	ENSURE PROJECT *Contract n° 212045*

WP5:

Application of an integrated vulnerability conceptual approach

Del. 5.3.3:

Development of the Integrated Approach on the Vulcano case study

Reference code: ENSURE – Del. 5.3.3

The project is financed by the European Commission by
the Seventh Framework Programme
Area "Environment"
Activity 6.1 "Climate Change, Pollution and Risks"

Project Acronym: ENSURE

Project Title: Enhancing resilience of communities and territories facing natural and na-tech hazards

Contract Number: 212045

Title of report: Del. 5.3.3: Development of the Integrated Approach on the Vulcano case study

Reference code: ENSURE – Del. 5.3.3

Short Description: The deliverable 5.3.3 describes the application of the ENSURE framework to the case study of Vulcano island, Italy. Vulcano is one of the seven islands of the Aeolian archipelago in the Mediterranean Sea (southern Italy) with a surface of about 20 km^2 and about 800 permanent residents. The most current active system on Vulcano is represented by the La Fossa cone, which, during the last 1000 years, has been characterized by a wide spectrum of eruptive styles, from effusive to medium-intensity explosive activity. We consider that all these eruptive styles are representative of the entire hazardous phenomena that La Fossa cone could reproduce in the future. The potential for short warning times and proximity of people on the island to hazards associated with an eruption exacerbate the risk to people and property on the island. Explosive volcanic eruptions typically produce a range of primary (e.g., tephra fallout, pyroclastic density currents) and secondary (e.g., tsunamis, landslides and lahars) hazards, which require independent studies. Vulcano island is highly exposed to all this hazards in combination to the hazard related to tectonic earthquakes. Hazard assessment was developed for tephra (including ballistic ejecta) and lahar phenomena related to a possible eruption with Volcanic Explosivity Index 3, considered as the most likely scenario based on past activity. The landslide hazard and risk evaluation were based on the "Piano di stralcio dell'Assetto Idrogeologico" done by the Sicily region. Seismic data confirm a relatively moderate seismic activity on Vulcano. To assess seismic hazard on Vulcano, two scenarios were retained: one similar to the 1981 local earthquake (M_w = 4.7) and one corresponding to the hazard level defined in the Italian building code, which indicated a Peak Ground Acceleration (PGA) of 1.8 m/s^2 for the island. Vulnerability of different areas and targets affected by tephra fallout, lahars and earthquakes has been analyzed with respect to physical and systemic aspects and to the capacity to prevent and/or mitigate risk. Three sets of indicators have been applied. Set 1 refers to physical vulnerability and is necessary to identify the primary factors that make an urban area vulnerable to hazards. Set 2 refers to systemic vulnerability and is mainly addressed to evaluate the capacity of critical equipment to continue functioning after some level of physical damage. Set 3 refers to mitigation capacities and is used to evaluate whether: i) different components of risk (hazard and vulnerability of exposed elements and systems) are currently known and assessed, ii) mitigation measures have been defined and/or implemented, and iii) different actors (individuals, communities, institutions) are adequately prepared for managing a hazardous event. Main conclusions highlight that knowledge and mitigation policies are still mainly focused on hazard.

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Partners owning: UNIGE, UNINA, T6, POLIMI, BRGM
Contributions: UNIGE, UNINA, T6, POLIMI, BRGM
Made available to: All project partners, European Commission

Versioning		
Version	Date	Name, organization
0.1		
0.2		
0.3		

Quality check
INTERNAL REVIEWERS:

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List of Abbreviations

AML Arc Macro Language

CPU Central Processor Unit

DEM Digital Elevation Model

DTM Digital Terrain Model

ERS Eruption Range Scenario

GIS Geographical Information System

NOAA NCEP/NCAR National Oceanic & Atmospheric Administration (National Centers for Environmental Prediction/National Corporation for Atmospheric Research)

OES One Eruption Scenario

USGS US Geological Survey

VEI Volcanic Explosivity Index

1 General presentation of the case study

Vulcano is one of the seven islands of the Aeolian archipelago in the Mediterranean Sea (southern Italy) with a surface of about 20 km^2 and about 800 permanent residents (Figs 1.1 and 1.2). The sub-aerial activity of Vulcano started between 135 and 120 ka years ago in the middle of the Aeolian archipelago (Zanella et al. 2001). Volcanism is related to collision of Africa and Eurasia and migrated from S-SE to N-NW generating a composite structure characterized by four, juxtaposed volcanic edifices: Vulcano Primordiale, Lentia, La Fossa cone and Vulcanello, and two polyphasic calderas: Caldera del Piano filled with both effusive and pyroclastic deposits (99.5-48.5 ka) and Caldera La Fossa whose last collapse occurred between 13 and 8 ka in the western and northern sector (Zanella et al. 2001) (Fig. 1.2). Processes of caldera formation are likely to be associated with tensional structures of the Tindari Letojanni fault system (Sbrana 1997). We focus our study on the activity of La Fossa cone, which represents the most current active system on the island. However, we do not exclude an eruption associated with a different vent system (e.g. Vulcanello). La Fossa is a 391 m high quiescent volcanic cone, which was characterized by five different successions separated by clear quiescence periods (Dellino and La Volpe 1997): Punte Nere (surges, tephra deposits and lava flow), Tufi Varicolori (mainly surges), Palizzi (surges, tephra deposits and lava flow), Commenda (PDC, surges and tephra deposits) and activity of the current cone (lava flow, surges and tephra deposits). In particular, the activity of the current cone consists of three units: Pietre Cotte (surges and tephra deposits followed by a rhyolitic lava flow extruded in 1739), post-1739 activity (surges and tephra deposits) and the 1888-1890 eruption (surges, bread-crust bombs and tephra deposits).

Fig. 1.1 Geographical location of the Aeolian islands

The stratigraphy has been revised as part of a collaborative project with the University of Pisa in order to better define hazard scenarios necessary to our risk analysis (Di Tragla 2011). In fact, we have revisited the stratigraphic history of the last 1000 years of eruptive activity of La Fossa cone that is characterized by a wide spectrum of eruptive styles, from effusive to medium-intensity explosive activity. We consider that all these eruptive styles are representative of the entire hazardous phenomena that La Fossa cone could reproduce in the future. We identified three main eruptive periods (successions), with at least twenty-eight discrete eruptions or eruptive events from La Fossa cone. From radiocarbon and archeo-magnetic data (Keller 1970; Arrighi et al. 2006), we established that within each period the events were close in time, causing a large amount of tephra accumulation around the cone, while the time in between each period was long enough to re-mobilize a large amount of pyroclasts, producing widespread lahar deposits in the northern-side of the island (toward Il Porto).

The potential for short warning times and proximity of people on the island to hazards associated with an eruption exacerbate the risk to people and property on the island. Since the end of the last magmatic eruption in 1890, activity at La Fossa cone has consisted of fumarolic emissions, earthquakes and accompanying landslides (these pose a threat of tsunamis), and deformation of the ground (Barberi et al. 1991). Fumarolic fluids are

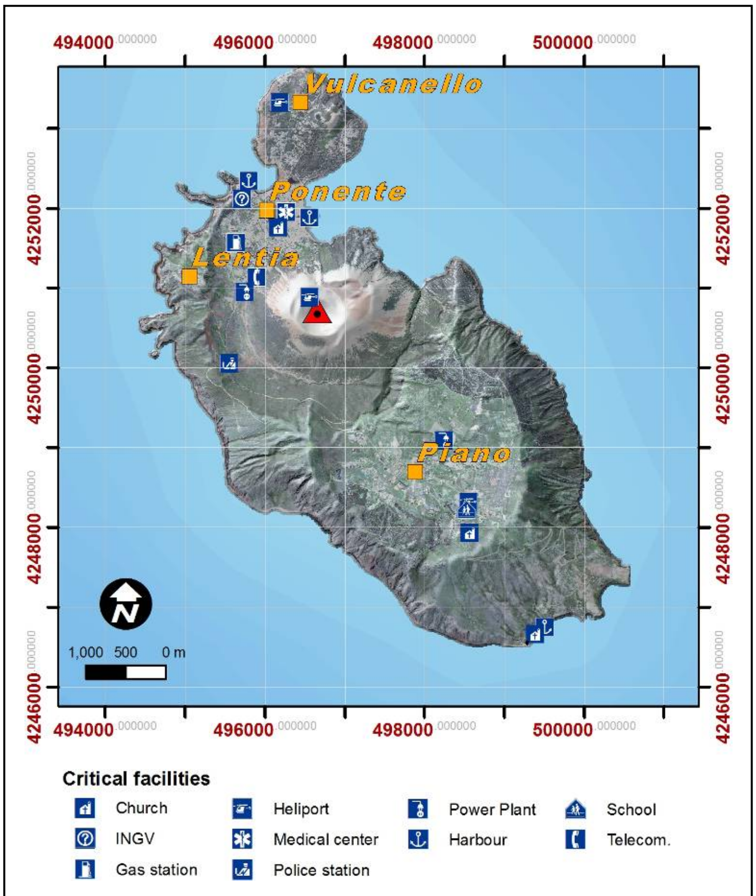


Fig. 1.2 Critical facilities on Vulcano

discharged almost totally in two main fumarolic fields located in the northern rim of the active crater of La Fossa cone and at the beach of Baia di Levante (Porto area; Fig. 1.2). Unrest mostly consists of increasing fumarolic activity and significant fluctuations in the physico-chemical characteristics of the fumarolic system: increase of maximum temperature of the crater fumaroles, changes in the chemical and isotopic composition of the fumarolic gases, variations of CO_2 soil output from Porto area, increase of steam and convective energy from crater fumaroles and increase of temperature and salinity of ground water, which indicates an increase in deep-fluid influx (Barberi 1991; Granieri et al. 2006). Two major episodes of volcanic unrest have occurred since the magmatic eruption of 1888-1890. The first occurred in 1913-1923 with an increase in the crater-fumarole temperature from 200 °C to 615°C (Sicardi 1941). The second one (ongoing) started in 1977 and has been characterized by several fluctuations in fumarole temperature and chemical composition. Between March and June 1988 a high regional seismic activity resulted in the landslide of April 1988 collapsing the coastal side of La Fossa cone into the sea. Following the latter episodes of activity in the late 20th century, increased scientific monitoring of volcanic activity was undertaken by the Italian scientific and Civil Protection agencies. This led to detection of a phase of significant ground deformation on Vulcano in 1990. The deformation was accompanied by increased thermal activity at the crater fumaroles and was probably associated with cooling and crystallization of magma in a shallow reservoir beneath La Fossa (Montalto 1996). In 2004 and 2005 La Fossa crater was affected by new phases of local anomalous seismicity with characteristics similar to the episodes of 1985, 1988 and 1996 and coinciding with peaks of CO_2 flux (Granieri et al. 2006).

