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Safety – Sentinel for geohazard prevention and forecasting

Deliverable DE.4: Impact assessment on structures and infrastructures over the two test sites of the project (V0)

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)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	
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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 1st 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 (CPA) with the capability of periodically evaluating and assessing the potential impact of geohazards on the selected sites.

The Impact Assessment maps are one of the four deliverables foreseen in Task E "Geohazard impact assessment". This deliverable, which will be updated three times throughout the project, aims at assessing the impact of detected and/or assessed geohazards on road networks and built-up areas. The final map consists in a simplified colour scale map indicating: those structures and infrastructures with a greater probability to suffer geo-hazard impact and those structures and infrastructures affected by the dynamic of an active geohazard. The final goal is to provide an operable methodology, a protocol, which can be integrated into the Civil Protection prevention activities.

Safety

REFERENCE DOCUMENTS

N°	Title
RD1	DoW Part B
RD2	D5.1: Test site selection
RD3	D2.1: User Requirements

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1 INTRODUCTION

The Impact Assessment maps are one of the four deliverables foreseen in Task E “Geohazard impact assessment”. This deliverable, which will be updated three times throughout the project, aims at assessing the impact of detected and/or assessed geohazards on road networks and built-up areas. The final map consists in a simplified colour scale map indicating: those structures and infrastructures with a greater probability to suffer geo-hazard impact and those structures and infrastructures affected by the dynamic of an active geohazard. The final goal is to provide an operable methodology, a protocol, which can be integrated into the Civil Protection prevention activities.

For this purpose, the elaborated geohazard activity maps (action E.3) has been combined with the available geodatabases of vulnerable structures and infrastructures to assess the impact level on the most critical areas, by using GIS spatial analysis.

In this first version of the Impact Assessment analysis, the final maps of the Volterra test site and of the Tenerife Island have been produced. In order to test the methodology, for the Canary Islands test site the Impact Assessment map has been generated only for the Island of Tenerife, where a highest number of information at detailed scale regarding the elements at risk is available. In the next two deliverables, the methodology will be also applied to the La Gomera and La Palma islands.

2 METHODOLOGY

In this section, we describe the methodology to generate the Impact Assessment (IA) maps on the basis of the Geohazard Activity maps derived from the interferometric analysis of Sentinel-1 images (action E.3) and of the available catalogues of elements at risk (Figure 1). The methodology is applied in a GIS environment, using only basic tools of analysis.

The methodology aims at intersecting the Hot Spots (HS) database, generated in the action E.3 – “Geohazard activity maps”, with a classified element at risk catalogue for each test site. The proposed classification is based on a qualitative system called “Strategic Vulnerability (SV)” that consider the potential damages of a certain structure that is already used, could be used or plays a crucial role in the risk management chain of an area or of a municipality. This system is particularly designed for Civil Protection Authorities (CPA). The element at risk are classified into four class of SV, ranging from Very High to Low. The first class (VH – Very High) is composed by the elements at risk that are of critical importance in the risk management chain. It comprises: transports network elements (roads, railroads, bridges, tunnels), which are essential for the movement of people and materials in case of an emergency, hospitals, administrative buildings and security/emergency structures, which are fundamental for both emergency and post emergency phases in terms of life saving and central organization. The second class (H - High) is constituted by all the residential buildings, in which people lives permanently, and structures of irregular occupation (i.e. hotels and educational buildings) that could be of high importance for recovering people after an emergency. The third class (M - Medium) is composed by all the elements with an economical or environmental relevance for the analysed area. These structures represent an important factor for the post emergency phase. The last class (L - Low) includes all the elements that have a strong impact on the social life of people but not a real strategic relevance in the emergency management framework.

The final output is an Impact Assessment map that includes the information of both the HSs, derived from the InSAR (Interferometric Synthetic Aperture Radar) analysis, and the SV of the elements at risk. In this way, each area affected by active deformations has been identified and included in a geodatabase containing attribute information about: the location of the HS, the geological context, the SV value of the element at risk and its description, the type of movement affecting the HS (landslide/creep or subsidence) and the LOS (Line of Sight) mean velocity value of the HS. Moreover, the territories of the two test sites has been divided in subareas (municipalities for Tenerife, districts for the Volterra municipality) in order to provide an easily readable information for the CPAs.

