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**Safety** – Sentinel for geohazard  
prevention and forecasting

**Deliverable - D.E4.5 Upgraded impact assessment on structures and infrastructures of the southern Tuscany (Volterra area) test site (V1)**

**A deliverable of Task E: Geohazard impact assessment**

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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TN	Technical Note, not a deliverable, only internal for members of the Consortium	





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## **EXECUTIVE SUMMARY**

SAFETY is a two-year research project funded under the ECHO (European Commission's Humanitarian aid and Civil Protection department) call "Prevention and preparedness projects in Civil Protection and marine pollution", which started the 1<sup>st</sup> January 2016. The mission of the project is to improve the efforts in detecting and mapping geohazards (i.e. landslides and subsidence), by assessing their activity and evaluating their impact on built-up areas and infrastructures' networks. SAFETY will enhance ground deformation risk prevention and mitigation efforts in highly vulnerable geographic and geologic regions. The outcomes of the project will provide Civil Protection Authorities (CPAs) with the capability of periodically evaluating and assessing the potential impact of geohazards on the selected sites.

Deliverable "D.E4.3, Upgraded impact assessment on structures and infrastructures of the southern Tuscany (Volterra area) test site (V1)" is a deliverable of Task E "Geohazard impact assessment", in the framework of the Action E4 "Impact assessment on structures and infrastructures". This Task aims at assessing the impact of detected and/or assessed geohazards on road networks and built-up areas. The final goal is to provide an operable methodology, a protocol, which can be integrated into the Civil Protection prevention activities.


*REFERENCE DOCUMENTS*

<b>N°</b>	<b>Title</b>
RD1	DoW – FormT3a
RD2	D.E4.5 V0

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## 1 INTRODUCTION

The SAFETY project aims to provide to the Civil Protection Authorities (CPAs) the capability of periodically monitor and assess the impact of geohazards (landslides and subsidence, volcanos, earthquakes) on urban areas. The project's objectives are to improve the ability to detect and map landslides, to assess and forecast the impact of triggered landslide events on vulnerable elements, and to model landscape changes caused by slope failures. SAFETY is addressed to CPAs at different administrative levels.

Action E4 is focused to assess the impact of detected geohazards on the elements at risk of the study area, in particular road networks and built-up areas. Using GIS spatial analysis, the geohazard susceptibility maps (action E.2) and the geohazard activity maps (action E.3) were combined with the available geodatabases of vulnerable structures and infrastructures to assess the landslide impact on the most critical areas. The results of the susceptibility assessment were used to evaluate the geohazard-impact on urban areas and infrastructures.

Landslides are responsible for significant loss of life and injury to people and their livestock as well as loss and/or damages to utility lines, infrastructures, agricultural lands, housing and public and private infrastructure and assets (Papathoma-Kohle et al., 2007). Landslide impact can be relevant and changing according to the geotechnical proprieties, land use distribution, and human characteristics (i.e., population densities and infrastructure networks). The assessment of landslide impact on urban setting includes the evaluation of the landslide hazard and vulnerability. For the Volterra Municipality, information on the temporal occurrence of landslides and a multi-temporal landslide inventory map are not available and it was not possible to evaluate the landslide hazard. Therefore, we have used for the analysis the susceptibility map that refers only to the spatial likelihood of landslide occurrence not taking into account the temporal probability. In the Volterra Municipality, the susceptibility zonation has been locally modified and improved using the ground velocities provided by the PSI information of this project.

Vulnerability of structure/infrastructure is defined as the “expected degree of loss experienced by the elements at risk for a given magnitude of hazard” (Glade et al., 2005). Following this definition, we consider the “degree of loss” of buildings and roads as the reduction or loss of functionality (addressed as “strategic vulnerability”), potentially reaching a state of limit.

The proposed approach provides maps showing the expected losses due to landslides and the potential impact for different elements at risk, considering the landslide susceptibility zonation and the strategic vulnerability. In particular, for the different Civil Protection phases (prevention and preparedness, emergency and recovery), the method considers different strategic vulnerabilities for each vulnerable element, and combine them with the susceptibility classes.

## 2 IMPROVED SUSCEPTIBILITY MAP

In this section, we briefly illustrate the improved susceptibility zonation obtained using the PSI data that provide additional information on ground velocity in some areas of the Volterra municipality.

The landslide susceptibility map for the Volterra Municipality (see Deliverable D.E2.2), was prepared by using the logistic regression model as implemented by Rossi et al. (2010) and recently upgraded by Rossi and Reichenbach (2016). The map was prepared using the slope-unit as mapping unit. Slope-units were defined considering two basic requirements: i) they represent a segmentation of the territory that maximizes intra-unit homogeneity and extra-unit inhomogeneity; and ii) are a hydrological partition of the territory, delimited by drainage and divide lines (Alvioli et al., 2016).