The preceding summary of activity at La Fossa clearly demonstrates that the volcano has shown evident signs of potential reactivation, with a slow but constant evolution towards increasing probability of eruption (e.g. Barberi et al. 1991). The need to better understand risk and mitigation strategies is underscored by the fact that there are three populations of people at risk on Vulcano: 1) resident, 2) seasonal migrant workers who provide for 3) visitors, whom, collectively speaking, represent a wide range of ethnic groups and demographics, speaking a host of languages and representing a substantial challenge to effectively respond to warnings of an eruption. Such a warning could involve evacuation from the island or sheltering in place, placing increased value on understanding the physical vulnerability of structures to serve adequately as shelters and the roads and ports to serve as evacuation routes and staging areas.

2 Hazards characterization

Explosive volcanic eruptions typically produce a range of primary hazards, which require independent studies. Amongst these hazards, which are likely to affect humans at different spatial scales, a distinction should be made between 1) hazards with direct deadly effects, 2) hazards with indirect deadly effects and 3) hazards able to disrupt the functioning of human settlements. The first category includes pyroclastic density currents (PDC) and ballistics. Whereas the impact range of ballistics is confined to proximal areas (a few kilometers), lahars and PDC's are able to reach larger distances (tens of kilometers). The second category consists mainly of proximal tephra fallout (i.e., fallout in proximal area), able to cause fatalities through collapse of roofs. As an example, it has been pointed out by Simkin et al. (2001) and Spence et al. (2005) that even though this threat is responsible of only 2% of recorded volcano-related fatalities since AD 1, it has been cited as a cause of death in 21% of volcanic eruptions, making it the most frequently occurring cause of death. In a lesser extent, tephra fallouts are also responsible for significant health complications. The third category includes lava flows and distal tephra deposits, which are able to reach hundreds of kilometers and disrupt socio-economic aspects, environmental aspects and systemic aspects.
Volcanic areas can also be affected by secondary hazards, which are produced as a result of volcanic eruptions, e.g. tsunamis, landslides and lahars. In particular, lahars can also occur long after volcanic eruptions as a result of remobilization of pyroclastic material from rain water. Vulcano Island, with a maximum length of 7 km and an area of 20 km^2, is highly exposed to all these hazards. In order to assess the magnitude, extent and effect of each separate hazard, numerical models help to develop proper land-use planning, emergency management planning and mitigation measures. Coupled with probability analysis, this type of modeling is able to consider the uncertainty associated with different magnitudes of eruption as well as the variability of atmospheric processes.

2.1 Tephra fallout

Tephra fallout is the volcanic hazard with the widest range of impact, this for three reasons. First, on a geographical scale, ground deposition of distal ash can reach distances as large as 100's of km, whereas the finest particles can be injected into global atmospheric patterns. Second, on a time scale, complications induced by ground deposition of tephra can last for weeks after the end of the eruption due to remobilization of the deposit, whereas high concentration of volcanic particles in the atmosphere can last for months. Finally, impacts of tephra deposition vary from proximal (collapse of roofs and buildings) to medial (destruction of vegetation and crops, blockage of roads) and distal (pollution of ground water, effect on livestock) areas. Furthermore, tephra deposition causes complex vulnerability patterns for surrounding populations, both with direct (health problems) and indirect (rapid corrosion of material belongings such as cars, air conditioning systems) effects.
The forecasting of such a hazard strongly depends on two variable factors, namely the type of eruption and the atmospheric pattern during the eruption. A necessary assumption made to model the variability of these parameters is that future activity will be similar to past activity, or will follow a present trend. In this study, the hazard induced by tephra fallout was assessed using the advection-diffusion model TEPHRA2 (Bonadonna et al. 2005) with probabilistic methods developed by Bonadonna (2006). Basics behind probabilistic modeling consist in running the model a large number of times, stochastically sampling at each run a wind profile and a set of eruption parameters within a statistically representative population, allowing to contour the probability of exceeding a given tephra accumulation. The following section describes how the variability of these two parameters was assessed.

2.1.1 Variability of eruptive parameters

A common way of measuring the intensity of explosive eruptions is the Volcanic Explosivity Index scale, or VEI (Newhall and Self 1982). Figure 2.1 shows how the historical eruptive record of La Fossa is dominated by eruptions of VEI 3 (erupted mass of 0.01-0.1 km^3 and plume height from 3-15 km above vent; Newhall and Self 1982). In this study, an Eruption Range Scenario (ERS; Bonadonna 2006) has been considered, where a Monte-Carlo simulation was performed to sample values of erupted mass and plume height within the range specified above (i.e. VEI 3). As shown by figure 2.2, sampling was achieved on a logarithmic scale in order to give a greater probability of occurrence to small events.

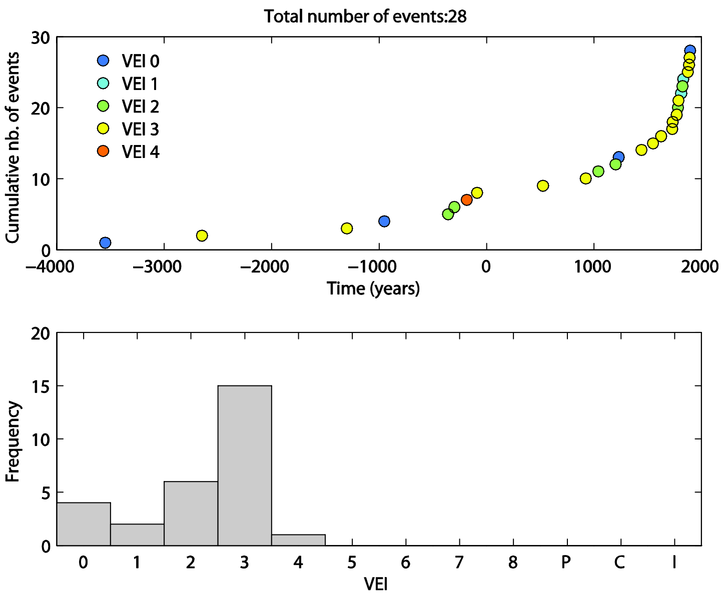


Figure 2.1: *Eruptive history of Vulcano according to the Global Volcanism Program of the Smithsonian Institution(Siebert and Simkin 2002). Recent volcanism is dominated by eruptions of VEI 3.*

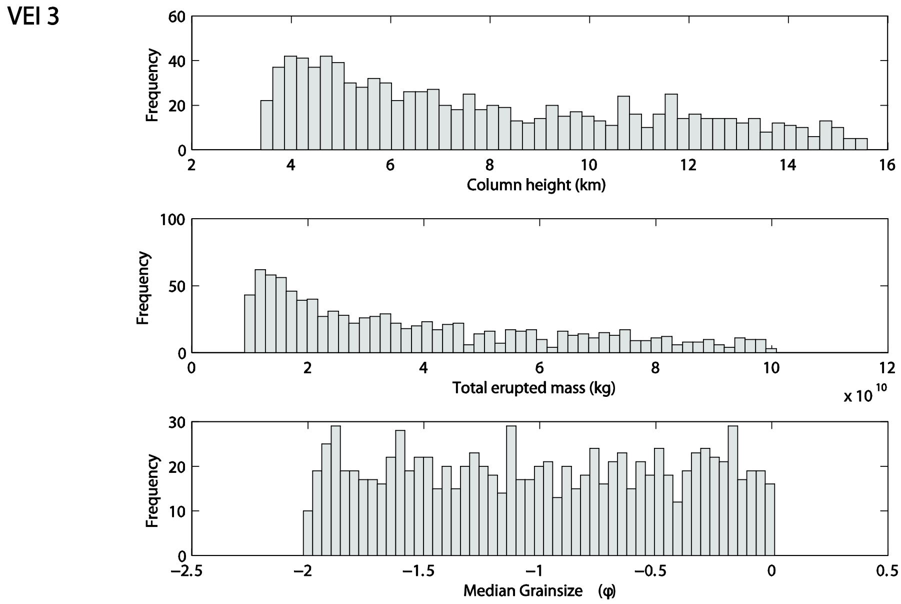


Figure 2.2: *Summary of Monte-Carlo simulations to sample eruptive parameters for an ERS of VEI 3. Sampling is achieved on a logarithmic scale in order to give more probability of occurrence to small events.*

2.1.2 Variability of wind patterns

The NOAA NCEP/NCAR Reanalysis 1 database (Kalnay et al. 1996) was used in this study, which provides 4-daily measurements of wind velocity and direction for 17 pressure levels, from 1948 to present on a 2.5 x 2.5 degrees grid. 10 years of wind have been used here, from 2000 to 2009. Figure 2.3 shows the mean and median wind velocity and wind direction (towards which wind blows) for the 10 years of wind. Figure 2.3 A is presented as the whole population ± standard deviation, and Figure 2.3B represents each year separately. Figure 2.4 shows the probability of the wind to blow in a given direction at a given velocity. Figures 2.3 and 2.4 mainly show wind blowing towards east and south-east.

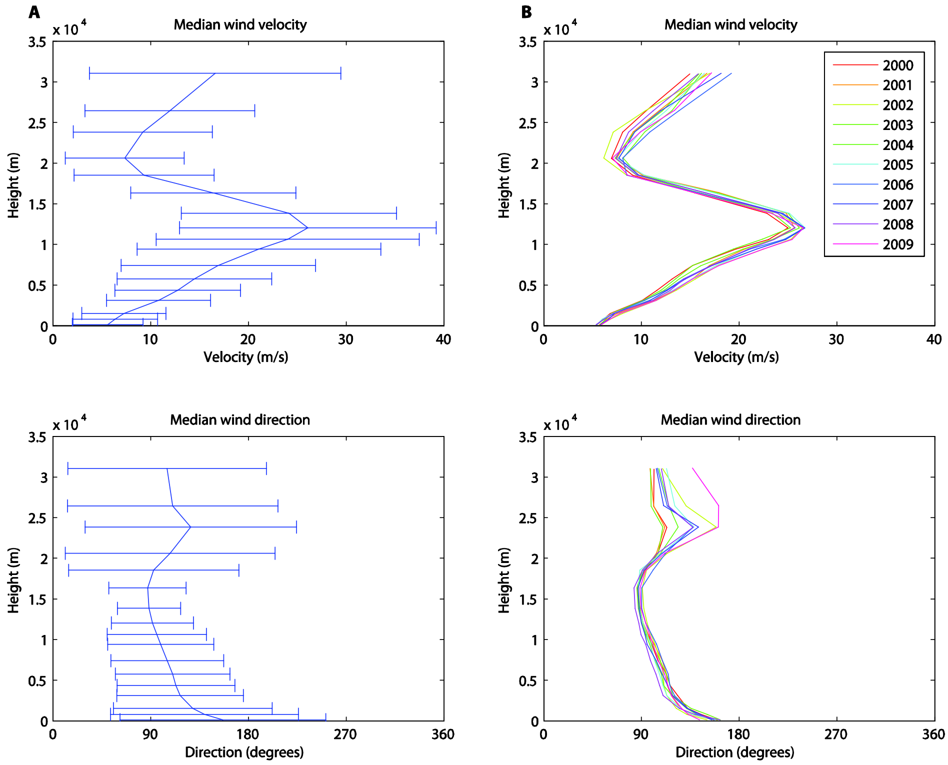


Figure 2.3: *Wind profiles inferred from the NOAA/NCEP Reanalysis 1 database, showing mean and median values of wind velocity and wind direction (direction where wind blows to) for* ***A*** *the whole wind population (2000-2009) ± standard deviation and* ***B*** *each separate year.*

2.1.3 Results

The overview of the modeling framework is presented in Table 2.1. Table 2.2 shows the input eruptive parameters used for the numerical model TEPHRA2.

