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assessment for urban areas”**

**U-Geohaz D15 -Updated Vulnerability elements at risk
map (VEAM) – Final version**

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

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EXECUTIVE SUMMARY

The aim of this task is assessing the impact on buildings and infrastructures of moving areas detected by means of interferometric analysis.

The ADA, generated in the Deliverable 2.5 “Updated Active deformation areas map (ADA)”, are the inputs for assessing landslide vulnerability applying the so called Vulnerable Elements Activity Maps (VEAM) procedure.

This deliverable represents the technical update of Deliverable 2.7 “Updated Vulnerable elements at risk map generation (VEAM)” and it can be considered as the final version of the VEAM procedure.

The Activity 2.7 is led by UNIFI which is in charge of the interpretation and validation of interferometric-derived products for the Valle d’Aosta Region.

REFERENCE DOCUMENTS

N°	Title
RD1	DoW Part B

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1 INTRODUCTION

The Vulnerable elements activity maps (VEAM) are one of the main outputs of the WP2 “Tools to support the Early Warning for Landslides geohazard”.

VEAM are derived starting from interferometric products, specifically from the ADAs (Active Deformation Areas). The ADA provide the spatial distribution and the magnitude of ground deformation over the Valle d’Aosta Region, updating the state of activity of already known phenomena or mapping new potential slope movements.

The aim of the VEAM procedure is to assess the impact of detected geohazard on road networks and built-up areas. The VEAM consists in a simplified color scale map indicating those structures and infrastructures with a greater probability to suffer for the impact of a geo-hazard and those structures and infrastructures affected by the dynamic of an active geohazard.

In the Valle d’Aosta Region more than 2000 landslides have been mapped in the last years. The geological/geomorphological context as well as local climatic conditions control landslide typology. Debris flows, rockslides, debris avalanches, complex and rotational landslides as well as Deep-Seated Gravitational Slopes Deformations are common.

The Valle d’Aosta Region, as many Alpine regions, is characterized by sparse urban areas, with the largest cities, including Aosta, located along the main valley (Dora Baltea Valley). In this context, Multi-temporal Interferometric Synthetic Aperture Radar (MTInSAR) techniques are a valuable support for landslide investigations, offering a good compromise between costs and spatial-temporal resolution and coverage.

In the VEAM approach, we go beyond the concept of MTInSAR data as mapping tools by proposing a simple and reproducible working chain that has a deformation map derived from satellite radar data as starting point. ADA are the first product of the chain, whose final goal is to quantify the potential loss (by an economic point of view) that can be suffered by a building or road if the motion persists or accelerates. The methodology aims at deriving landslide intensity using the ADA in a dual form: as direct estimation of landslide magnitude (and thus intensity) and as source area of an unstable debris mass that in the future can evolve into an abrupt phenomenon, whose runout is foreseen by means of a basin scale model (Gravitational Process Path/GPP - Wichmann, 2017). Intensity, vulnerability and potential loss are directly derived from the results of the two approaches, producing as final output color scale maps which contain a preliminary but quantitative evaluation of landslide impact.

This deliverable will define in detail the updated version of the VEAM procedure with some examples of application. All the data here proposed came from north-eastern Valle d’Aosta which has been selected as test site of the methodology and where MTInSAR data have been produced in the framework of the project.

2 VEAM PROCEDURE

The methodology aims at deriving vulnerability and potential loss maps starting from a regional scale deformation map obtained through MTInSAR analysis, which is the main input (Figure 1).

The first product to be derived is the ADA database that contains all the moving areas detected in the area of interest, following the approach proposed by Barra et al. (2017). Depending on the localization of each ADA, landslide intensity is defined in a twofold manner:

“ADA-related intensity”. Landslide intensity depends on the average velocity of the ADA. This approach is only applicable when the moving area directly overlaps one or more buildings/roads or an urban area (“Urban area – YES” condition in the workflow of Figure 1);

“Model-related intensity”. Landslide intensity depends on the run out of a potential landslide that could be originated from an already moving debris mass and that could hit one or more buildings/roads. This approach is applicable when a moving area is found outside of an urban area (“Urban area – NO” condition in Figure 1) and in correspondence of a debris area (“Geo-indicators – YES” condition in Figure 1) that could evolve into an abrupt debris flow if triggered by intense rainfall events.