The susceptibility map (derived from Action E.2.2) was locally modified and improved by means of PSI data, with the following steps and criteria:

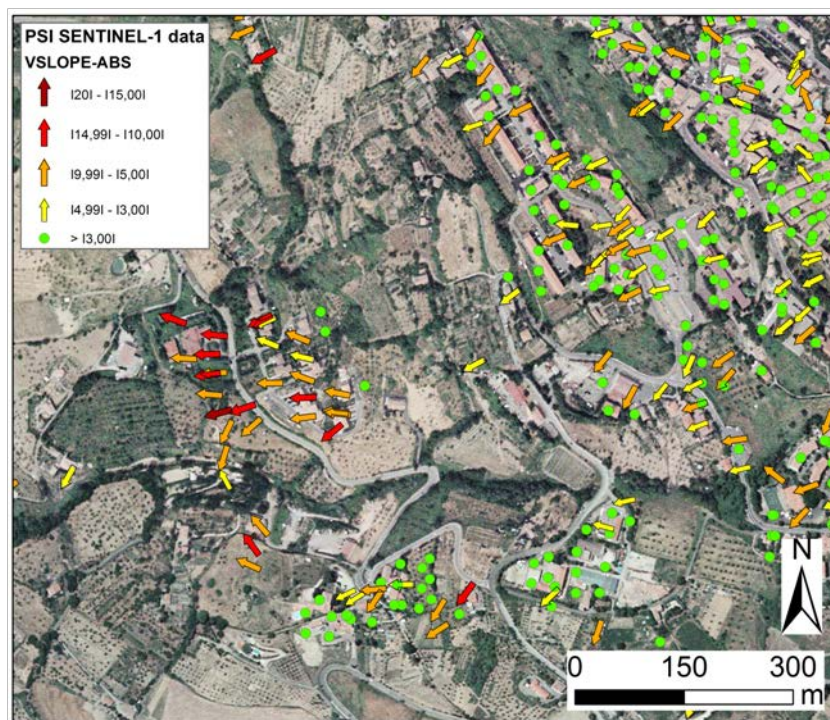
- *PSI LOS velocities conversion:*

The LOS velocities of Sentinel-1 PSI data were converted to ground velocities by means of a downslope projection, according to procedures proposed in the scientific literature (Herrera et al., 2013; Bianchini et al., 2013; Notti et al., 2014). In particular, all the PSI VLOSs (mm/yr) were projected along the same direction of the steepest slope through a correction factor (C), in order to determine the “real” velocity (not the velocity measured along the LOS direction, but the one occurring along the landslide direction). The relation between the “real” velocity along the landslide direction (VSLOPE), the measured velocity along the satellite LOS (VLOS) and the correction factor is given by the equation:

$$VSLOPE = VLOS / C$$

where the correction factor C depends on topographic (slope and aspect map of the area) and the satellite-dependant parameters (LOS directional cosines).

The VSLOPE values were taken as absolute values (VSLOPE-ABS) since not referred anymore to movements away/towards the satellite. This procedure allows providing VSLOPE-ABS values with stability thresholds set to 3 mm/yr, according to the standard deviation of the PSI population and in agreement with similar choices already tested in the scientific literature (Fig.1). The VSLOPE conversion was performed for the ascending and the descending datasets, separately.



**Figure 1 – Example of PSI VSLOPE-ABS values.**

- *Merge of the PSI VSLOPE-ABS ascending and descending datasets*

The VSLOPE-ABS conversion allows merging ascending and descending geometries, obtaining “VSLOPE\_ABS” PSI data, thus avoiding misinterpretation and underestimation of the movement due to combination of topography and satellite acquisition orbit (i.e. layover and shadowing problems) and obtaining absolute velocity values corresponding to movement rates along the local steepest slope, which is assumed to be the most likely motion direction.

- *Intersection of “VSLOPE\_ABS” PSI data with “susceptibility slope-units”*

We performed an *Intersect* between the point layer of PSI data and the slope-unit polygons using GIS tools. For each slope-unit, we carried out *summary statistics* to provide: i) the MAXIMUM value of VSLOPE\_ABS among all the PSs (MAX VSLOPE\_a), and ii) the FREQUENCY, that is the count of the PSs.

- *Improvement of susceptibility map with PSI VSLOPE values*

We update the susceptibility class based on the ground velocity values of the PSI VSLOPE. In the attribute table of each slope-unit, we added a “field” called “updating”. The field is coded as “YES” when we were able to evaluate the modified susceptibility class using the PSI information. We modified the susceptibility classification, increasing a class (for instance, class 3 → to class 4, or class 4 → to class 5). To update the susceptibility class, the following criteria should be accomplished:

- MAX VSLOPE\_ABS > 10 mm

The threshold of 10 mm has been set by considering 2  $\sigma$  (deviation standard), since the  $\sigma$  of the VSLOPE PS population is 4.5 mm and 5 mm, in descending and ascending orbit, respectively.