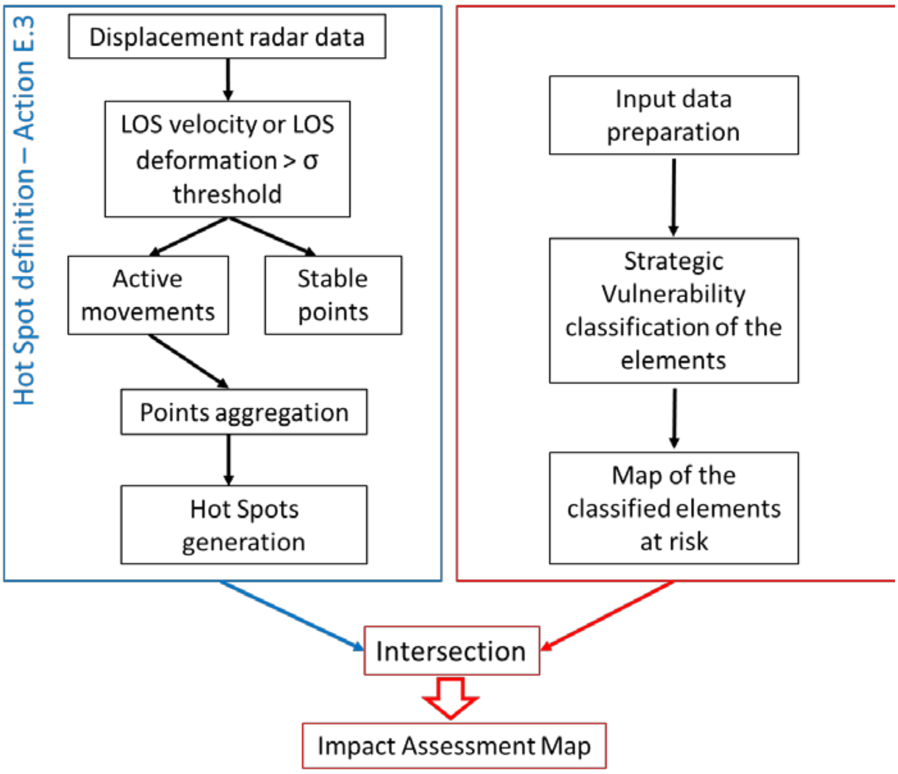

Figure 1 – Flow chart of the generation of the Impact Assessment map in the two test sites. The blue contour represents the data already elaborated within the SAFETY project while the red contours represent the task that are implemented in the current deliverable.

2.1 Input data

As a result of the InSAR analysis phase, focused on the generation of the Geohazard activity maps, 78 HSs for the Tenerife Island and 89 HSs for the Volterra municipality have been identified. Each HS is characterized by a mean velocity value in the monitored period, for the Tenerife area, and a mean value of the accumulated displacement in the monitored period for the Volterra area: negative values represent a movement away from the sensor while positive values represent a movement toward the sensor. These HSs are used as input data for the satellite part of the proposed methodology (blue contour in Figure 1).

According to the bibliographic definition of an element at risk (Dai et al., 2002; Fell et al., 2008), the catalogues contain information about private buildings, economic and industrial activities, public services utilities and infrastructures. The spatial distribution and availability of the data, as well as the level of detail of each layer constituting the catalogues, depends on the public entity (e.g. municipality, Civil Protection authorities) that provided the data. Each database is composed of linear, punctual and polygonal shapefiles with a brief description of the various elements at risk (Figure 2a and 2b).

Because of the Tenerife peculiar geodynamic asset, with the presence of a quiescent volcanic system, has been also included the “natural” element at risk of the Teide caldera area, where new eruptions can be possible. This element has been represented as a polygon and defined on the base of a high resolution digital terrain model (DTM, 5x5 m cell resolution), the DTM derived slope map and bibliographic sources (Figure 2c).