If an ADA does not fall into one of the two limiting conditions of the workflow, then the approach cannot be applied.

Once landslide intensity is calculated, elements at risk exposure and vulnerability are defined. Exposure evaluation is performed on a cadastral polygonal database of buildings and roads which is reclassified on the basis of the presumed asset value. Vulnerability is expressed as loss value (ranging from 0 to 1) with respect to a given intensity. The potential loss is calculated as product between vulnerability and exposure considering a certain level of intensity.

The final products are two: a database of elements at risk indicating, in addition to the type of structure and its exposure, the value of vulnerability and potential loss for an event of given intensity (as defined in Figure 1); and color scale maps of vulnerability and potential loss for each case study in which the methodology has been applied.

For a more detailed explanation on how deformation maps and ADA maps are derived we refer to deliverables 2.5 “Updated Active deformation areas map (ADA) – (V0)” and “Updated Active deformation areas map (ADA) – (V1)”. We will now briefly introduce the strategies developed for deriving landslide intensity, vulnerability of the elements at risk and potential loss starting from MTInSAR products.

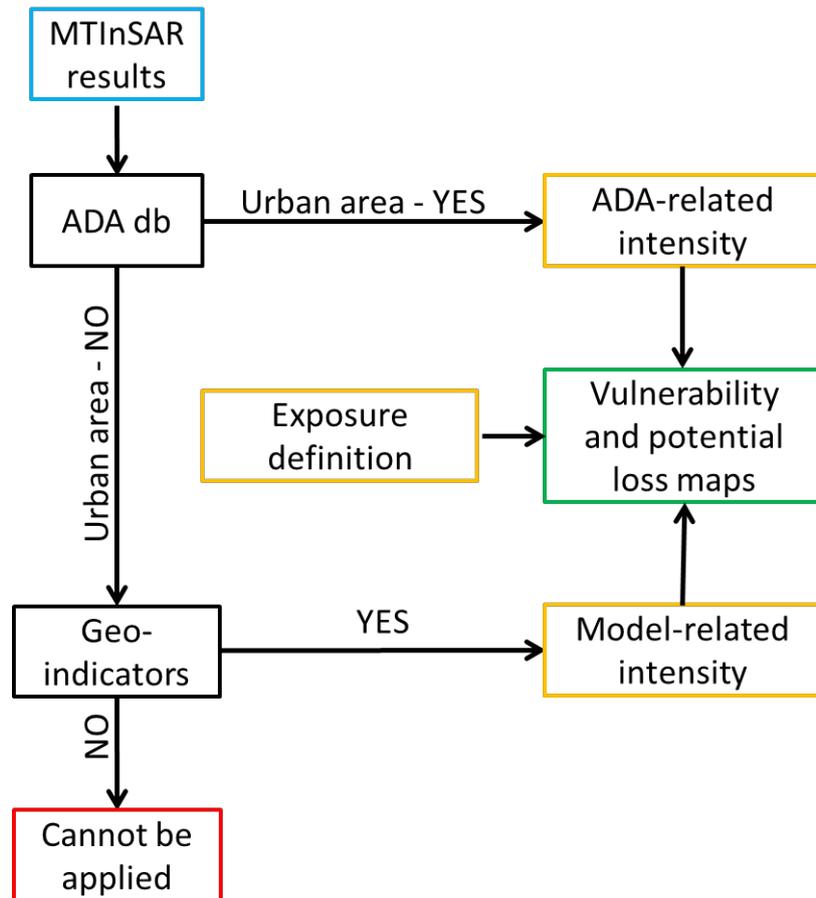


Figure 1 – Workflow of the methodology. MTInSAR, Multi-Temporal Interferometry; ADA, Active Deformation Areas; db, database.

2.1 Landslide intensity evaluation

Each ADA can be used for landslide intensity estimation in two different ways: one as direct estimation of landslide magnitude (and thus intensity) and one as source area of an unstable debris mass that in the future can evolve into an abrupt phenomenon, whose runout is foreseen by means of a basin scale model. The first approach is named as “ADA-related intensity”, the second one as “Model-related intensity” (Figure 1).