Figure 2.5 shows the resulting probability maps of exceeding a given hazardous threshold of tephra accumulation for an eruption of VEI 3, considered as being the most likely scenario (Fig. 2.1). Maps presented here were compiled for four critical hazardous thresholds:

- Map A: 1 kg/m^2, critical value for airports and air traffic (Bonadonna 2006)
- Map B: 10 kg/m^2, critical value for vegetation and crops (Blong 1984)
- Map C: 100 kg/m^2, critical value for collapse of weak roofs
- Map D: 300 kg/m^2, critical value for collapse of strong roofs.

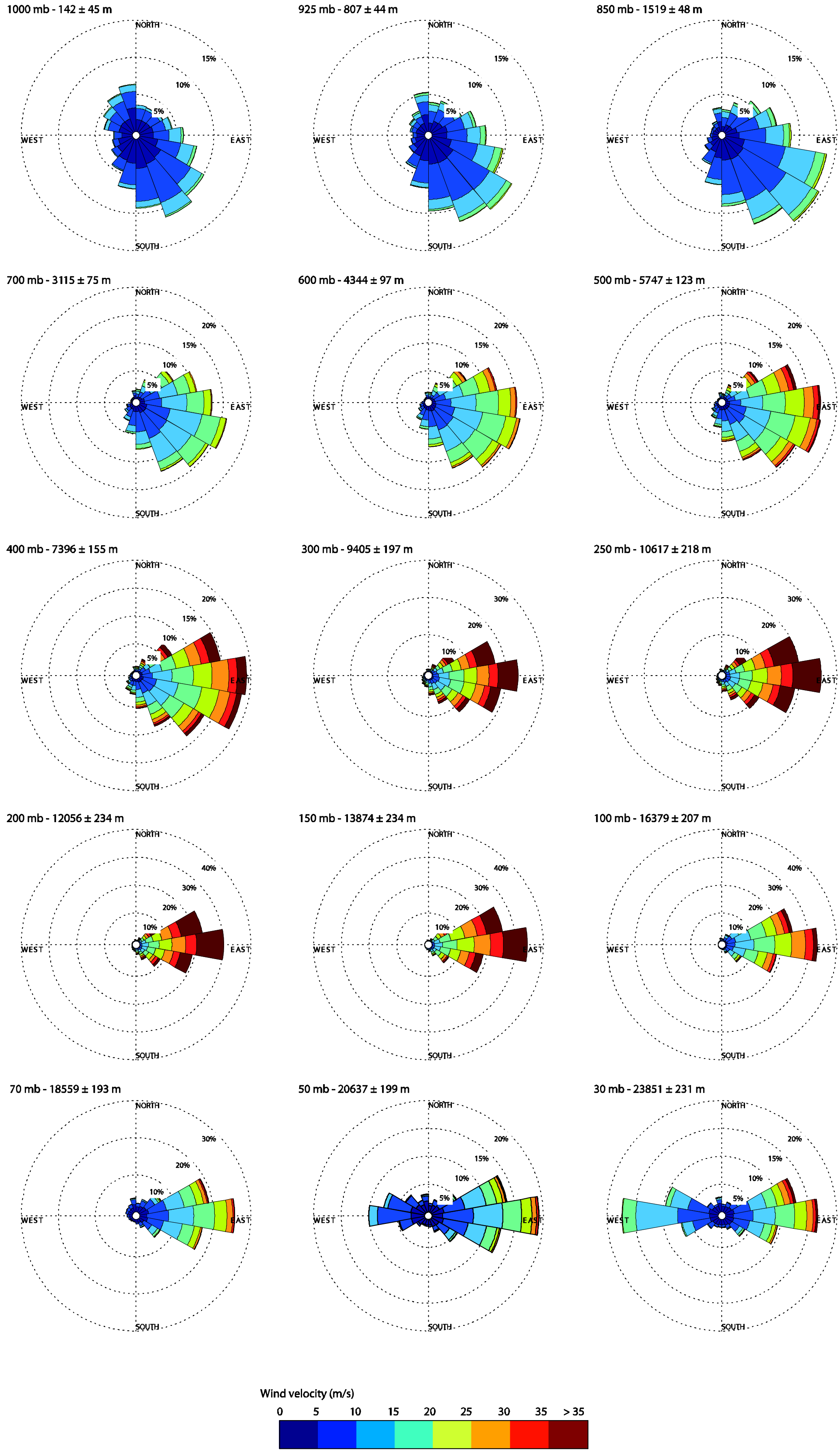


Figure 2.4: *Probability of wind blowing in a given direction at a given velocity. Bins are 20°.*

These maps, in agreement with wind patterns presented in Figures 2.3 and 2.4, show how most of the dispersal is directed towards south-east, with significant sedimentation in the town of Il Piano. Figure 2.5A shows that 95% of the island has a >90% probability of reaching an accumulation of tephra of 1 kg/m^2. Figure 2.5B shows that the same proportion of the island has a >80% probability of reaching 10 kg/m^2 of tephra. Figure 2.5C and D show that the town of Il Piano has a probability of 40-60% to be affected by roof collapse.

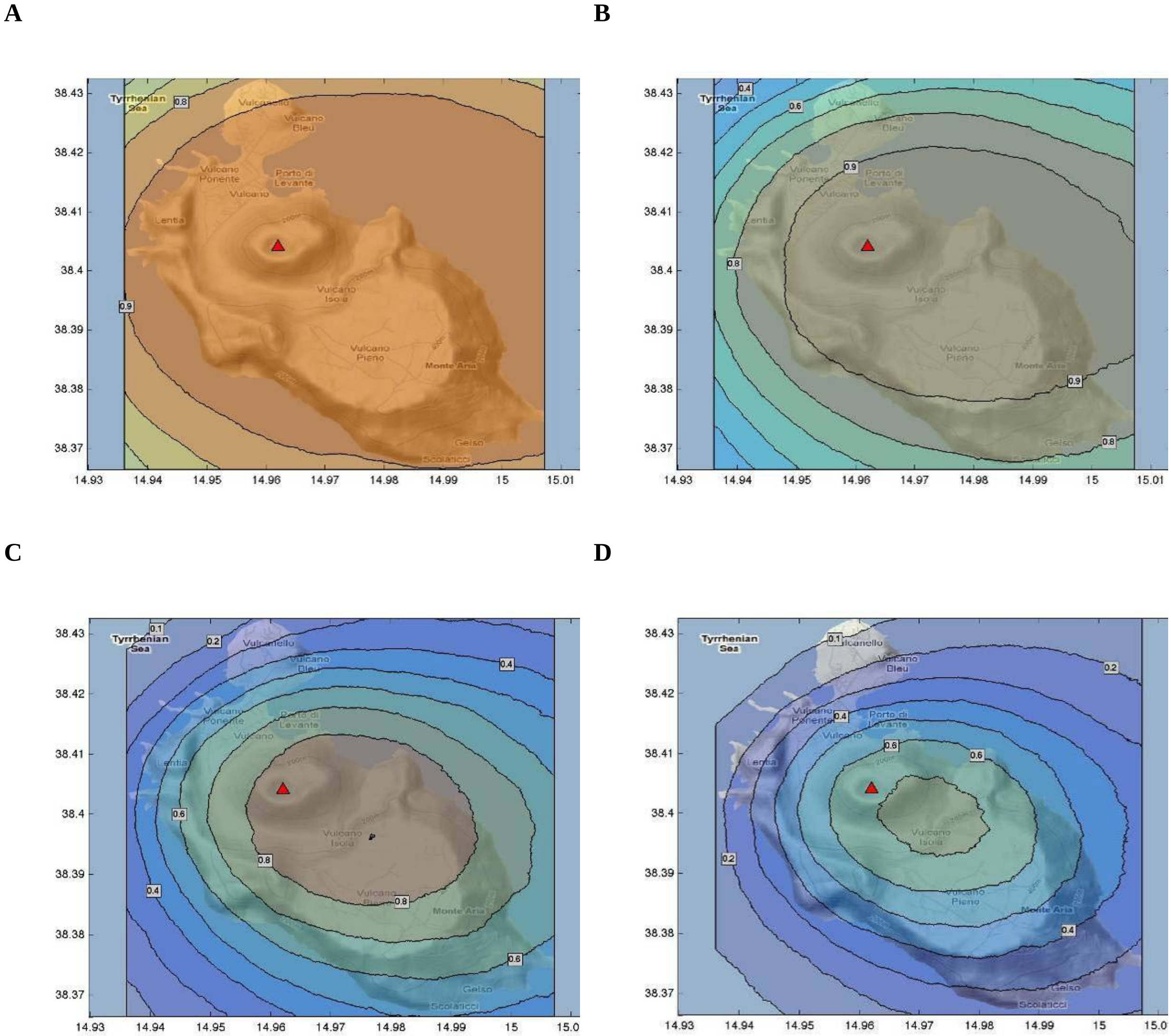


Figure 2.5: *Probability maps for an ERS of VEI 3, showing the probability of exceeding a given tephra accumulation for **A** 1 kg/m^2 (blockage of air traffic); **B** 10 kg/m^2 (impact on vegetation and crops); **C** 100 kg/m^2 (impact on weakest roofs); **D** 300 kg/m^2 (impact on strongest roofs).*

Figure 2.6 shows hazard curves compiled for critical facilities and localities specified in Table 2.3. As an example, it shows that the school in Piano has a 50% probability to be affected by a tephra accumulation of 300 kg/m^2 (roof collapse). One of the heliports is also at the same location, with obvious consequences for the landing of aircrafts. In order to assess the dispersal of tephra resulting from probabilistic modeling, isomass maps for a given probability were compiled. Figure 2.7 presents the resulting maps for probability thresholds of 50% and 90%. Figure 2.7 A shows that in the case of an isomass fixed for a probability of 50%, 90% of the island is covered by an accumulation of 100 kg/m^2 of tephra.