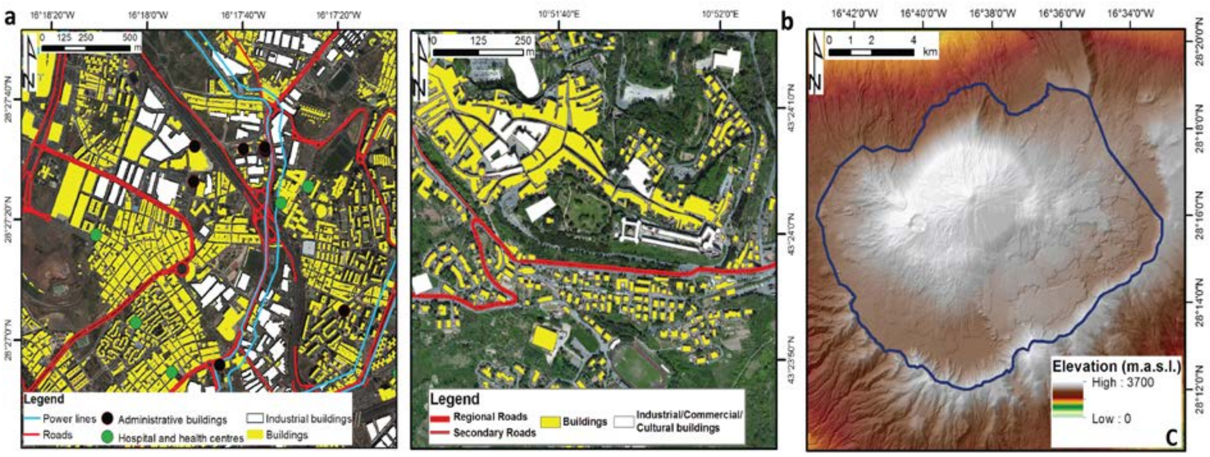

Figure 2 - a) example of element at risk catalogue in the Tenerife Island (Santa Cruz de Tenerife); b) example of the element at risk catalogue in the Volterra municipality (Volterra city centre); c) Cañadas caldera perimeter used as “volcanic element at risk”.

3 IMPACT ASSESSMENT MAPS

The application of the proposed work flow (Figure 1) to the two test sites has allowed to test the methodology over areas of two different scales: large scale for the entire Tenerife Island, that includes 31 municipalities, and small scale for the municipality of Volterra. For each test site, the Impact Assessment map of the entire territory, of the subareas and of some selected HSs of interest are shown.

3.1 Volterra test site

The methodology applied to the test site of Volterra municipality has allowed to identify 89 anthropic HS areas, among which 15 (17% of the total) affect vulnerable elements and 74 are not associated with any element at risk (83% of the total).

In particular, an amount of 12 HSs affect elements with Very High Strategic Vulnerability (Class 1), one HS is located on elements with High Strategic Vulnerability (Class 2), and two are related to a Medium Strategic Vulnerability element (Class 3) (Figure 3a)
The spatial distribution of the hotspot areas is highly related to the lithology of the area, as almost all the HS are located where marine “Blue Clays” Formation and lacustrine “Fosci clays” Formation respectively outcrop. Moreover, it is worth to highlight that the zones where HSs are recorded correspond to arable lands, fallows and crops with dispersed vegetation. The selected 15 HSs are mostly concentrated on the south-western portion of the Volterra municipality. This area is characterized by a hilly morphology widely affected by slow-moving and superficial processes which involve mainly clayey terrains and colluvial deposits: very slow shallow landslides and soil creep, gully erosion and badlands formation processes (Bianchini et al., 2016). On the contrary, in the north/north-eastern portion of the municipality prevails a more abrupt morphology affected by more rapid movements, i.e. complex landslides and falls (Bianchini et al., 2015), which are less easily detectable by means of SAR Interferometry.

The Volterra municipality is divided into 19 local districts, among which 8 include at least one HS affecting elements at risk (Figure 3b). The district where the maximum number of HSs have been detected (4 HSs) is the Mazzolla district (MAZ), located in the SE portion of the test site. It must be noted that the hotspot areas are located only on the northern part of this district where soft lithotypes (i.e. Fosci Clays) crop out. In seven out of eight districts, at least one HS with Very High strategic vulnerability is found. On the other hand, the Saline di Volterra district (SAL) is the only one that comprises one HS referred to High SV and two HSs referred to the Medium Strategic Vulnerability Classes.