2.1.1 ADA-related intensity

This approach relies on the overlapping between ADA and urban area/single building/road. This approach has been already followed by Solari et al. (2018) for geohazards mapping in Canary Islands (Spain). Vulnerability and potential loss are derived by the simple intersection between ADA and cadastral inventory (see section 2.2). Landslide intensity is defined by the average velocity of the ADA, following the classification:

- intensity 1, average velocity lower than 16 mm/yr;
- intensity 2, average velocity ranging between 16 and 32 mm/yr;
- intensity 3, average velocity higher than 32 mm/yr.

The first threshold (16 mm/yr) is representative for the passage between extremely slow and very slow landslides, as assumed by Cruden and Varnes (1996).

2.1.2 *Model-related intensity*

In the area of interest, the use of the ADA-related approach is limited. In fact, the urban density is quite low and just a part of the ADA that have been derived respect the input condition (“Urban area – YES”, Figure 3). For this reason, a second approach (Model-related intensity) has been defined to maximize the information extracted from the satellite data.

If one ADA does not directly intersect elements at risk, further evaluations are made. In this case the presence or not of debris discriminates between the possibility or not to apply this approach (“Geo-indicators – YES” condition in Figure 3). It is based on the use of ADAs as indicators of active mass wasting processes, especially involving unstable debris that could be source areas for catastrophic debris flows/debris avalanches. These types of events, usually triggered by extreme rainfalls, are the most damaging, in terms of economic and life loss, for the Valle d’Aosta Region (Ratto et al., 2003). If an ADA is found within a possible unstable debris area, defined on the basis of geological and ortophotographic information, a run-out model will be used to evaluate the possible landslide evolution, in terms of landslide path and spatial distribution of the accumulation zone. In this work, the Gravitational Process Path model (GPP, Wichmann et al., 2017) has been chosen to define the potential run-out of moving debris along slopes.

The GPP model is specifically designed to simulate the path and run-out area of gravitational processes, such as debris flows or avalanches and rockfalls. The model is suited for regional or basin scale analysis requiring only few and simple terrain parameters for the source area and a digital terrain model of the slope. In brief, the GPP model simulates the motion of a mass point from a source to the deposition area through the use of different release, process path, run-out and deposition models. The modelling approaches are not entirely physically based but created starting from empirical principles that simulate the main feature of a mass moving along a slope (Wichmann et al., 2017). The simplest model configuration requires only a DEM and a contour of the potential source area to run; thus, it is the best operational solution for basin/regional scale investigation, where detailed geotechnical and hydrogeological parameters, which are the inputs for physically based numerical simulations, cannot be gathered. The GPP model is implemented into the open source GIS SAGA (Conrad et al., 2015).

In this work, we used a 2m DEM as input for the model. The source areas have been defined within each ADA and selected considering the distribution of moving points and the local morphology. If the material height for each starting cell of the source area is given as input data, the GPP model allows modelling both sink filling along path and deposition. For obtaining soil/debris thickness, we used the results derived within the area of interest by Salvatici et al. (2018) using the Geomorphologically Indexed Soil Thickness model (Catani et al., 2010).

In summary, the ADA that respect the “Geo-indicators” condition are grouped for geomorphological macro-areas (same flank, basin, etc...); then, the GPP model is run to reconstruct the morphology of a known debris flow in each macro-area in order to obtain the input parameters to be used for the new models (based on the ADA distribution). If this is not possible, one of the ADA in each macro-area have to be selected as test site for the GPP model.

The outputs of the model are four: 1) process area, which defines the transition frequencies at every cell; 2) deposition, equal to the height of the material deposited at each cell; 3) maximum velocity reached by the flow at every cell and 4) stopping position, i.e. all the cells in which the run-out length is reached. In this work, we used the height of material at every cell as a proxy for landslide intensity. The three intensity classes are:

- intensity 1, height of the material lower than 1.25 m;
- intensity 2, height of the material between 1.26 and 2 m;
- intensity 3, height of the material higher than 2.01 m.

The values chosen are defined following the vulnerability functions derived by Papathoma-Kohle et al. (2015) using real debris flow events in South Tyrol (Austria) and represent a degree of loss of 30%, 60% and higher than 60%, respectively.