Vent coordinates (UTM)	Easting: 496682
	Northing: 425064
	Zone: 33 S
Grid X_{min} (UTM)	494410
Grid X_{max} (UTM)	500620
Grid Y_{min} (UTM)	4246460
Grid Y_{max} (UTM)	4253800
Grid resolution (m)	10
Grid size (lines, columns)	622 x 735
Wind data	NOAA NCEP/NCAR Reanalysis
	1/1/2000 to 31/12/2009
	4 wind profiles per day
Number of runs	1000

Table 2.1: *Modeling framework used in this hazard assessment.*

Plume height (m a.s.l.)	3500-15500
Erupted mass (kg)	$1x10^{10}$-$1x10^{11}$
Median grain size (Φ)	-2-0

Table 2.2: *Boundary values for Monte-Carlo simulations for sampling eruptive parameters for ERS modeling. Φ is a logarithmic measure of grain size, where each increase of the class corresponds to a decrease in grain size by a factor ½. -2Φ = 4 mm, 0Φ = 1 mm.*

	Easting (UTM)	Northing (UTM)
Porto Levante	496537	4251812
Porto Gelso	499531	4246728
School of Piano	498572	4248246

Table 2.3: *Coordinates of critical facilities used to compile hazard curves.*

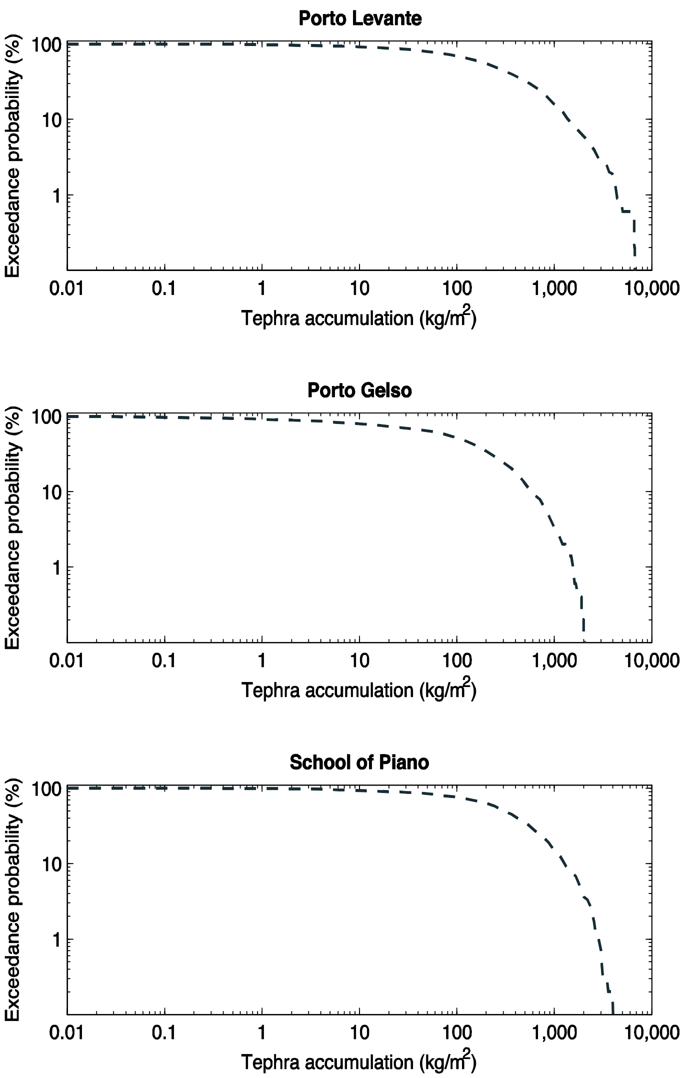


Figure 2.6: *Hazard curves compiled for the three locations defined in Table 2.3 and shown in Figure 2.5.*

2.2 Lahars

Vallance (2000) describes four conditions required for lahar generation: 1) an adequate water source, 2) abundant unconsolidated debris, 3) steep slopes and 4) a triggering mechanism. Whereas conditions 2 and 3 are often fulfilled on volcanic edifices after an explosive eruption, condition 1 highly depends on atmospheric processes, which is closely related to the geographical situation and/or the season. Neglecting the fact that water saturation can itself be a mechanism of lahar triggering (Pierson 1998), it is possible to assess possible zones of lahar generation using an accumulation map of tephra deposition (as presented in Fig. 2.7) combined with a precise digital elevation model (DEM) and assuming i) a water saturation of the deposit, ii) a simple Mohr-Coulomb failure criterion to describe slope failure (Volentik et al. 2009; Iverson 2000).

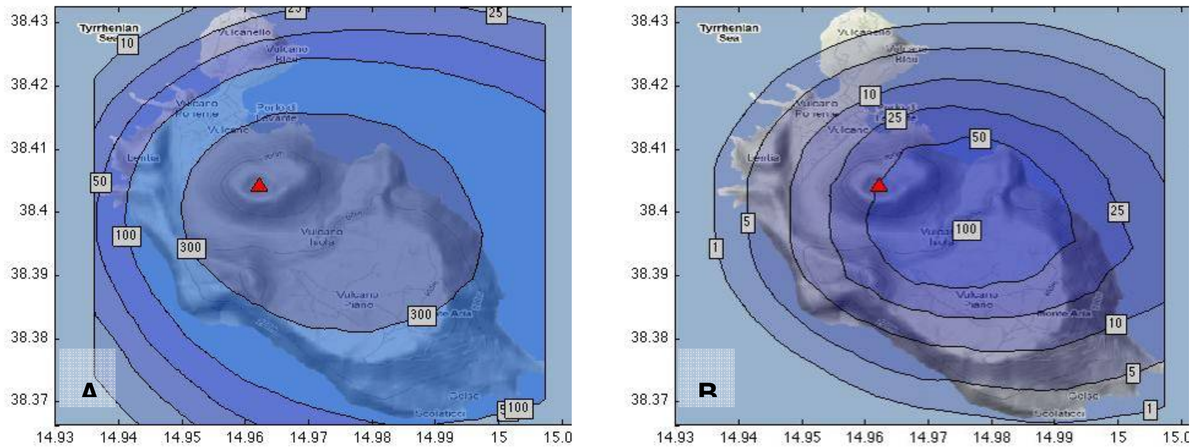


Figure 2.7: *Isomass (kg/m^2) for given probabilities for **A** 50% and **B** 90%.*

Figure 2.8 shows zones of instability associated with an isomass map for a 50% probability. From this map, the volume of loose material likely to be remobilized into lahars on the cone only is 7.1×10^5 m^3, assuming a density of the deposit of 1000 kg/m^3. Such a volume has been split with respect to the drainage network according to the areal extension of the drainage sub-basins.

An in-depth review carried out on the methods used in current literature to calculate the run-out of debris-flows has shown the existence of different solutions based on empirical methods and physical models. Due to the similarities shown with landslides, many computer-based modeling tools developed for landslides have also been applied to lahars. The spatial features of such a phenomenon has made convenient to couple the mentioned models with Geographical Information System (GIS) applications. In this respect, the US Geological Survey (USGS) has supported "LAHARZ", a GIS program using Arc Info Grid and Arc Macro Language (AML) for automated mapping of lahar-inundation hazard zones. The program was created by Schilling (1998) and developed on the basis of the model of Iverson et al. (1998) that predicts inundated valley cross-sectional and planimetric area as functions of lahar volume[1] (Fig. 2.10). In detail, using a DEM and several values of lahar volumes, LAHARZ employs the above mentioned equations to delineate, for user-selected stream drainages, a set of nested, lahar-inundation hazard zones. LAHARZ has been preferred to other models (eg. Titan2D) because of its easier and faster application and because it appears to provide a reliable spatial distribution (Franco et al. 2010).

[1] In detail, according to the model of Iverson et al. (1998), the area inundated by a lahar of volume V (m^3) is $B=200\ V^{2/3}$

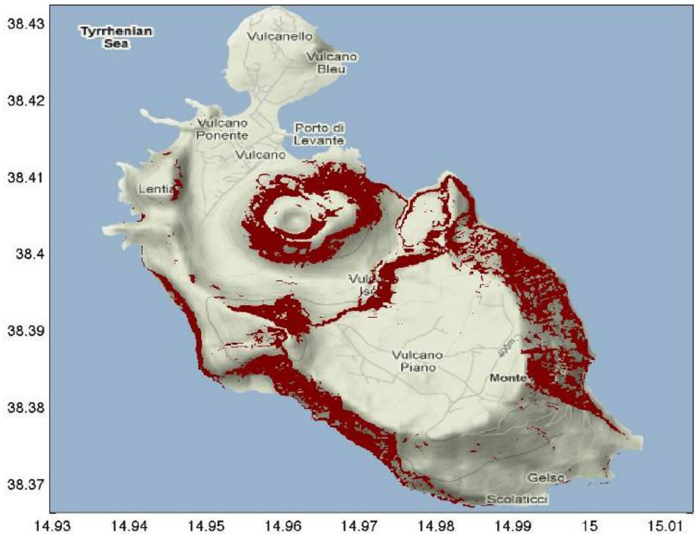


Figure 2.8: *Zones of slope instability assessed with a Mohr-Coulomb failure criterion on a water-saturated deposit.*

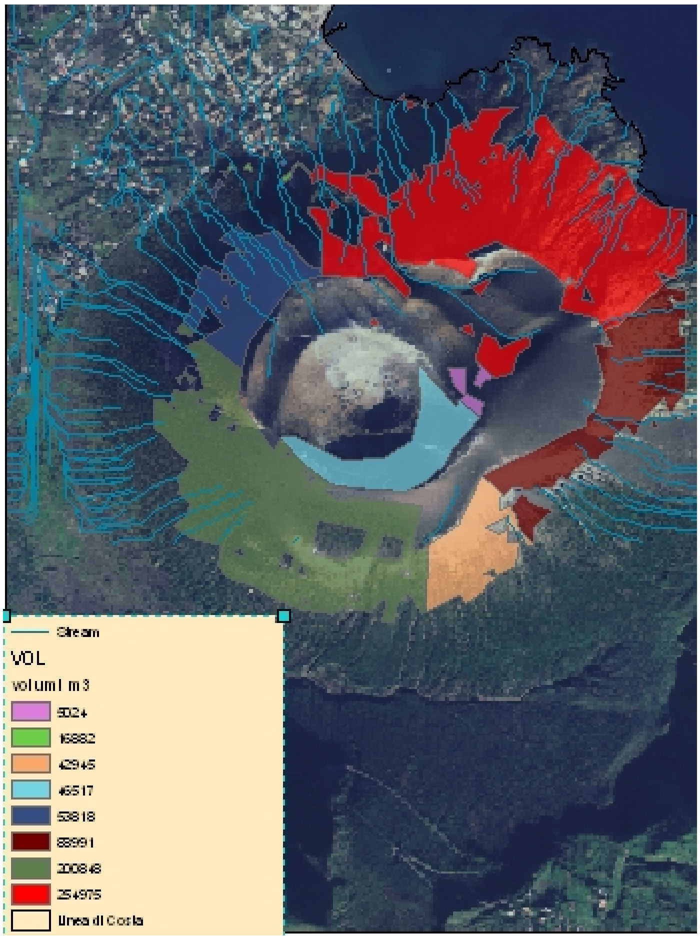


Figure 2.9: *Volume sharing of a VEI=3 event according to the drainage basins;*

blue lines represent the drainage stream network

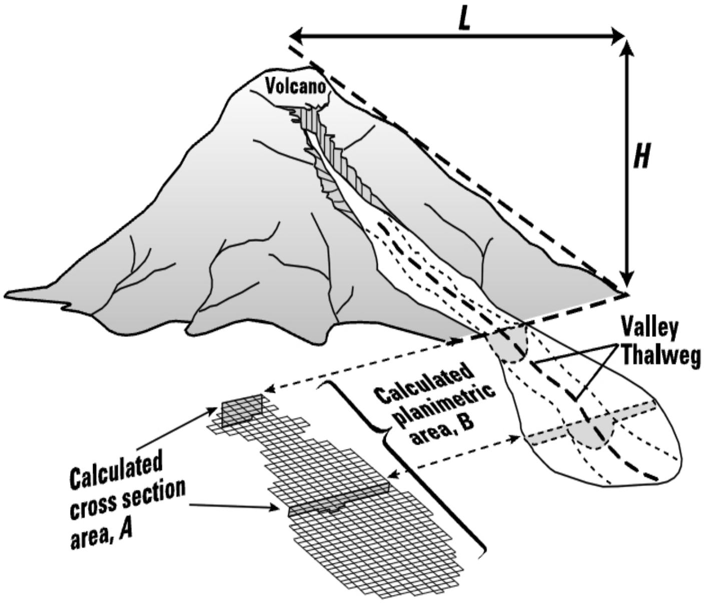


***Figure 2.10:** An idealized lahar path and geometric representation of the proximal hazard zone (given by the relationship between H and L) and the distal lahar-inundation hazard zone (Iverson et. al.1998)*