A percentage of 66% of the total number of active hot spots affecting vulnerable elements are likely related to soil creep and landslide phenomena (10 areas among the total of 15 HSs), according to the analysis of auxiliary data (i.e. HR orthophotos, geological information and data from the existing Landslide Inventory Map of the test area). A number of 3 HSs located in Saline district are probably due to subsidence phenomena. Conversely, for 2 HSs the cause of movement is actually undefined.

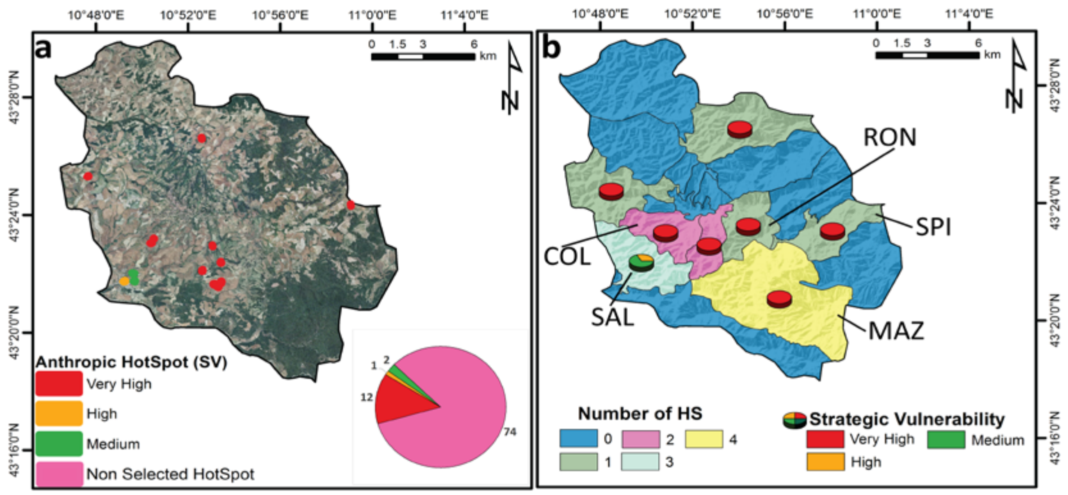

Figure 3 - a) Impact Assessment Map for the municipality of Volterra. The pie chart shows the proportional amounts of different detected Hot Spots; b) Number of HS for district and pie charts indicating the elements at risk classification. COL – Colombaino; district; MAZ – Mazzolla district; RON – Roncolla district; SAL – Saline di Volterra district; SPI – Spicchiaiola district.

Active movements related to ground movement are recorded by the HS number 8 (Figure 4a), located within the Roncolla (RON) district, southward the Volterra city center. The movement is involving clayey terrains (Blue Clays Formation) on a NW-facing slope, covering a length of about 150 meters on the ground. The generated HS is composed of 8 PS points, with an overall mean DLOS (Displacement along the Line of Sight) of -20 mm downslope, in the monitoring period. The proposed methodology allowed to associate this HS to an element at risk with Very High SV value, corresponding to a local road (Class 1). This ground deformation would represent a hazard for its serviceability as it may evolve in a retrogressive movement reaching the road and making the buildings isolated.

Two other representative hot spots potentially related to landslide movements are HSs number 1 to 4, within the northern part of Mazzolla district. The Figure 4b shows these 4 HSs affecting S-SE gentle hills covered by arable lands and deriving from distributed PSs with a cumulative DLOS ranging from -10 mm up to -35 mm in the monitoring period. The detected terrain movements could be associated to soil creep, and the HS have been included in Very High SV since they are locally intersecting a main road.
The HSs number 10 and 11 are located on Colombaie district (Figure 4c) and are characterized by average LOS displacement of about 10-15 mm, away from the satellite direction, corresponding to downslope movements towards SE. These HSs are classified as Very High SV, because they cross (HS 10) or are nearby (HS 11) the road SR68, which is the main regional road of the municipality, whose interruption would compromise the efficiency of the whole Volterra road network. It is worth to notice that these hot spot clusters are recorded on slope where landslide phenomena were already mapped within the pre-existing LIM (Landslide Inventory Map). Figure 4d shows another hotspot in Spicchiaiola district classified as Very High SV on a S verging slope yet again facing the regional road SR68 and characterized by potential diffuse soil surface motions.