2.2 Vulnerability and exposure definition

A value of vulnerability or exposure is assigned to every building or road, depending on their typology and using a simple classification approach illustrated in Table 1. The building/road database derives from the 1:2000 cadastral map of the VdA region, from which the polygons/lines have been extracted.

Vulnerability varies between 0 (no damage) and 1 (complete loss) as a function of landslide intensity. Each value of vulnerability is defined by the typology of element at risk following a data driven approach and considering the possible interactions between elements and landslide. Linear elements have the highest vulnerability values for each intensity class. If intensity is equal to zero, then vulnerability is null.

Exposure is referred to the economic value of the object and is estimated separately in different ways for each building class. We decided to implement different sources of information (market and income value, construction cost, renovation cost) in order to provide a plausible value for every structure. This is the maximum level of detail we could reach when working at basin scale; further information regarding people occupancy and day/night activity cannot be collected at this scale in a reasonable time and working cost.

VdA is a region mainly devoted to tourism and just few large industries are present. Considering this, an effort was made to properly define the value of private houses, that can be rented, and, in general, of building related to the tertiary sector.

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. Every Italian municipality is subdivided by the Agency of Revenue into subzones with different market values depending on the location (city center, industrial area and so on) and on the building state. The database is open and available online¹. The area of interest is composed by 33 municipalities; for each one on them the average market price for private houses is taken as reference (depending

¹ https://www.agenziaentrate.gov.it/geopoi_omi/index.php

on the OMI zonation) and used to estimate exposure. The OMI database contains also information regarding the quotation of buildings used as offices (or as service sector in general), of commercial buildings (including shopping malls) and of industrial laboratories (including warehouses and sheds). For each of these categories the average market value is again used as reference. The exposure value of all the other buildings and roads categories is calculated on the basis of the construction cost for square meter.

It is recalled that the values of vulnerability of Table 1 are common for both the ADA-related and Model-related approaches; only landslide intensity is derived in two different ways.

Table 1 - Vulnerability and exposure values for the area of interest. V, vulnerability; I, intensity; E, exposure.

Type of building/ infrastructure	Vulnerability for I=1	Vulnerability for I=2	Vulnerability for I=3	Exposure (€/m ²)
Barn	0.2	0.4	0.6	80
Camping	0.4	0.6	0.8	2600
Greenhouse	0.2	0.4	0.6	50
Hotel	0.15	0.3	0.5	1550 – 4600
Industrial laboratory	0.1	0.2	0.5	740 – 1000
Local road	0.6	0.8	1	50
Motorway	0.4	0.6	0.8	350
Municipal road	0.6	0.8	1	150
Office/service sector	0.1	0.3	0.6	1175 – 2600
Private house	0.2	0.35	0.6	1075 – 4350
Provincial road	0.6	0.8	1	180
School complex	0.3	0.5	0.7	4000
Shed	0.2	0.4	0.6	540-890
Commercial building (shop, restaurant, etc...)	0.2	0.35	0.6	865 – 2100
Shopping mall	0.2	0.35	0.6	1400 – 2200
Sport facilities	0.3	0.5	0.7	15-120
Stable	0.15	0.4	0.6	120
Regional/State road	0.4	0.6	0.8	250
Warehouse	0.2	0.4	0.6	680 - 1000
Barn	0.2	0.4	0.6	80
Camping	0.4	0.6	0.8	2600
Greenhouse	0.2	0.4	0.6	50

2.3 Potential loss estimation

Once exposure and vulnerability (depending on the intensity level) are evaluated, the potential loss is calculated as product between vulnerability and exposure (Catani et al., 2005). The potential loss is referred to the direct impact of a landslide on a building or road and it is expressed

in quantitative terms (Euros for square meters). If one or both vulnerability and exposure are null, the potential loss is obviously zero.

3 RESULTS

The following section will show two examples of vulnerability and potential loss estimation using both ada-related and model-related intensity approaches. The results obtained by analyzing Sentinel-1 images (deformation map and ADA map) have been previously presented in the Deliverable 2.5 “Updated Active deformation areas map (ADA) – (V1)” and are here used as input data.