In line with the main objectives of the ENSURE project (e.g., to provide and test an integrated framework for the assessment of vulnerability of territories), the attention of the analysis has been focused on the northern part of the island that is the most interesting in terms of vulnerability, due to i) the presence of some critical elements/targets (e.g. electrical power plant, harbour infrastructures of *Porto di Levante*), ii) the high building density and iii) the proximity to the volcano of a group of buildings[2], located at the foot of the volcanic cone along the line of a main valley.
Hence, starting from a selection of some likely trigger points that have been established based on topographic and land cover criteria within the identified lahar source area, and, according to some main drainage channels, the potential inundated zones by lahars including the above mentioned targets have been simulated using the model LAHARZ.
The selected trigger points (A, B, C, D, E; Fig. 2.11) are closely and univocally linked to the main drainage channels (better defined starting from the central sector of the cone). Nevertheless, it should be underlined that the drainage network in the upper part of the cone is characterized by secondary streams flowing into the main channels. For this reason, the images provided as a result of LAHARZ elaboration have been later integrated with other (narrow) paths with the only aim of showing the direct connection with the lahar source region. It is worth noting that lahars, as debris flows, might be multi-site phenomena with more than one trigger in the same span of time. Consequently, different flows can merge in the plain area if they are near to each other.
The results of LAHARZ simulation are shown in the figure below (figs. 2.12, 2.13, 2.14, 2.15, 2.16, 2.17).

[2] This group of buildings represents an element of interest also with respect to the vulnerability assessment of landslides.

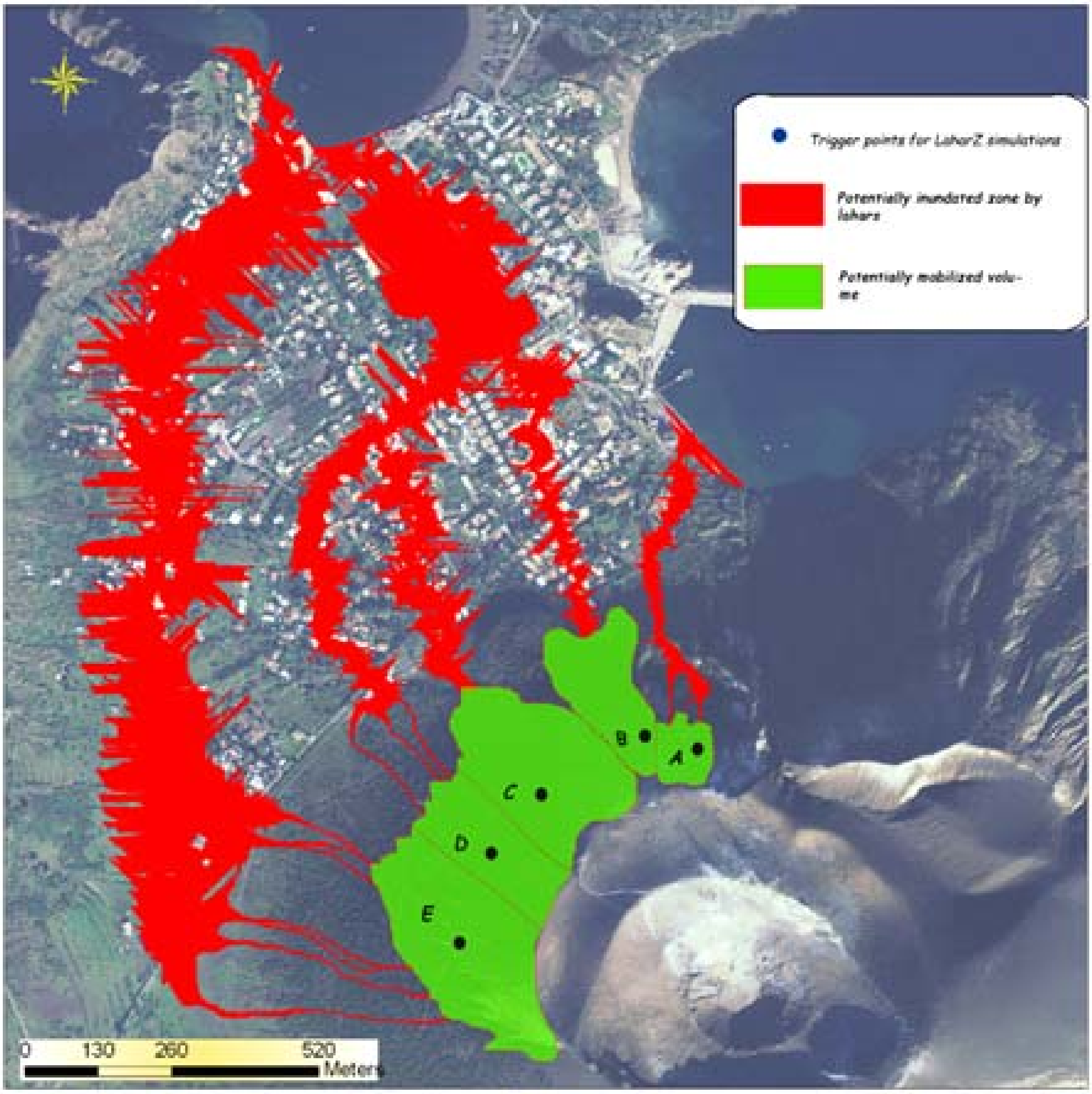


Figure 2.11: *Overall sketch of LAHARZ simulations including source areas, trigger points and inundate zones*

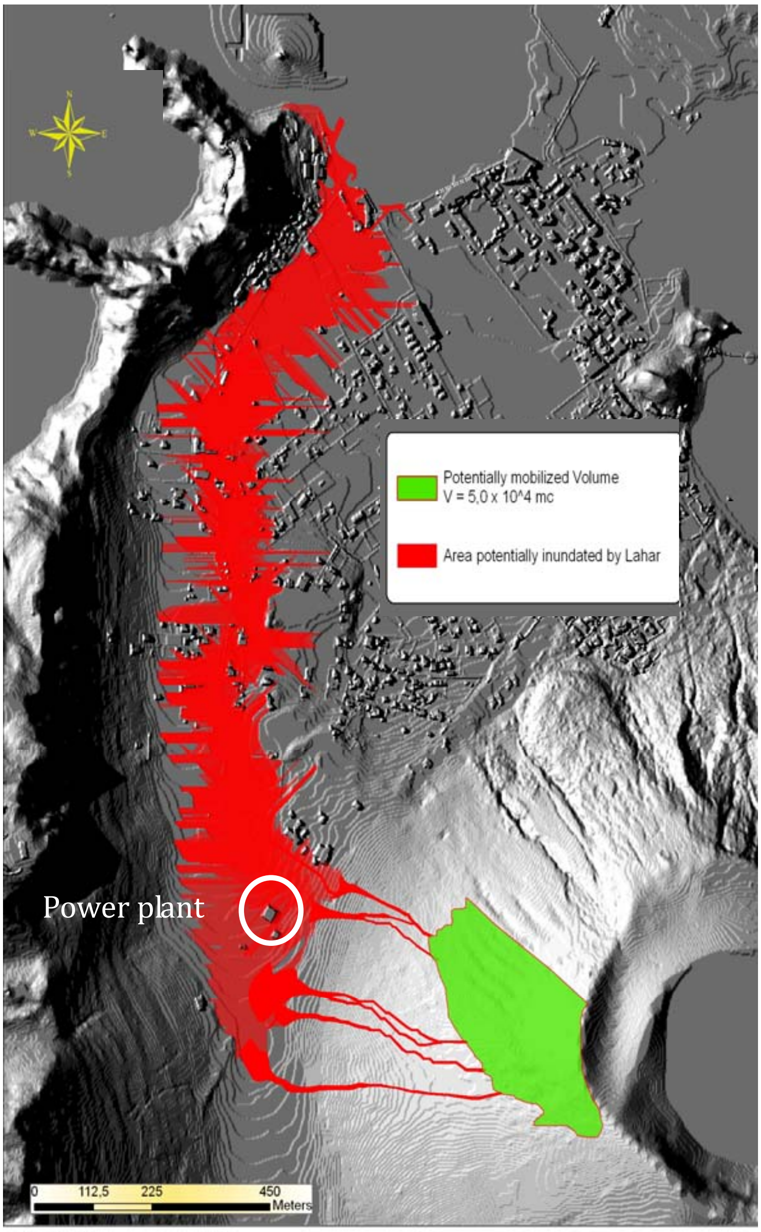
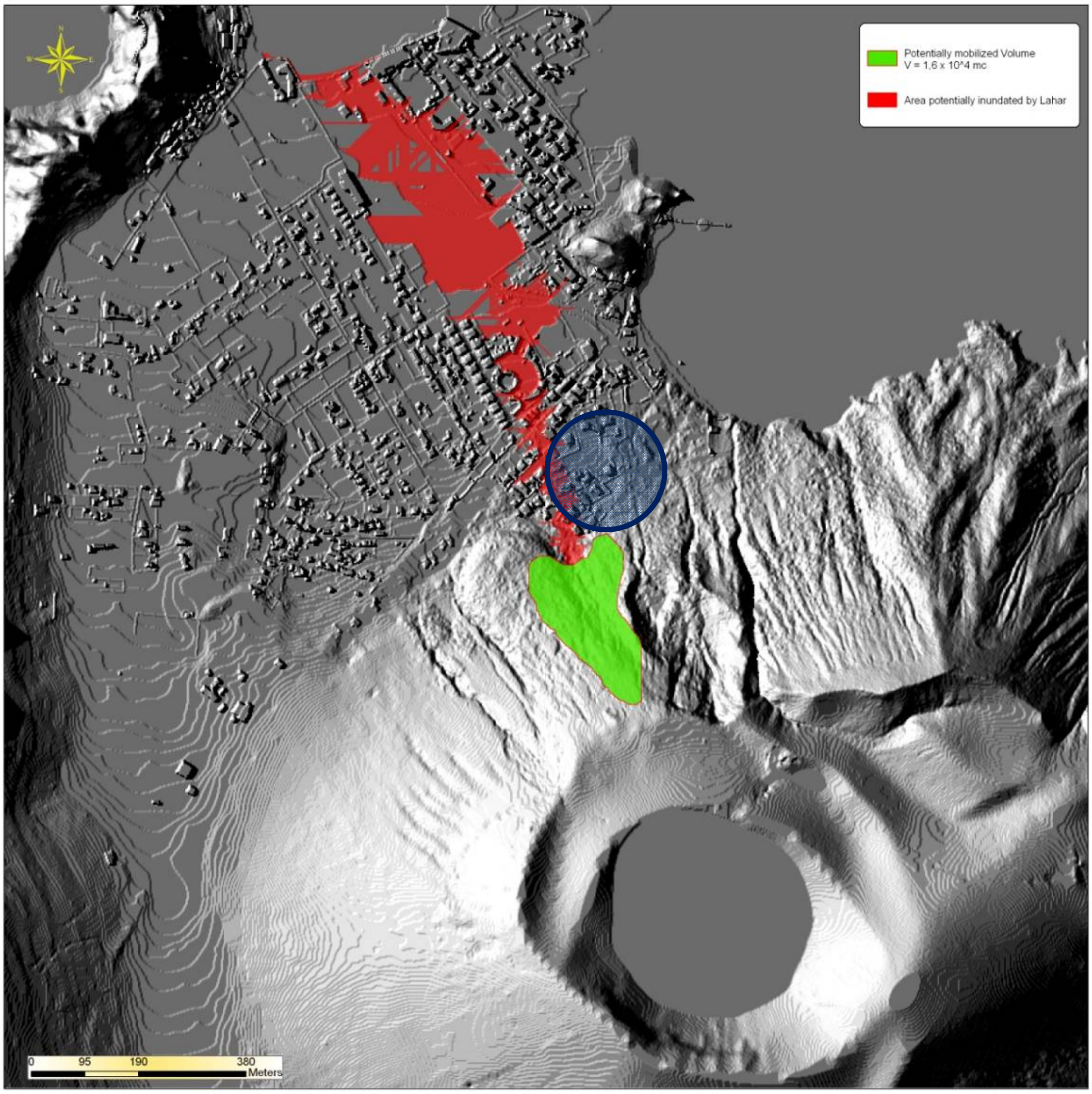