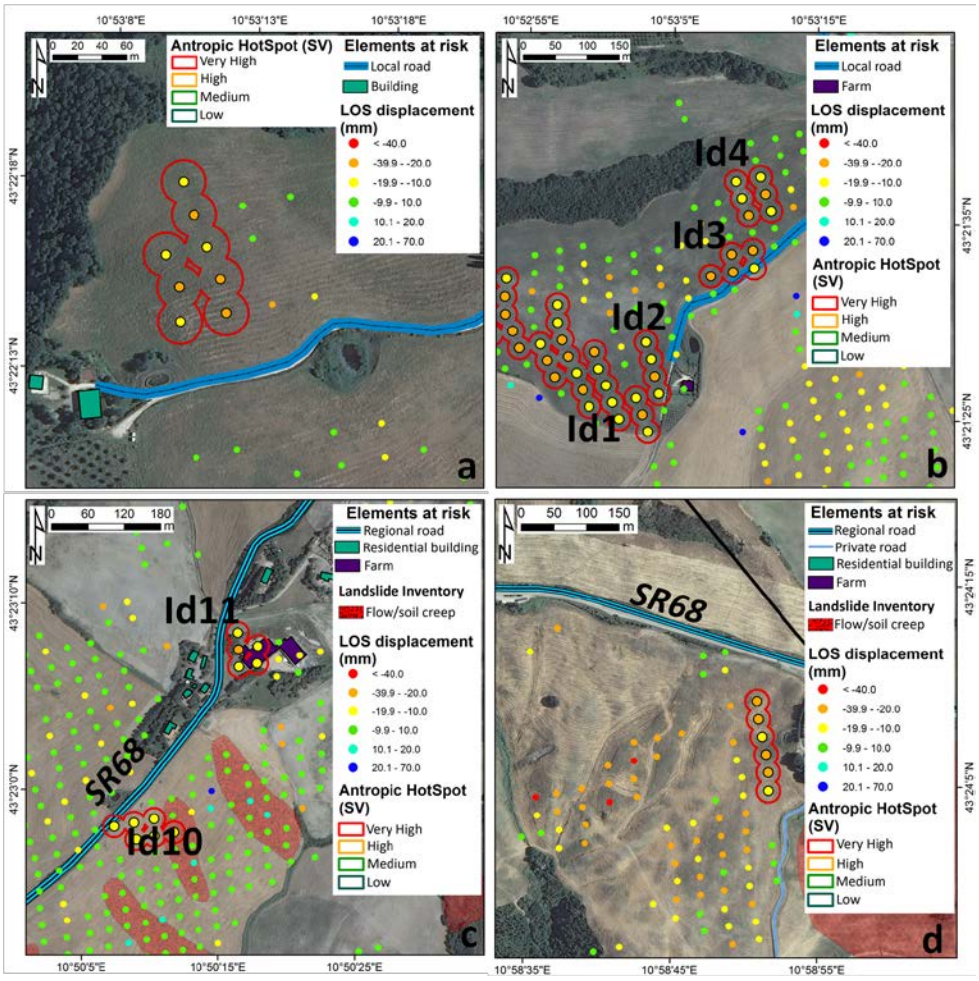

Figure 4 – Examples of HS composing the Vulnerable Elements Activity Map (VEAM) in the Volterra Municipality. a) HS number 8, Roncolla district; b) HS number 1, 2, 3, 4, Mazzolla district; c) HS number 10 and 11, Colombaie district; d) HS number 12 in Spicchiaiola district. The PS points outside the HS contour line are displayed in transparence for a better visualization of the background images.