The first example comes from the Valtournenche municipality (Chaloz hamlet) in the homonymous valley located in the central portion of the study area (Figure 2). This is an example of ADA-related intensity in which ADA directly overlap with elements at risk. The moving areas are detected along a west-facing slope in which several landslides are already known and mapped. In particular, a large DSGSD (“Valtournenche” DSGSD) involves the entire flank on which the Chaloz is located, from a height of 2900 m a.s.l. to 1500 m a.s.l. The Valtournenche DSGSD activity has been already testified by Giordan et al. (2017); these authors shown how the landslide can be subdivided into different sectors with different velocities, as testified by the ADA distribution obtained from Sentinel-1 data. In addition to the DSGSD, 7 rotational landslides are mapped in the toe area of the deep-seated phenomenon.

Four ADA are found within the Chaloz hamlet with average LOS velocities between 11 and 16 mm/year; intensity is then equal to 1 for all the ADA. Several buildings of the Chaloz hamlet are exposed to landslide risk; in particular, 390 structures are found within the contour of the ADA. Of these, 90% are private houses, some shops, warehouses, four hotels, barns and a tennis court are present as well. Some local roads and a provincial road cut through the area of interest. Considering the type of edifice/road and the intensity level, vulnerability varies between 0.1 and 0.2 for buildings and between 0.4 and 0.6 for roads (local roads are more vulnerable than provincial roads). The potential loss ranges between 21 and 490 €/m²; the highest value is reached by private houses (Figure 2).

The second example is taken from the Montjovet municipality (Tron hamlet), in the southern part of the area of interest. It represents a model-related intensity case study in which ADA do not coincide with elements at risk, but the presence of potentially unstable debris masses allows adopting the model-based approach. Tron hamlet is located within the contours of one DSSGD and two complex landslides connected to the geometry and evolution of the Emarese DSGSD. The ADA is located in the upper portion of the complex landslides, where debris deposits are found. The motion of this sector has been also reported by Broccolato and Paganone (2012) for ERS 1/2 data. The GPP model is exploited to simulate the run-out of debris flows from two different source areas (S1 and S2 in Figure 9). The thickness of the material for S1 is between 2 and 2.4 m, whereas for S2 the input material thickness is lower, varying between 0.6 and 1 m. The flows originated from the two source areas converge and create a fan-like deposit with variable thickness between 0.2 and 1.6 m (intensity 1); they do not involve any building but two local roads. Considering an exposure of 50 €/m² and a vulnerability of 0.6, the resulting potential damage is 30 €/m².

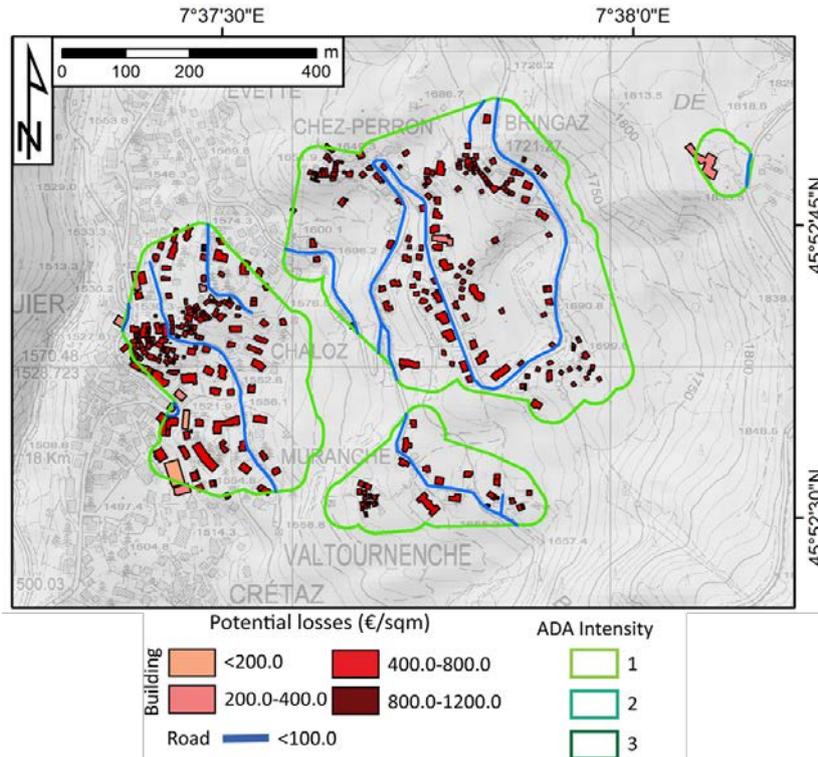


Figure 2 - Potential loss map derived using the ADA-related intensity approach in the Valtournenche municipality. The map is overlaid on a 1:10,000 topographic map of the Vda region.