Figure 2.12: *Lahar path impacting the electrical power plant (scenario E)*



Figures 2.13 & 2.14: *Lahar path impacting the urban fabric at the toe of the cone (scenario "B") and a related aereal photo*

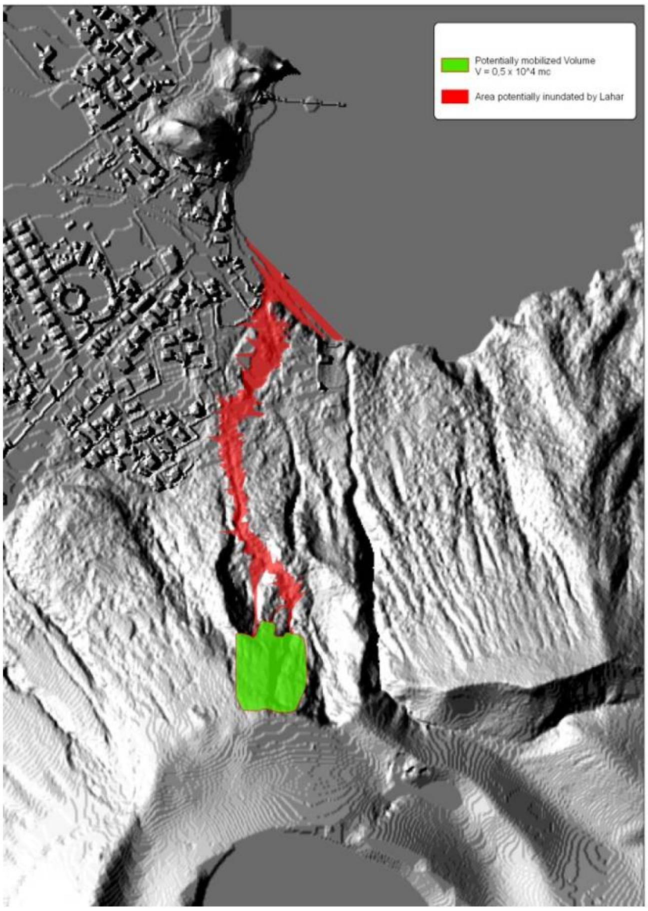
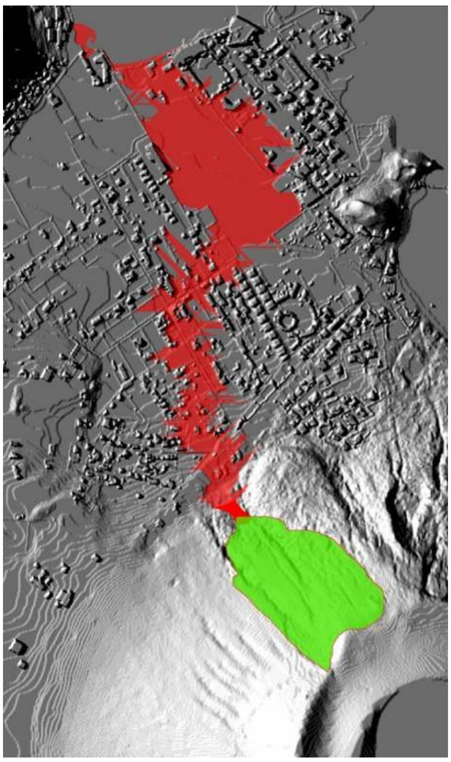
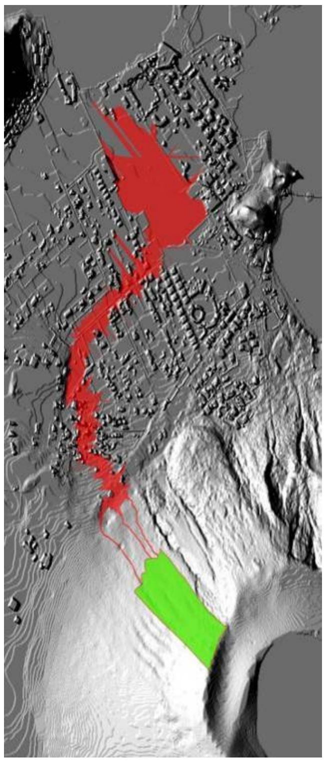


Figure 2.15: *Lahar path surging towards the sea with likely consequences on the activity of the port (scenario A)*

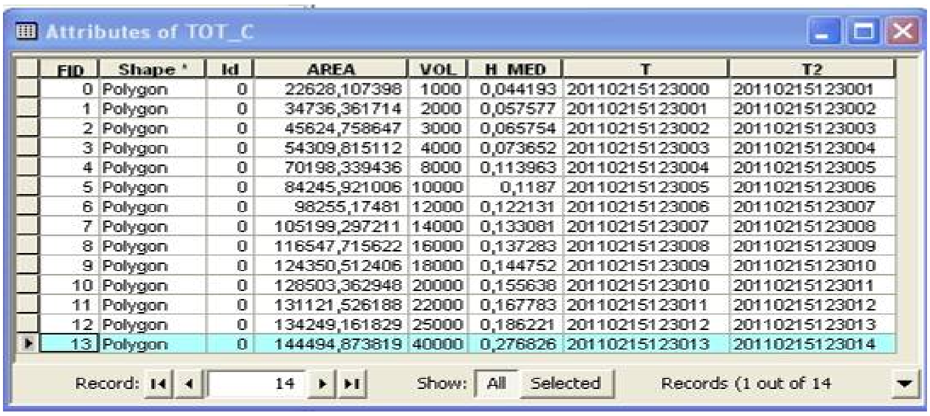




Figures 2.16 & 2.17: *Other lahars paths impacting the residential area (scenario "C" and "D")*

Some considerations can be made with respect to the proposed scenarios.

1. Boundaries of the inundation zones may widely vary according to the level of detail of the used Digital Terrain Model (DTM). In fact, a larger scale allows to take into account also some minor elements, such as retaining walls, that acting as an obstacle to the flow, modify its path.
2. In terms of force of impact, the scenario "D" is expected to be the most severe due to the fact that the lahar flow is supposed to have a high velocity determined by the narrow dimensions of the channel and to the sudden change of the gradient slope.
3. The scenario "C" shows a path that surges forward the sea. Although such a scenario entails only marginally residential buildings, the effect of a flow entering the sea should not be under-estimated. In fact, a huge quantity of mud in the sea can result into perturbations of the sea conditions which can prevent the ships from wharfing or moving close to the coast during the emergency phase;
4. LAHARZ simulations do not provide any information about velocity. Nevertheless, for a given value of volume, the related inundated area can be derived. As a consequence, by a simple division between the volume (m^3) and the area (m^2), it is possible to get an approximate value of the medium height (m) of the deposit within that area. It is clear that the smaller is the considered area, the more reliable is the derived height of the deposit. For this reason, it might be useful to make a particular simulation by limiting the footprint of the lahar to a given "distance" from the source, for example referred to the first group of buildings at the toe of the volcano.


Attributes of TOT_C

FID	Shape *	Id	AREA	VOL	H_MED	T	T2
0	Polygon	0	22628,107398	1000	0,044193	20110215123000	20110215123001
1	Polygon	0	34736,361714	2000	0,057577	20110215123001	20110215123002
2	Polygon	0	45624,758647	3000	0,065754	20110215123002	20110215123003
3	Polygon	0	54309,815112	4000	0,073652	20110215123003	20110215123004
4	Polygon	0	70198,339436	8000	0,113963	20110215123004	20110215123005
5	Polygon	0	84245,921006	10000	0,1187	20110215123005	20110215123006
6	Polygon	0	98255,17481	12000	0,122131	20110215123006	20110215123007
7	Polygon	0	105199,297211	14000	0,133081	20110215123007	20110215123008
8	Polygon	0	116547,715622	16000	0,137283	20110215123008	20110215123009
9	Polygon	0	124350,512406	18000	0,144752	20110215123009	20110215123010
10	Polygon	0	128503,362948	20000	0,155638	20110215123010	20110215123011
11	Polygon	0	131121,526188	22000	0,167783	20110215123011	20110215123012
12	Polygon	0	134249,161829	25000	0,186221	20110215123012	20110215123013
13	Polygon	0	144494,873819	40000	0,276826	20110215123013	20110215123014

Record: 14 Show: All Selected Records (1 out of 14

Figure 2.18: *A table of attributes of inundated area by lahar showing the possibility to get, through some hypothesis, a mean value of the height (in meters) of the flow (detail from a GIS elaboration).*

In other words, such an area could be limited in the upper part, by choosing a trigger point located in a lower part of the cone and modifying the contour lines of the foot of the slope (by suddenly increase the value of the contour elevation) in order to create an obstacle to the flow and limit the run of the program. In such a way, it can be possible to point out the area in which the height of the flow exceeds a given height. The results of these considerations are shown in Figure 2.19.