3.2 Tenerife Island test site

The methodology applied to the Tenerife test site has allowed to detect 29 hot spot areas, equal to the 33% of the total number of HSs, affecting vulnerable elements (Figure 5a). Of these, 16 are anthropic HSs (20% of the total) and 21 are natural HSs, within the Cañadas caldera area (27% of the total); 41 HS were not associated with an element at risk (53% of the total). Five of the anthropic HSs affect an element with Very High Strategic Vulnerability (Class 1), 10 HSs are represented by elements with High Strategic Vulnerability (Class 2) and one HS is related to a Medium Strategic Vulnerability element (Class 3).

Nine municipality territories (30% of the total) include at least one anthropic HS, with the maximum of 4 for the San Crístobal de La Laguna municipality (Figure 5b). In 4 municipalities, at least one HS with Very High strategic vulnerability is found; five municipalities include only one or more HS related to a High SV element, while, in only one municipality (Arico) an element at risk with Medium SV intersect with the HS database (Figure 4b). The 56% of the Vulnerable Elements Active Hot Spots are affected by deformation that can be related to landslide or superficial creep phenomena, while the 46% is associated with subsidence.

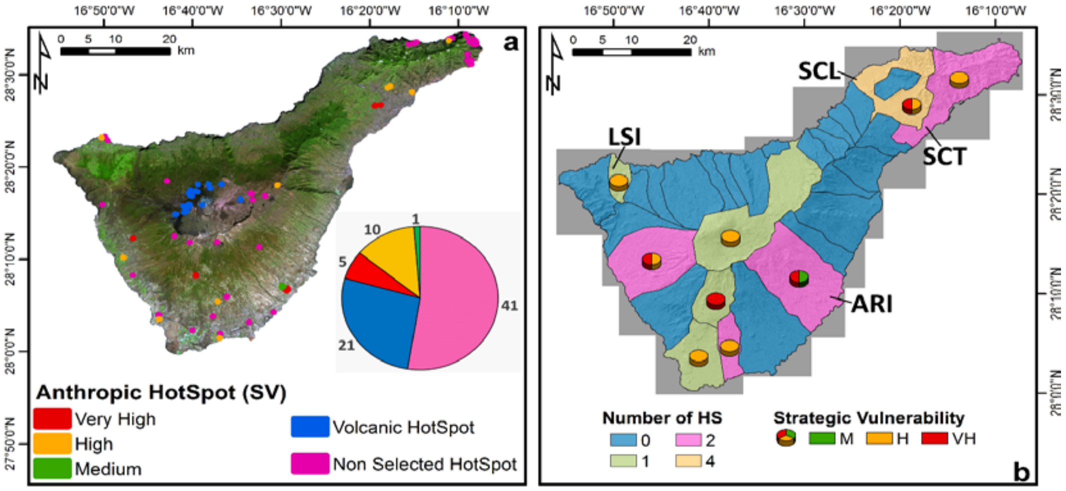

Figure 5 - a) Impact Assessment Map for the Tenerife Island; b) number of HS for municipality and pie charts indicating the elements at risk classification. ARI – Arico municipality, LSI – Los Silos municipality, SCL – San Crístobal de La Laguna municipality, SCT – Santa Cruz de Tenerife municipality.

One area affected by active movements related to a possible landslide is the HS number 31, located in the eastern part of the city of Guía de Isora in the homonym municipality (Figure 5a). The instability is affecting a SW - W exposed slope with a maximum gradient of 20° in its upper portion. By the geological point of view, the area is characterized by the presence of the deposits belonging to the "Cañadas Edifice" formation. The generated HS has a mean velocity of -14.5 mm/yr (Figure 6a); the negative sign is coherent with a movement away from the sensor in the LOS direction. This HS is associated with an element at risk with Very High SV value, represented by the TF-82 Road that is intersecting the active movement area.

Another example of active hot spots related to possible landslide movements is represented by the HS number 19. The HS is affecting a W exposing slope located in the SE part of the city of San Miguel in the San Miguel de Abona municipality (Figure 6b). This slope represents the western flank of a small cinder cone and is characterized by maximum gradient of 30°. The volcanic deposits constituting the slope belong to the recent eruptions of the Teide-Pico Veijo stratovolcano. The HS is characterized by an average LOS velocity of -13.3 mm/yr, coherent with a movement away from the sensor and is associated with an element at risk with High SV value, corresponding to the residential buildings at the bottom of the slope.