AND

- FREQUENCY < 4 PS

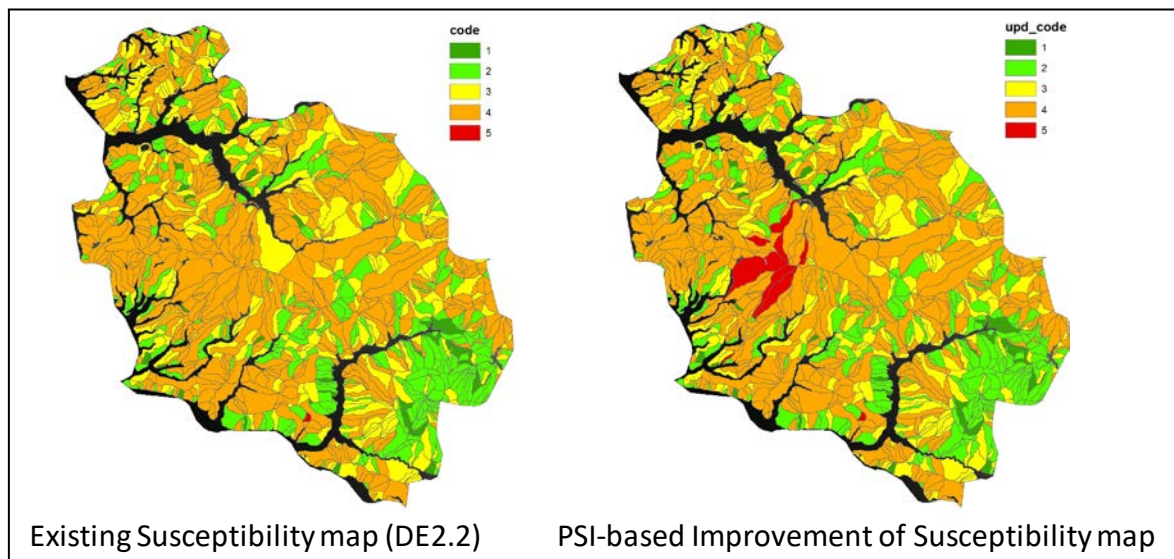
To modify the slope-unit susceptibility class, we considered as representative a minimum number of 4 PS radar targets, regardless the spatial extension of the single landslide. The velocity measurements recorded on one single target may not be representative of terrain movements due to landslides.

Table 1 shows the list of the slope-unit attribute, including the updating PSI VSLOPE-ABS data.

Field	Description	Value
<b>prob</b>	Probability value obtained from the original model	0 to 0.81
<b>code</b>	Class of susceptibility	1 = prob 0.0 - 0.2 2 = prob 0.2 - 0.45 3 = prob 0.45 - 0.55 4 = prob 0.55 - 0.8 5 = prob > 0.8
<b>Area</b>	Polygon area	Value expressed in m <sup>2</sup>
<b>FREQUENCY</b>	Count of PSI data (both ascending and descending) within each slope-unit polygon	Number (a number of 0 PS up to 355 PS)
<b>MAX_VSLP_a</b>	Maximum velocity of VSLOPE in absolute value (VSLOPE_ABS)	<b>Active Updated</b> = updated due to high PSI velocity rates <b>Active</b> = active state of activity derived from existing LIM <b>Dormant</b> = dormant state of activity derived from existing LIM
<b>updating</b>	Update of the susceptibility class due to moving PSI data	<b>YES</b> = the susceptibility class was increased to the higher class <b>NO</b> = the susceptibility class was not modified
<b>upd_code</b>	Update class of the susceptibility due to moving PSI data	The class number from 1 to 5

**Table 1 - Table of attribute of the slope-unit feature class.**

The result of the procedure is an improved susceptibility map where some slope-units were modified to the higher class with respect to the original model. In particular, PSI data allow us to update the area in the southwestern and northern part of the Volterra city, near the center of the municipality, where the area is characterized by more reliable and higher ground motion velocities provided by the PSI radar targets. The original susceptibility map and the modified version, classified in five classes, are shown in Figure 2.



**Figure 2 - The original susceptibility map as described in the Deliverable DE.2.2 and the improved susceptibility map, classified in 5 classes.**

### 3 THE STRATEGIC VULNERABILITY

The vulnerability of a structure/infrastructure is defined as the “expected degree of loss experienced by elements at risk for a given magnitude of hazard” (Glade et al., 2005). Following this definition, we consider the “degree of loss” of buildings and roads as the reduction or loss of serviceability, potentially reaching the service state limit of the infrastructure. Analysis of the literature (i.e. Kong et al., 2002, Fell et al., 2008) shows that does not exist a unique way to classify the elements at risk, and that this is highly related to the quality and scale of the available information.

In this task, the available catalogues, provided by the regional and local administrations, contain only information on the location and the type of structures: structural condition of the infrastructures and information about the occupancy of buildings are not available.

In this framework, we propose a qualitative classification system based on the Strategic Vulnerability (SV) that considers the potential damages of a given structure, already used and that plays a crucial role in the risk management chain. Different SV values are defined for the three Civil Protection phases (Pagliara et al., 2014) (Figure 3).



**Figure 3 - Definition of the three Civil Protection phases: (i) Prevention and preparedness, (ii) Emergency, and (iii) Recovery (source: Bianchini, 2014).**

- *First phase – Prevention and preparedness (PP).* As defined by the European Union (*Decision No 1313/2013/EU of the European Parliament*), prevention means “any action aimed at reducing risks or mitigating adverse consequences of a disaster for people, the environment and property, including cultural heritage”. In particular, the proposed PSI-based methodology provides, during this phase, information to reduce the potential risk by forecasting and mapping potential geohazards.