It should be pointed that the response of buildings can depend greatly on the characteristic of the lower floors, besides obviously on the type of foundation, and that, as a consequence, the height of the flow can be very important to define the type of vulnerability and the expected level of damage to a given event. In the latter case, the features of the flow also play an important role. The displacement following a given impact is related to different parameters, amongst which the height of the flow[3].

5. Figures showing LAHARZ runs consider the maximum mobilized volume calculated for every sector of the probably source area of lahars placed around the cone of the volcano. Nevertheless, simulations have also been carried out using lower volume. This exercise proved to be very useful, as it shows how some of the established target can be impacted by a lahar flow even for values of volume significantly smaller than the maximum estimated volumes. For example, referring to scenario "D", the group of buildings at the toe of the cone would be impacted even for a volume equal to 1000 m^3 (Fig. 2.22). To sum up, in order to carry out a vulnerability assessment, it is very useful to work referring to a likely scenario. Such operation has been led by fixing some hypothesis and simulating events through the LAHARZ model that results quite reliable in respect to the spatial distribution of the phenomena. These results represent a starting point for an in-depth analysis on the different facets of the vulnerability of the island in face to lahar events.

LAHARZ program and the construction of DEM

LAHARZ is a GIS-coupled model based on the description of Iverson et al. (1998), which requires a Digital Terrain Model (DTM) and user-specified lahar volumes for mapping areas of potential lahar inundation.

Boundaries of the inundation zones strongly depend on the resolution of the DTM.

Thanks to the availability of geographical data at different scales for different parts of the Italian territory, the 2-m resolution DTM used here has been produced as a mosaic of data with a different levels of accuracy. The DTM has been made uniform on a 2-m grid using the following available data:

- a 1 m resolution DTM in the north part of the island;
- a 2 m resolution DTM in the N-E part of the island as stemmed by the cartography of the Sicilian Region* at the scale 1:2000;
- a 5 m resolution DTM is the other parts of the island.

Considering that the area of study for the vulnerability assessment is included into the area at the scale 1:2000, data have been elaborated in order to obtain a 2 m resolution DTM.

Starting from the original DTM, a cloud of points (one for every pixel), have been generated for every area with a different level of accuracy. Such a cloud of points (with 1, 2 and 5 m of spatial resolution) was overlapped and re-sampled by an interpolation process based on the natural neighbor algorithm in order to produce a DTM with a uniform level of accuracy.

Another problem arose from the lack of topographic attribute of the urban fabric in the aerophotogrammetry at a 1:2000 scale. The missing height above ground level of these elements was therefore obtained by a photo-interpretation based on available data. In the latter respect, our in-situ survey has provided the characteristics, including the number of floor of some buildings in the chosen area of study. Such buildings have been supposed to have a floor height equal to 3m. By an analysis of the shadows related to these buildings with known height, the height has been assigned to every building in the studied area.

Considering that the LAHARZ model works only with integer value, a height of 1 m has been assigned to walls, whereas a height of 2 m was assigned to retaining walls. A 2 m raster matrix was generated including the height value of the aerophotogrammetric cartography. The final model** used for LAHARZ elaboration has been obtained by summing this matrix (aerophotogrammetric raster in which the value of pixels refers exclusively to the heights of buildings) and the matrix associated to the previous DTM reporting the contour elevations.

* In this respect, a specific requested was made to Regione Siciliana by UNINA team.

** The model takes into account the morphological surface and the urban fabrics but ignores vegetation.

[3] Other important parameters of the flow that play an important role in the occurrence and the intensity of damage are the debris flow density (r), the width of the flow (b), the area hit by the flow (A) and the speed (v).

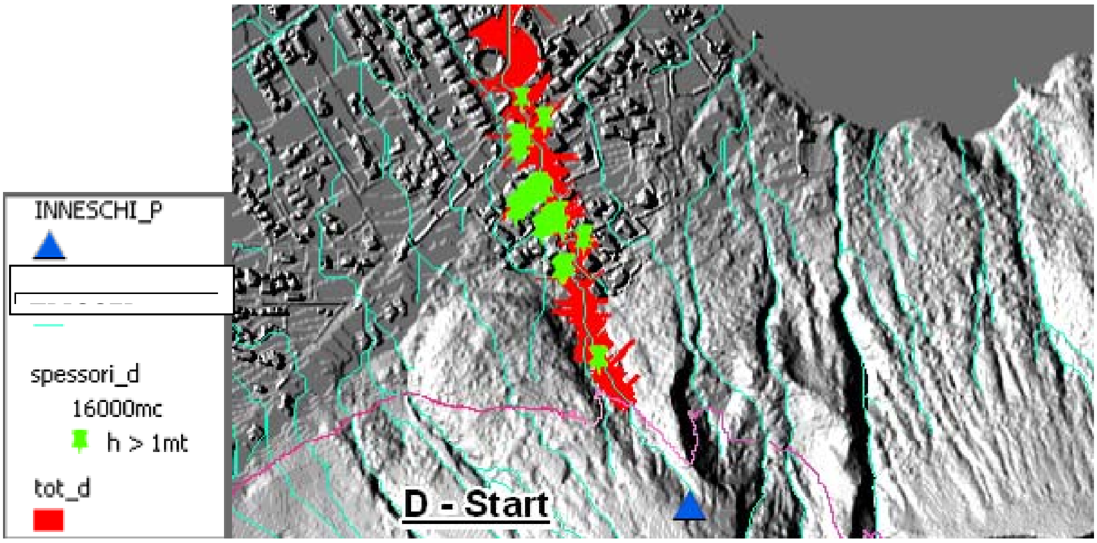


Figure 2.19: A snapshot of a possible result of the simulation implemented to get the height of the flow in a given area.

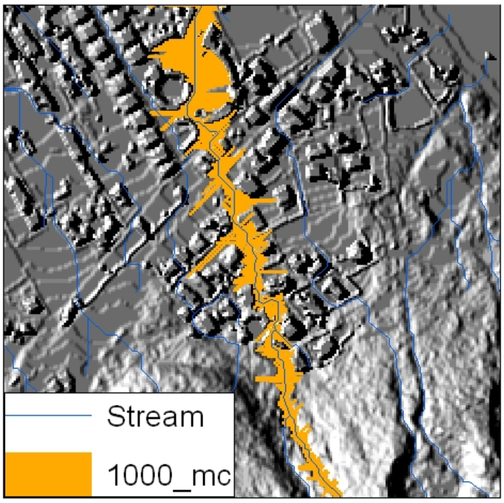


Figure 2.20: Details of scenario "D" limited to a volume equal to 1000 m^3

2.3 Ballistics

Ballistics ejectas, represented by rocks with diameters of at least 15-20 cm blown at velocities of tens to hundreds of meters per second, are common hazards in the vicinity of the active vent and can affect surrounding populations in two main ways. First, although rarely, ballistics are easily capable of causing lethal skull injuries due to their high terminal fall velocities. Second, hot ballistics commonly ignite fires due to their high temperature, thus threatening both physical and environmental aspects. The hazard assessment for ballistics presented here considers two possible scenarios elaborated from field observations coupled with a discrete events numerical model.

2.3.1 Method of Calculation

In our model, particle trajectories are fully analytically implemented in three dimensions. The movement of particles can be modeled using discrete time approaches (Wilson 1972; Alatorre-Ibargüengoitia and Delgado-Granados 2006) and detecting collisions at each time step. This results in a time complexity of $O(n^2t)$ where n is the maximum number of bombs in

flight and *t* is the number of time steps. Since collisions are uncommon, this approach wastes CPU cycles with unnecessary checks. Instead, we used a discrete events method to model three types of events: ejections, collisions and depositions. Each event time is calculated analytically for each pair of two particles, and event times are sorted by chronological order. During the simulation, the simulator jumps from one event to the next and the trajectory is calculated between these two events. The remaining events may be updated or deleted when a new event is scheduled. Ultimately, calculation of trajectory is faster because the whole trajectories (parabolas) are compared in one step, lowering the complexity to $O(n^2c)$ where c is the actual number of collisions. Another advantage of our model is that the collision detection and the trajectory calculation are fully analytical. Therefore we do not miss the collision which is possibly missed by the discrete time step method when the collision happens in between the time steps.
For the context of volcanoes, one next step would be to assess the topographic effect of ballistic trajectories. However, if detailed topographical data are considered, advantages of our type of simulations (analytically and fast calculation by event based time step) is lost. In order to simplify, we used a topographical model where the crater is at an altitude of 350 m a.s.l. and habitations are at sea level. If the particle arrives at the larger distance than radius of crater area, they are transported to sea level.

2.3.2 Input parameters

Ballistic trajectories were calculated using input parameters in Table 2.4.

Parameter	Units	Value
Total Particle Number	-	1000
Average of Density	kg/m^3	2000
Standard deviation of Density	kg/m^3	500
Average of Particle diameter	cm	20
Standard deviation of Particle Diameter	cm	80
Standard deviation of displacement of ejection point. (0,0) is crater center	m	100
Crater altitude	m	350
Radius of crater area	m	400

***Table 2.4**: Input modeling parameters for the ballistic assessment*

Grainsize distribution

Particle size distribution was decided based on the field work carried out in Vulcano (May 2010) (Fig. 2.21). Axes of selected blocks were measured in the field. From these field data, mean of 3 axes is considered as a representative value of particle diameter. From this distribution of field data, a mean of 20 cm and a standard deviation of 80 cm were derived.

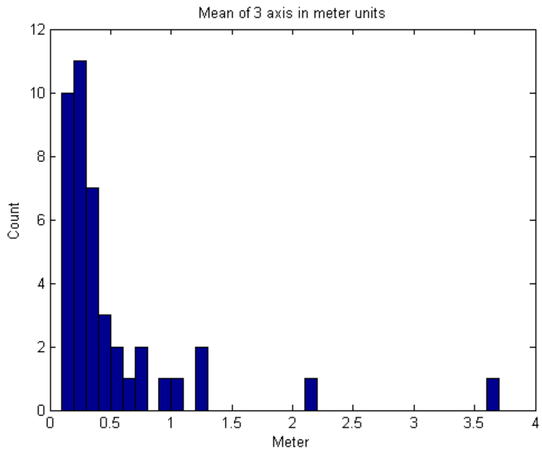


Figure 2.21: *Histogram of particle diameter (m) obtained from field study. 42 blocks were measured around the volcano on a uniform grid of 30 x 30 m.*

Block density

Density distribution was also defined from field observations (Fig. 2.22). Volumes of blocks were calculated using the following equation:

$$V = \frac{4}{3}\pi abc$$

where V is the volume of block and a, b and c are 3 axes of blocks. The density was obtained by dividing the block mass by the volume. Mean of this distribution is 2234 kg/m^3 and standard deviation is 550 kg/m^3.