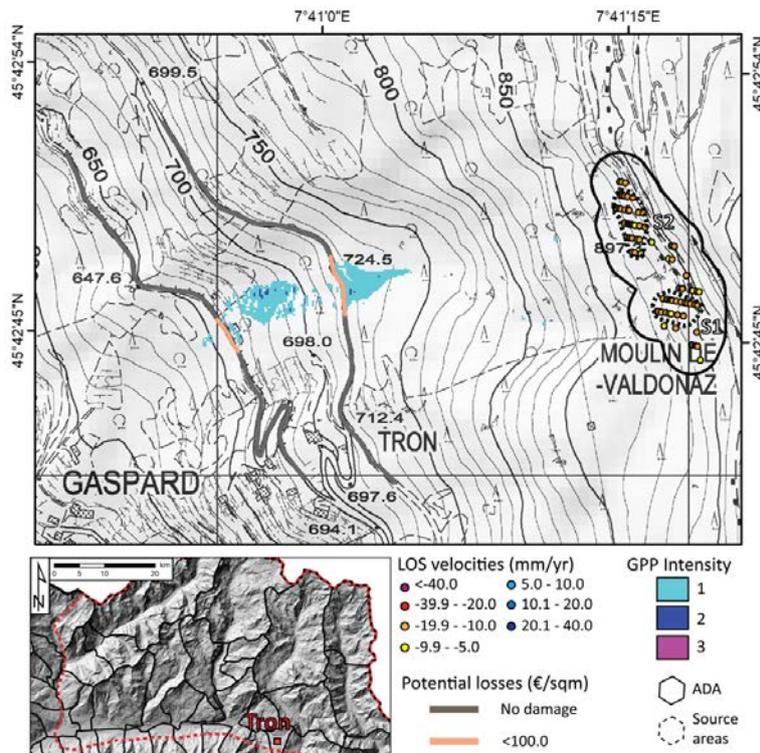


Figure 3 - Landslide potential loss derived using the Model-related intensity approach for the hamlet of Tron in the Montjovet municipality. S1 and S2 are referred to the two source areas chosen to run the GPP model. The background image is a 1:10,000 topographic map of the Vda region.

4 FINAL CONSIDERATIONS

The final version of the VEAM methodology for landslide intensity estimation based on satellite interferometric products. The deformation map derived from a MTInSAR analysis of Sentinel-1 radar images is the starting point of the procedure which has as first product the hot-spots of deformation “ADA” and as final goal the estimation of potential loss experienced by one or more elements at risk (building and roads) with a given level of landslide intensity (derived in a dual way).

The procedure exploits the demonstrated potential of satellite interferometric data for geohazard mapping (focusing on landslides) in a new way, by developing a procedure aimed at estimating vulnerability and potential loss of structures and infrastructures at regional scale. Here, interferometric results, intended as ADA or in general moving “hot-spots”, are the key input for landslide intensity and vulnerability estimation which, combined with elements at risk exposure, allow calculating the potential loss of a structure. The concept of PS hot-spot is not new in literature (see for example Bianchini et al., 2012), but the use of moving areas for quantitative or qualitative estimation of landslide impact on built-up areas is uncommon.

The procedure relies on MTInSAR data in three different ways:

- as proxy for ground movement hot-spots (i.e. the ADA);
- as landslide intensity tool (“ADA-related” approach);
- as instrument for debris flow potential source areas detection (“Model-related” approach).

The last application represents an original approach for interferometric data exploitation and has been specifically designed to be implemented in mountain regions at basin scale or smaller. In the model-related approach the interferometric data are both a proxy for something moving and an input for the GPP model, acting as the main factor for the source areas definition. In this way, it is possible to improve the information extracted from each ADA by assuming that a debris mass, already in motion (as testified by the PS data), could evolve into a debris flow if external triggering factors are present (i.e. an intense rainfall period).