For this phase, we have defined 3 classes of SV:

- ✓ High (H). Elements with stable occupancy or with high flow of tourism; emergency infrastructures and health facilities; main roads and supply networks;
  - ✓ Medium (M). Elements with occasional occupancy, with an economic, environmental or social value;
  - ✓ Low (L). Elements with occasional occupancy with a low economic value.
- *Second phase – Emergency Phase (E).* The response to a certain geo-hydrogeological event is defined by the United Nations Office for Disaster Risk Reduction (*UNISDR*), as “the provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected”. In this phase, PSI-derived data are used; i) to monitor the post-event residual deformations threatening the population and affecting the strategic infrastructures used in the emergency chain; and ii) to map secondary geohazards induced by the main hydrogeological event.

For this scenario, we have defined 4 classes of SV:

- ✓ Very High (VH). Strategic elements, active part of the emergency chain during an event;

- ✓ High (H). Elements with stable living people or/and that can be used as recovery structures during an event;
  - ✓ Medium (M). Elements that can be useful for single phases of the emergency management or with a relevant economic value that represent a valuable resource for the restoration of an area after an event;
  - ✓ Low (L). Elements that do not constitute a main priority during the event management.
- *Third phase – Recovery Phase (RP)*. The recovery after a hydrogeological or volcanic event is defined by the UNISDR as “the restoration of facilities, livelihoods and living conditions of disaster-affected communities including efforts to reduce disaster risk factors”. InSAR data can be used in the Recovery Phase to evaluate the possible reactivation of existing phenomena or the presence of precursors of new movements affecting areas involved in the reconstruction.

For this scenario, we have defined 3 classes of SV:

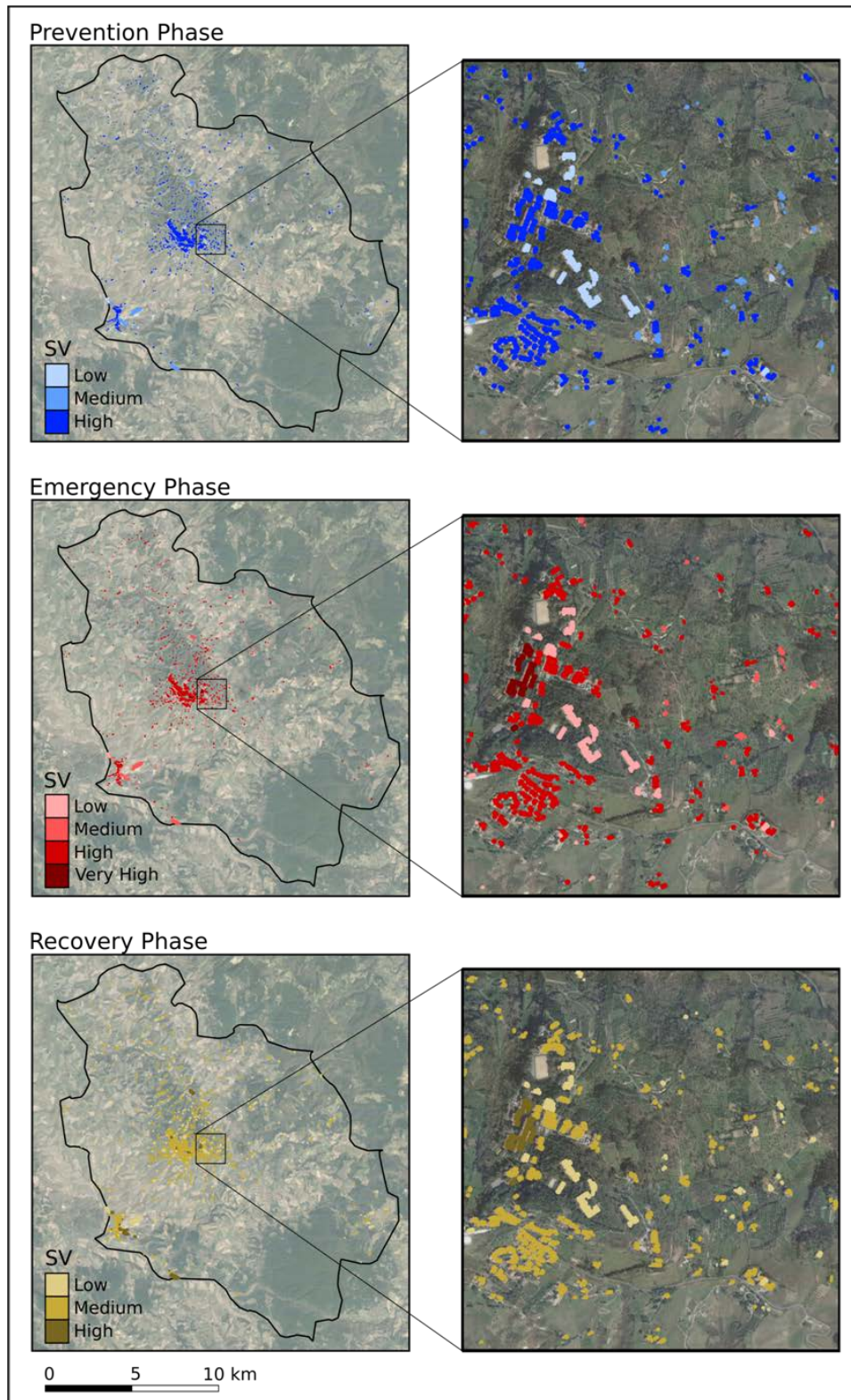
- ✓ High (H). Elements that represent a main priority in case of damages restoration or reconstruction works because of their economic or strategic value.
- ✓ Medium (M). Elements that represent an artistic or social value that have to be restored after the main priority elements.
- ✓ Low (L). Elements with a subordinate importance in case of the definition of the actions related to the damages restoration activities.

