ii) social, related to the exposure of a person to a hazard; (iii) Economic, i.e. how many resources an area can lose if an event occurs; (iv) Environmental; (v) Political.

Sterlacchini et al. (2014) report that vulnerability is a function of the objective of the study (which establish the number of dimensions to be included) and the temporal and spatial scale of analysis. By the physical point of view, vulnerability is expressed as the percentage of loss (between 0: no damage, to 1: total damage) caused by given hazards. This is the definition we have follow in our vulnerability approach definition. It can be expressed in metric or non-numerical scale, depending if tangible or intangible losses are considered.

Our approach defines vulnerability using a simple classification approach in which vulnerability is defined as a value between 0 to 1 and in 3 levels corresponding to three damage levels: aesthetic, functional and structural. This qualitative subdivision has been firstly proposed by Cardinali et al. (2002). This subdivision is classically used for qualitative vulnerability evaluation (Sterlacchini et al., 2014). Considering one level of intensity, vulnerability varies on the basis of just the type of element at risk.

The VEAM approach does not consider damage catalogues related to a certain event (because they are not available), neither vulnerability curves related to a defined typology of construction (masonry, concrete, etc…). In this framework, Mavrouli et al. (2012) proposed a wide and detailed overview on the definition of vulnerability curves for concrete buildings affected by slow-moving or flow-like landslides. The approach, rather complex, produced generalized curves that can be applied to similar single-storey concrete structures. This is one example of how vulnerability can be perfectly tuned for single building typology, but this approach fails when multiple elements at risk are found over large areas, as in our case. For this reason, we believe that it is not possible to derive such curves for our test area, even more considering the ancillary data available.

When working at regional scale, some assumptions must be done in every stage of risk assessment including vulnerability. Puissant et al. (2014) presented an interesting work regarding this topic. These authors subdivide the geographical working scale into: micro-, meso- and macro-scale, as already proposed by Puissant et al. (2006) and Papathoma-Köhle et al. (2011). Our approach is considered as a “macro-scale” analysis in which the final goal is “strategic regional planning” (Puissant et al., 2014) based on expert knowledge. The first two objectives of this method are: to make an inventory of elements at risk (e.g. the cadastral catalogue of VdA) and to rank their value on the basis of categories of structures (e.g. OMI value or construction costs). Only those elements at risk that could be impacted by a landslide are considered at this scale (this imply the use of ADA from our point of view). The product should be a preliminary risk map which includes the definition of all the critical facilities ranked by potential damage or risk.

We believe that VEAM fits well into the definition of macro-scale approach, following the type of analyses proposed by Puissant et al. (2014) and proposing a final output which can be used for regional scale planning and for the identification of potential treats. By this point of view, our vulnerability approach is considered validated, falling into a well-established bibliography.

5 CONCLUSIONS

In this deliverable we proposed some practical examples on how interferometric data and their derived products can be validated without the need of ground data or other detailed information. This topic follows the general concept of the U-Geohaz project: provide simply updatable tools ready-to-use for end users, in order to follow the frequent update of interferometric data over wide regions.

PSI data can be validated and compared with GPS or GNSS data. Even with the use of a single satellite orbit is possible to cross-correlate the general trend of GNSS and PSI data in a qualitative way. When it is not possible to gather local measurement stations, the EUREF GNSS permanent network can provide updated information from over 300 continuously operating stations around Europe. This kind of data is useful for PSI data processed over wide areas, as in this case.

When damage event or landslide state of activity information are not available, the validation of PSI derived products such as ADA and VEAM maps can be performed using only simplified approaches. In the first case, it is useful to understand if the ADA are coherent or not with the local morphology or if they intersect mapped phenomena. In the second case, the only way to validate the VEAM products is to assess the consistency of the methodology (and not of the results) with previous literature examples.

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