Mainly vertical movements are shown by the two HSs, ID 23 and 24, located 2.5 km inland from the coast, in the Arico municipality (Figure 6c). These two HSs are located in the biggest urban solid waste dump of the island; part of the waste deposit is affected by these movements. Deformation rate values are equal to -38.8 mm/yr for HS 23 and -39.5 mm/yr for HS 24. The presence of this dump landfills suggest that the registered deformations are mainly related to vertical movements, connected to the compaction of the waste deposits. An industrial building (Medium SV) is intersected by the HS 24, while the HS 23 intersects the main power line of the Island (Very High SV). In this second example, these elements at risk are not directly affected by the phenomena, except for possible localized settlements for the industrial building or for the electricity pylons.

The volcanic HSs, within the Cañadas caldera perimeter, show LOS velocities ranging from -10.0 to -30.6 mm/yr and average value of -14.6 mm/yr. These points are mainly grouped around the volcanic edifice of Mount Teide – Pico Veijo, along the W-NW flanks at a height ranging from 2000 to 3000 m.a.s.l. (Figure 5a). The area with the highest density of volcanic HSs is the NW flank of the Pico Veijo edifice (Figure 6d), where LOS velocities higher than -20 mm/yr are found. These negative velocities cannot be related to superficial movement of the flank related to landslides; in fact, in that case, the movement would be towards the sensor considering the direction of acquisition of the sensor in the ascending orbit. Considering this, the Cañadas caldera is so affected by mainly vertical movements, related to the natural subsidence of the volcanic edifice. Some authors have already reported this ground lowering, detected by InSAR and GPS (Global Positioning System) data, ascribing it to different causes. As suggested by Fernández et al. (2009), the subsidence is related to the gravitational sinking of the caldera into a weak lithosphere for the weight of the Teide-Pico Veijo strato-volcano. On the other hand, Sanchez-Alzola et al. (2016) consider that the lowering is related to local and regional causes, related to the high drop of the phreatic surface in recent years and to the lateral spreading of the whole volcanic edifice.