For the three phases of Civil Protection, different values of Strategic Vulnerability (SV) were assigned to each type of element at risk. In Table 2, the Strategic Vulnerability is classified with different colour-shades with the following legend: 3 classes with shades of blue for the prevention phase, 4 classes with shades of red for the emergency phase and 3 classes with shades of brownish for the recovery phase.

Type of Element at Risk	Prevention Phase (P)	Emergency Phase (E)	Recovery Phase (R)
Cultural heritage	High	Medium	Medium
Agricultural activities	Low	Low	Low
Gas stations and fuel deposits	Medium	Medium	Low
Hospitals and health centres	High	Very High	High
Hotels and accommodation facilities	High	High	Medium
Industries	Medium	Medium	High
Markets and shopping malls	Medium	Low	Low
Media-related structures	Medium	Medium	Low
Main Roads (Regional, Provincial and Municipal) and railway network	High	Very High	High
Parking areas and parking lots	Low	Low	Low
Power lines	High	Very High	High
Private houses with continuous occupancy	High	High	Medium
Private houses with discontinuous occupancy	Medium	Medium	Low
Public administration buildings	High	Very High	High
Recreational areas	Low	Low	Low
Secondary Roads	Medium	High	Medium
Schools	High	Very High	High
Sport centres	Low	High	Low
Urban security and Civil Protection structures	High	Very High	High
Waste deposits	Medium	Medium	Low
Warehouses	Medium	Low	Medium
Water supply network and facilities	High	Very High	High

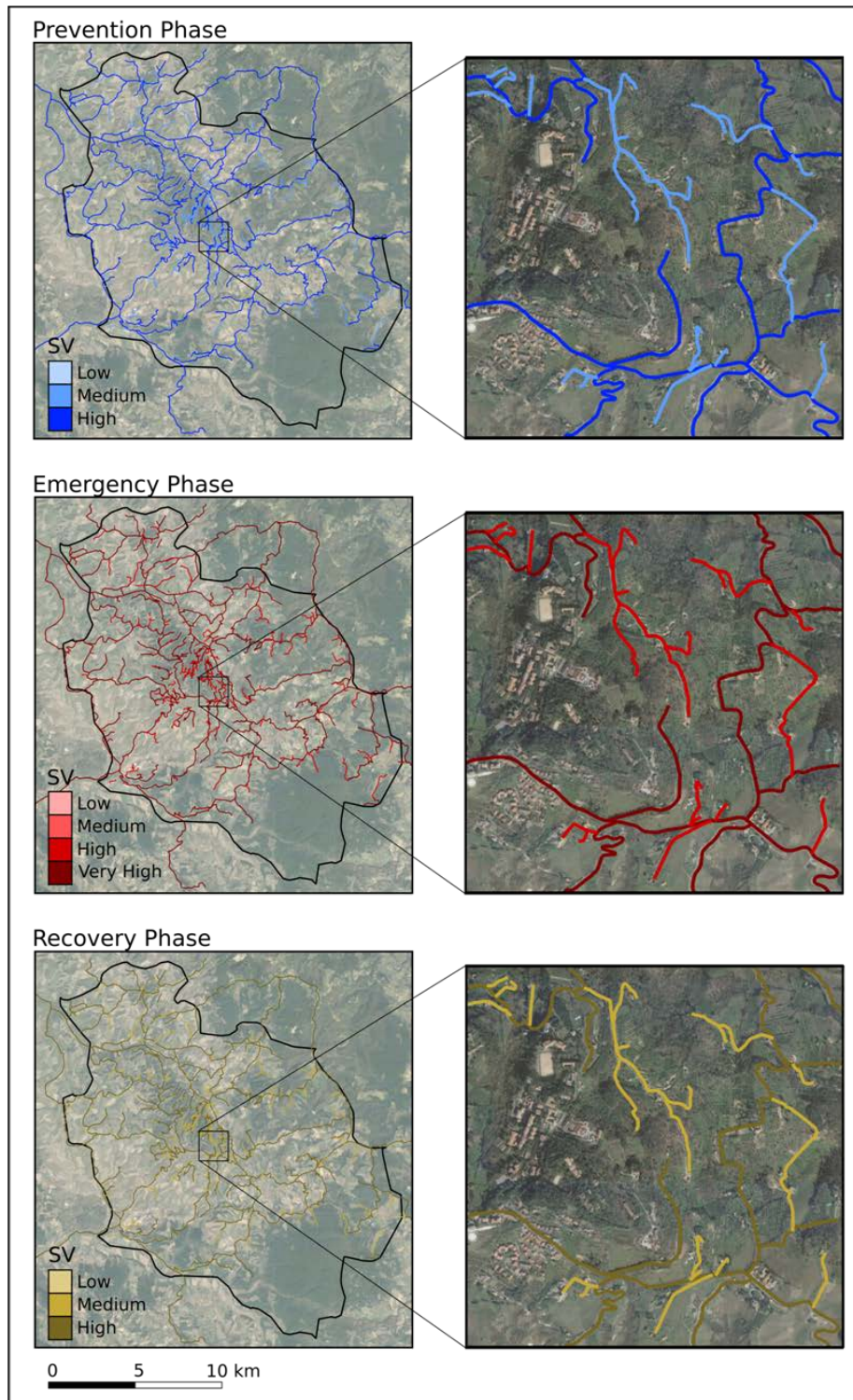
**Table 2. Values of Strategic Vulnerability (SV) assigned to elements at risk, for each phase of Civil Protection.**