Our approach is designed for regional scale studies with few ancillary data available. The working scale is at the same time an advantage and a limitation. On one side, it is possible to rapidly detect those area showing the highest displacement rates and verify if they affect or could affect one or more elements at risk. On the other side, some assumptions must be made, especially when configuring the GPP model and when selecting the source areas. The economic value of each element at risk cannot be assessed precisely because detailed information about the state of conservation of buildings and roads cannot be gathered in short time over entire basins; moreover, the population cannot be considered because the difficulties in estimating the day/night occupancy of each edifice. Another assumption regards the velocity threshold used to derive the ADA; although it depends on the quality of the interferometric dataset (standard deviation) it

assures only to select motion with high deformation rates, not considering extremely slow deformation that could create damage to buildings and roads over longer periods.

Considering its limitations, VEAM is able to provide useful outputs for risk management at regional scale in a short time. In fact, the selection of moving areas and the calculation of exposure, vulnerability and potential loss requires 2 or 3 weeks of work of an expert in the field of satellite interferometric data interpretation. The same amount of time is required to analyze the SAR images and derive the deformation map. Some phases of the methodology are quite fast, as the generation of ADA through the use of the ADA-finder package (less than a minute is needed). This time requirements allow setting up a monitoring plan based on 4 or 5 updates of the deformation map every year, re-evaluating each time landslide intensity and the potential damage that could be experienced by buildings and roads, at the same time analyzing the evolution of instability phenomena.

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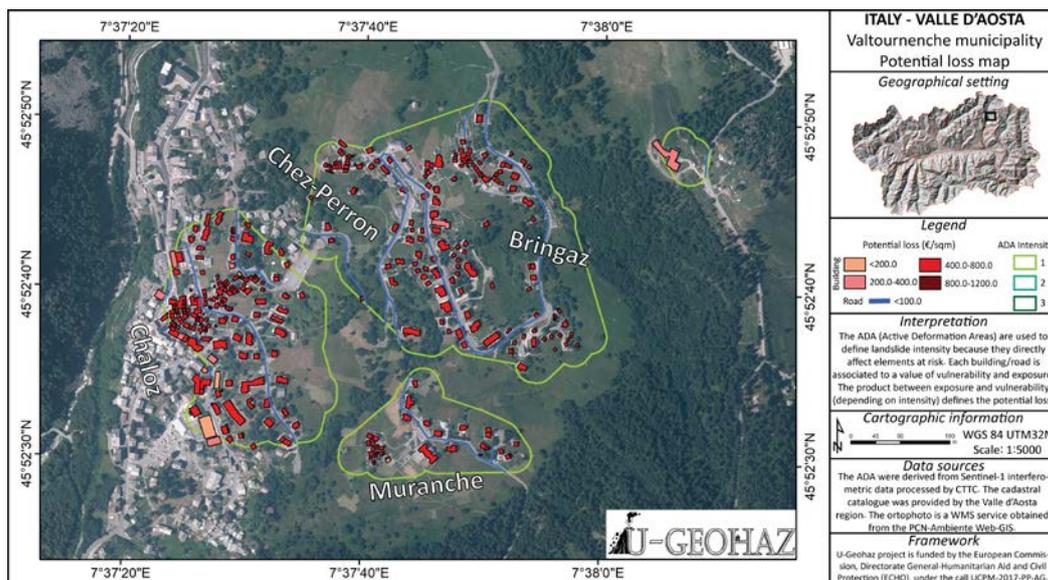
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ANNEX A

Two examples of complete VEAM maps are attached to the deliverable. The maps propose the same two examples presented in the main text of the deliverable and are derived following the specifications given in Deliverable 2.1 "User requirements – Annex B". The maps are generated in .pdf format. In order to grant a readable output we chose to not produce valley or flank scale maps and to deliver the data at regional scale as elements at risk database in shapefile format.

1. Example of potential loss map for the Valtournenche municipality following the ADA-related intensity estimation.



2. Example of potential loss map for the Montjovet municipality following the model-related intensity estimation.