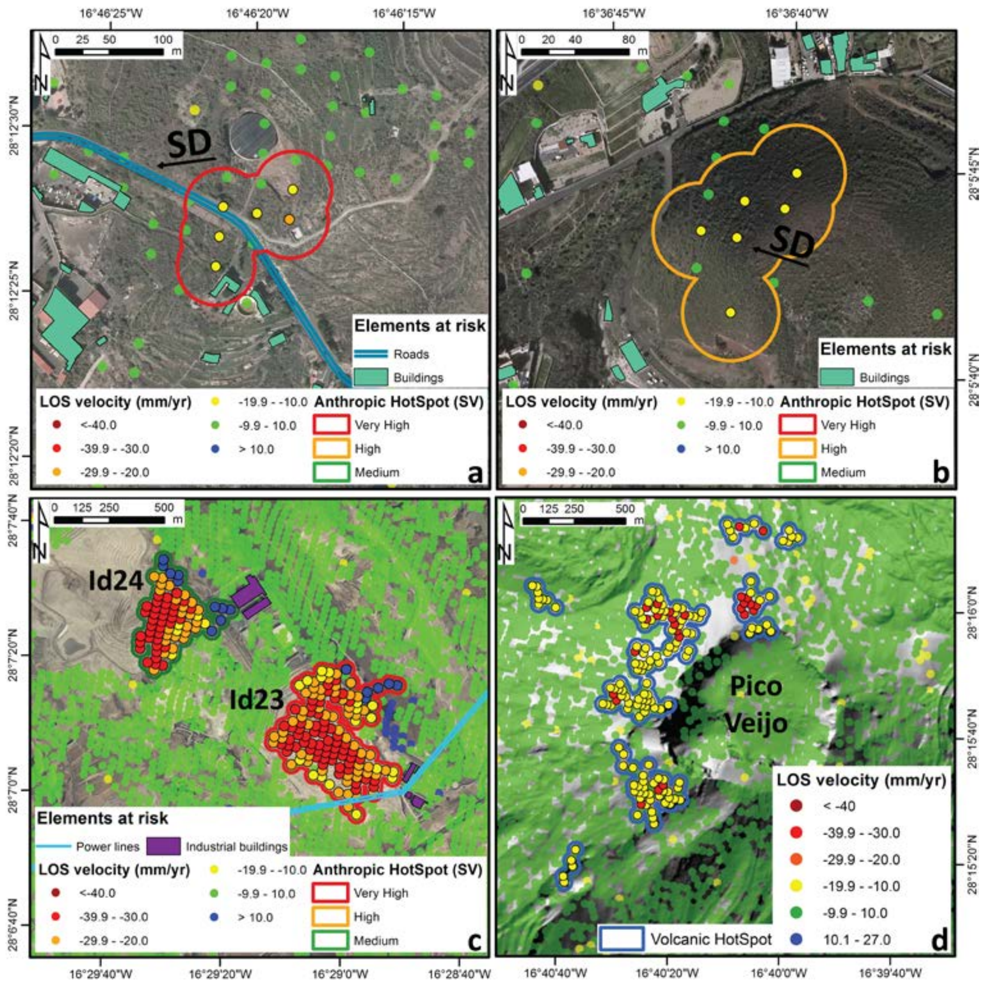

Figure 6 – HS of interest extracted from the Impact Assessment map of the Tenerife Island. a) HS number 31, Guía de Isora municipality; b) HS number 19, San Miguel de Abona municipality. The black arrows indicate the slope direction (SD); c) HS number 23 and 24, Arico municipality; d) volcanic HS within the Cañadas caldera, around the Pico Veijo volcanic edifice.

4 CONCLUSIONS

This deliverable describes the first delivered Impact Assessment maps for the two test sites and the procedure to generate them. The methodology demonstrated its usefulness in providing reliable results in different geological and geodynamical context, with different geohazards and at different scales. This type of product is designed for defining areas of possible active movements at large scale with a simple and reproducible work-flow that can be used by CPAs members and that can be implemented in the risk management chain. The final result requires also a ground validation for the most representative and with the highest hazard HS areas, but the number of field checks needed is highly limited thanks to the application of this approach. Because of the dependence from the outputs of the InSAR processing (Action C.2) and thus from the results of the Geohazard Activity maps (Action E.3), it is expected to improve the quality of the Impact Assessment map.

5 REFERENCES

Bianchini S, Pratesi F, Nolesini T, Casagli, N (2015) Building deformation assessment by means of persistent scatterer interferometry analysis on a landslide-affected area: the Volterra (Italy) case study. Remote Sens 7:4678-4701. doi:10.3390/rs70404678

Bianchini S, Del Soldato M, Solari L, Nolesini T, Pratesi F, Moretti S (2016) Badland susceptibility assessment in Volterra municipality (Tuscany, Italy) by means of GIS and statistical analysis. Environ Earth Sci 75:1-14. doi:10.1007/s12665-016-5586-5

Dai FC, Lee CF, Ngai YY (2002) Landslide risk assessment and management: an overview. Eng Geol 64:65-87. doi: 10.1016/s0013-7952(01)00093-x

Fell R, Corominas J, Bonnard C, Cascini L, Leroi E, Savage WZ (2008) Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning. Eng Geol 102:99-111. doi: 10.1016/j.enggeo.2008.03.009

Fernández J, Tizzani P, Manzo M, Borgia A, González P, Martí J, Camacho AG, Casu F, Berardino P, Prieto JF, Lanari R, Pepe A (2009) Gravity-driven deformation of Tenerife measured by InSAR time series analysis. Geophys Res Lett 36:L04306. doi:10.1029/2008GL036920.

Sánchez-Alzola A, Martí J, García-Yeguas A, Gil A J (2016) Subsidence and current strain patterns on Tenerife Island (Canary Archipelago, Spain) derived from continuous GNSS time series (2008–2015). J Volcanol Geoth Res doi:10.1016/j.jvolgeores.2016.08.006