Figure 4 shows the spatial distribution of the buildings located in the Volterra Municipality, coded according to the SV classes for the Prevention, the Emergency and the Recovery phases.



**Figure 4 - Three maps that show the spatial distribution of the buildings classified according to the Strategic Vulnerability, as defined for the three Civil Protection phases: Prevention, Emergency, and Recovery.**

Similarly, Figure 5 shows the spatial distribution of the roads network, classified according to the three phases listed above.



**Figure 5 – The three maps show the spatial distribution of the roads classified according to the Strategic Vulnerability, as defined for the three Civil Protection phases: Prevention, Emergency, and Recovery.**

## 4 IMPACT ASSESSMENT

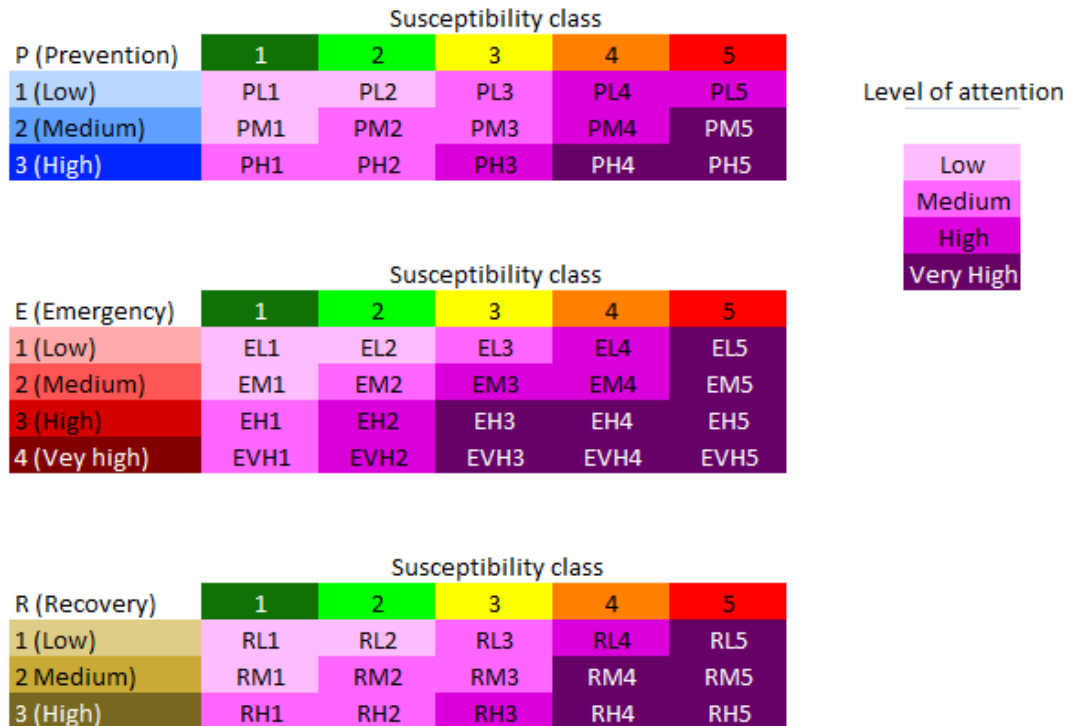
We have tried to formalize the innovative concept of *Level of Attention* (LA), combining the improved landslide susceptibility zonation with the Strategic Vulnerability assigned to each type of structure and infrastructure (Table 2). The Levels of Attention can be considered as a proxy of levels of risk, defined for the exposed elements when a landslide susceptibility zonation is known.

The Level of Attention (LA) was formalized considering the landslide susceptibility map and the Strategic Vulnerability. For each Civil Protection phase, we have proposed a table (see Figure 6), where the columns show the landslide susceptibility values in five categories (1-dark green (0-0.2); 2-green (0.2-0.45); 3-yellow (0.45-0.55); 4-orange (0.55-0.8); 5-red (0.8-1)) and the rows the SV as defined in Table 2 (low, medium, high and very high). For each phase, the SV is color-coded using the same shades of Table 2 (Prevention - blue scale; Emergency - red scale, Recovery - brownish scale). The Level of Attention is labelled with an alphanumeric code containing letters and a number. The first letter represents the Civil Protection phase (Prevention (P), Emergency (E) and Recovery (R)); the second (and third) letter indicates the SV class (Low (L), Medium (M), High (H), Very High (VH)) and the number the class of the susceptibility model. The Levels of Attention, for the three phases, were further re-classified in four classes of increasing magnitude (Low, Medium, High, Very High) that can be seen in shades of pink in the matrixes of Figure 6.

Using the codes shown in Figure 6, we have assigned the Level of Attention to each element at risk. The LA is related to the landslide susceptibility class of the slope-unit where the element is located. When an element (e.g., a building) intersects more than one slope-unit, with different susceptibility values, the higher value is assigned to the LA code.

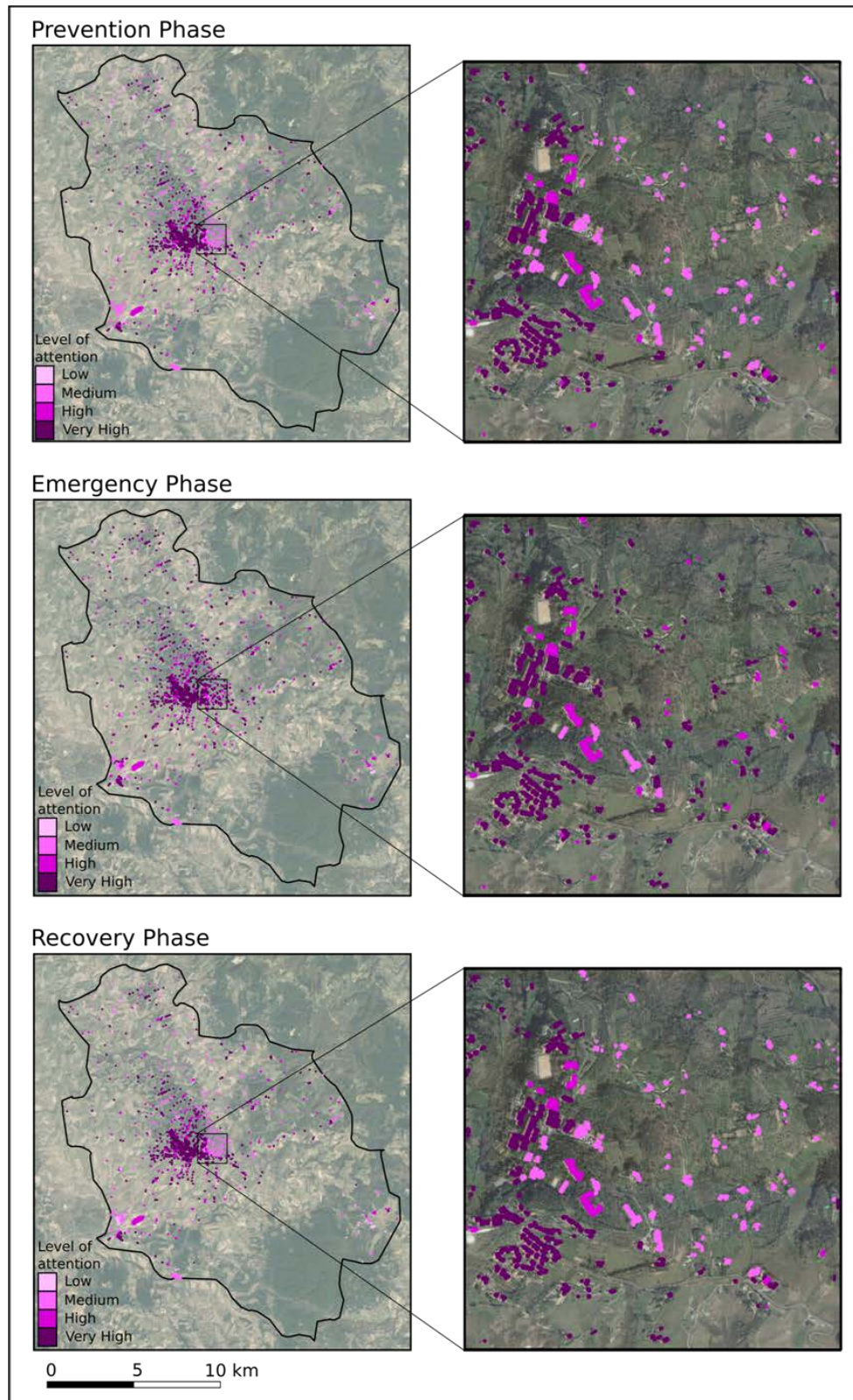
It is worth highlighting that the method identified to assign the LA code to the road network is slightly different for the Prevention/Recovery phases and the Emergency.

For the three phases, each road is classified with a unique SV value but it can have numerous landslide susceptibility values if it crosses more slope-units. For the Prevention/Recovery phases, a unique LA code is assigned to segments of road delimited by slope-unit boundaries. For the Emergency phase, we have considered the strategic role of the network and we have assigned a unique PA value to each segment between two road intersections (infrastructure nodes). The LA code was assigned to each road segment, selecting the highest value of landslide susceptibility among all the slope-units crossed by the infrastructure. In the GIS analysis, to overcome possible topological errors due to vector format of the road network, we have considered a 12-m buffer for the MR and SR (main and secondary roads) and a 6-m buffer for the PR (private roads). Where the susceptibility zonation is not available, the LA code is not calculated.

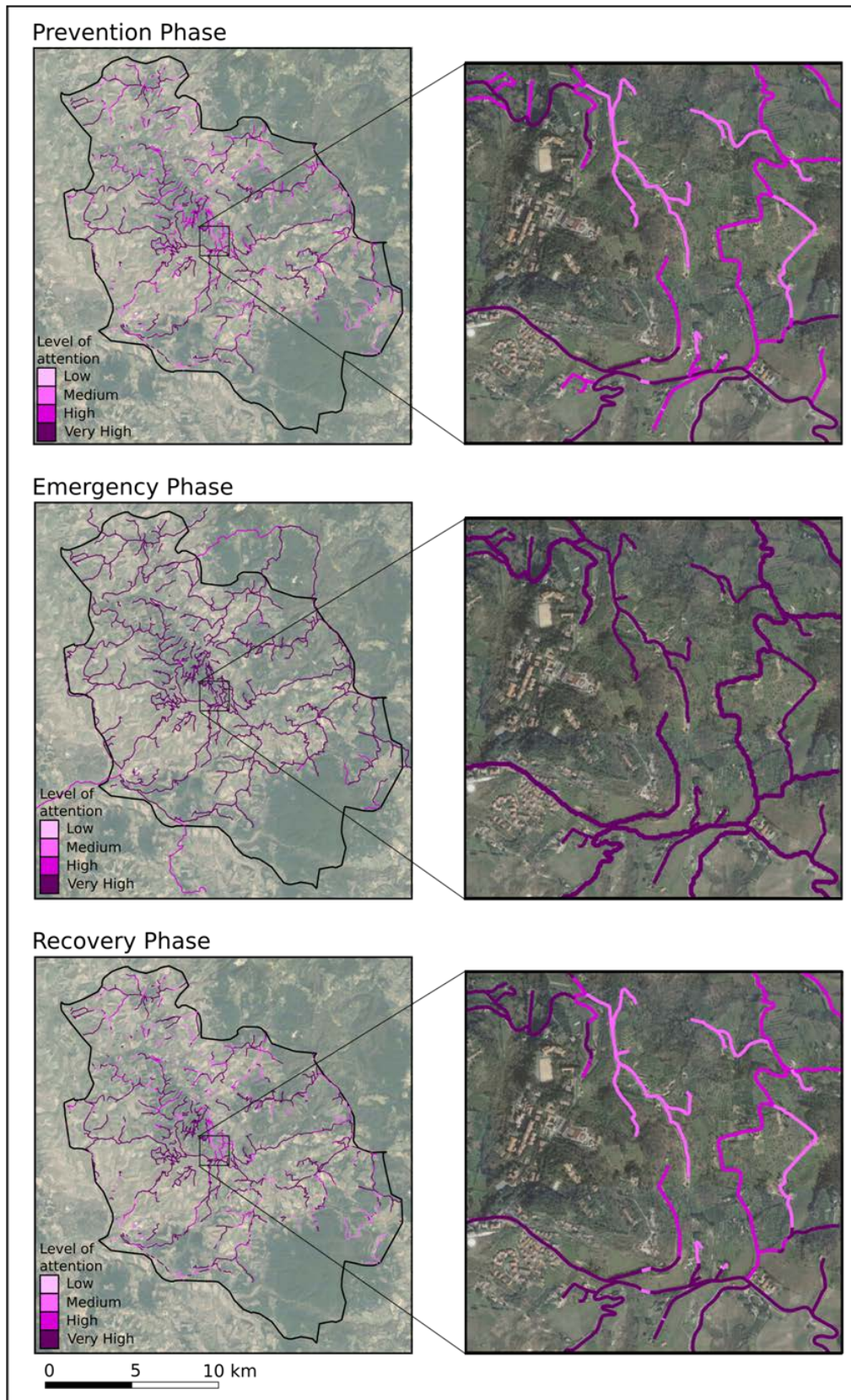


**Figure 6 - Level of Attention. The three tables show the classification of Level of Attention as defined for the three Civil Protection phases: Prevention, Emergency and Recovery.**

Figure 7 shows the LA codes attributed to the buildings of the Volterra municipality, for the three Civil Protection phases. For each Civil Protection phase, is shown a close-up view of the eastern portion of the Volterra city center. Figure 8 shows the LA codes attributed to the road network of Volterra municipality, for the three Civil Protection phases. For each Civil Protection phase, is also presented a close-up view of the road-network in the southeaster portion of Volterra city center.



**Figure 7 – The three maps show the spatial distribution of the buildings classified according to the Attention levels as defined for the three Civil Protection phases: Prevention, Emergency and Recovery (see Figure 6).**



**Figure 8 - The three maps show the road network classified according to the Attention levels as defined for the three Civil Protection phases: Prevention, Emergency and Recovery (see Figure 6).**

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