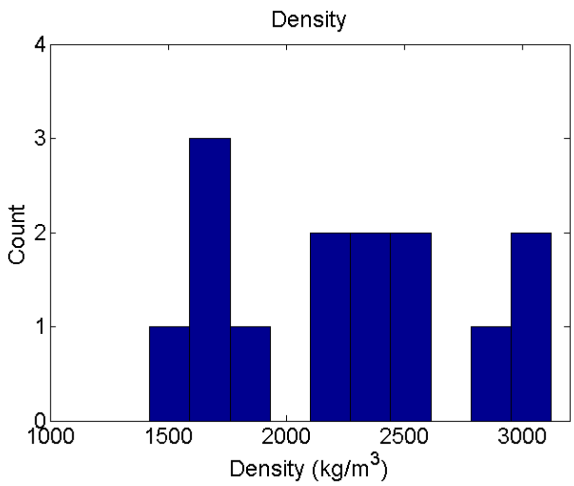


Figure 2.22: *Histogram of block density (kg/m^3) obtained from field study. 14 blocks were considered in our density analysis.*

Ejection angle and exit velocity

We based our values of velocity and ejection angle on data from Bianchi (2007). To explain ballistic trajectories, Bianchi (2007) considered two scenarios for Vulcano Island. First, a trajectory with a large velocity (350 m/s) and an angle of ejection of 75 degrees and second, a smaller velocity (145 m/s) and an angle of ejection of 45 degrees, providing the maximum distance within the same velocity. Considering the morphology of the crater, the author concluded that bombs should be ejected with an angle greater or equal to 75 degrees (fig.

2.23). However, the related exit velocity of 350 m/s is unlikely to have occurred with the considered volcanic eruption. As an example, Stromboli volcano exhibits ejection velocity around 150-200 m/s during paroxysmal eruptive phases. As a result, we adopted two average values of exit velocities, namely 100 and 50 m/s. These two scenarios are summarized in table 2.5.

Parameter	Unit	Scenario 1	Scenario 2
Average of Velocity	m/s	100	50
Standard deviation of Velocity	m/s	50	10
Average of ejecting angle (from horizontal plane)	degree	90	90
Standard deviation of ejecting angle (from horizontal plane)	degree	75	75

Table 2.5: *Parameters for the two considered scenarios*

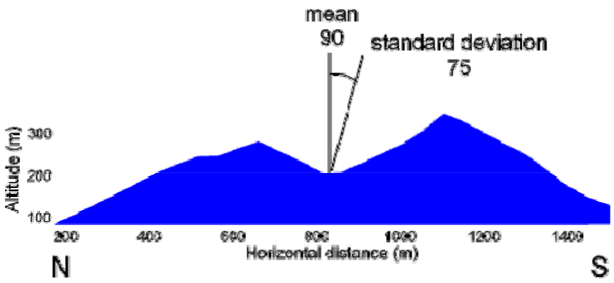


Figure 2.23: *North and South cross section of Vulcano and mean and standard deviation of ejection angle.*

2.3.3 Results

Calculation results are shown for energy and particle diameters on Vulcano map (Figs. 2.24, 2.25, 2.26, 2.27).

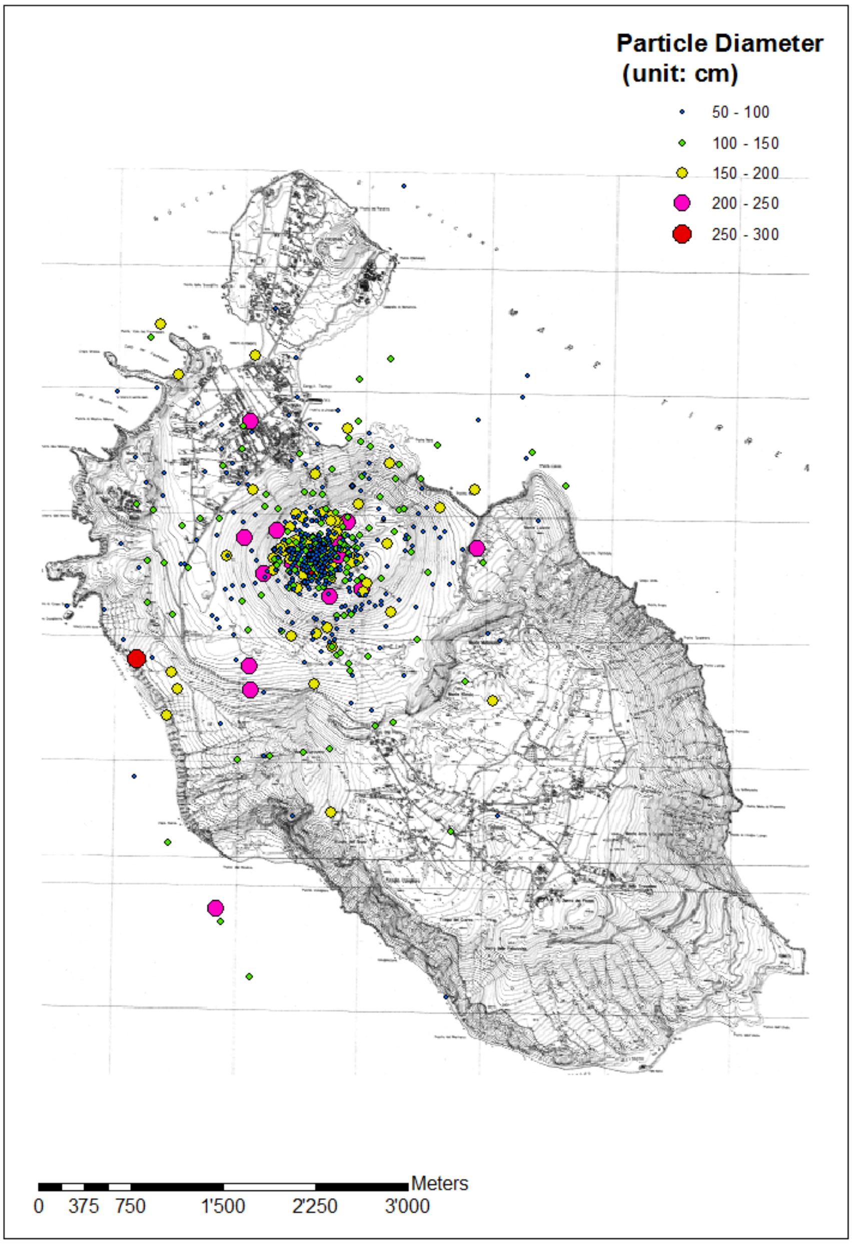


***Figure 2.24:** Particle size distribution for scenario 1.*

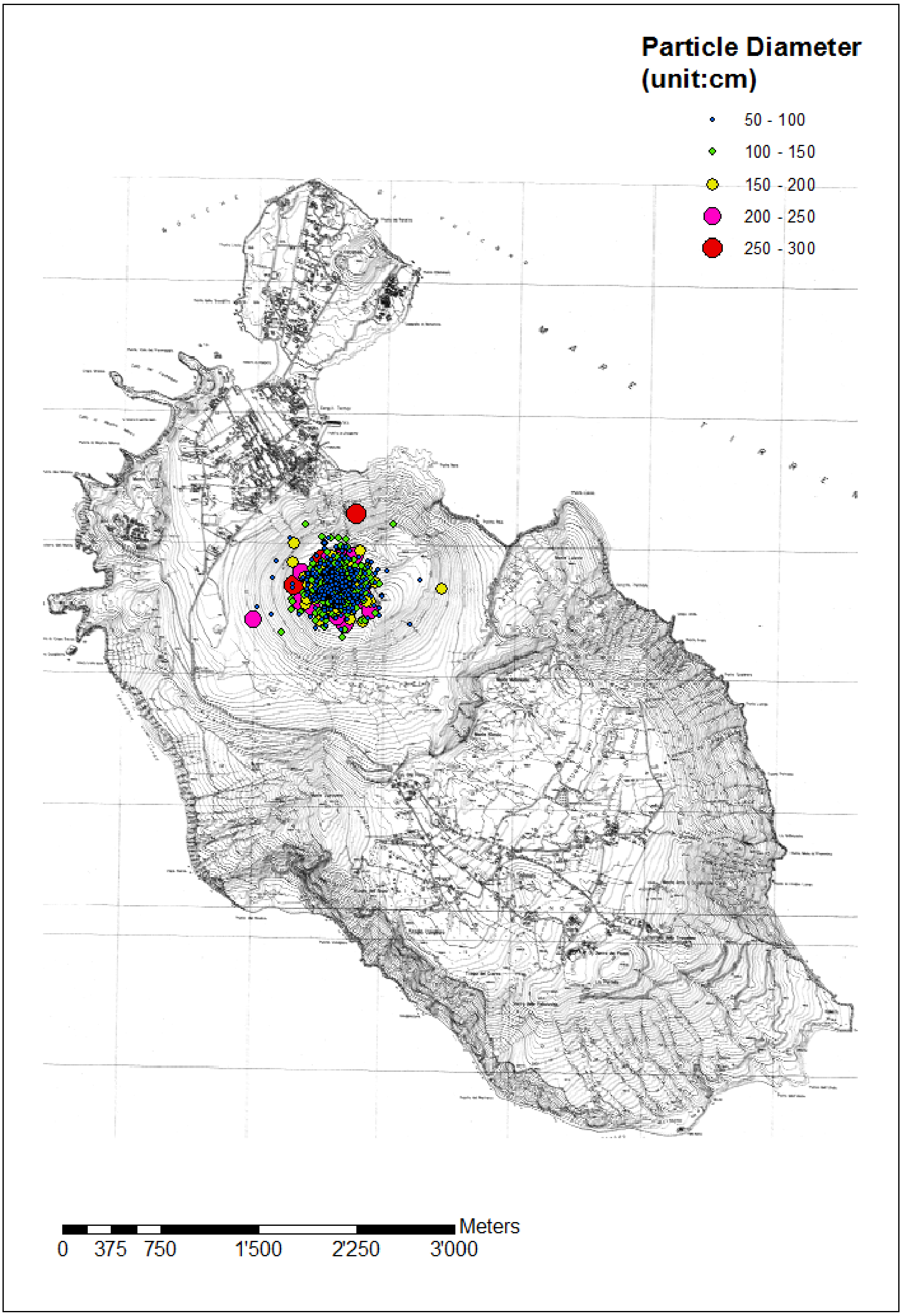


Figure 2.25: *Particle size distribution for scenario 2.*

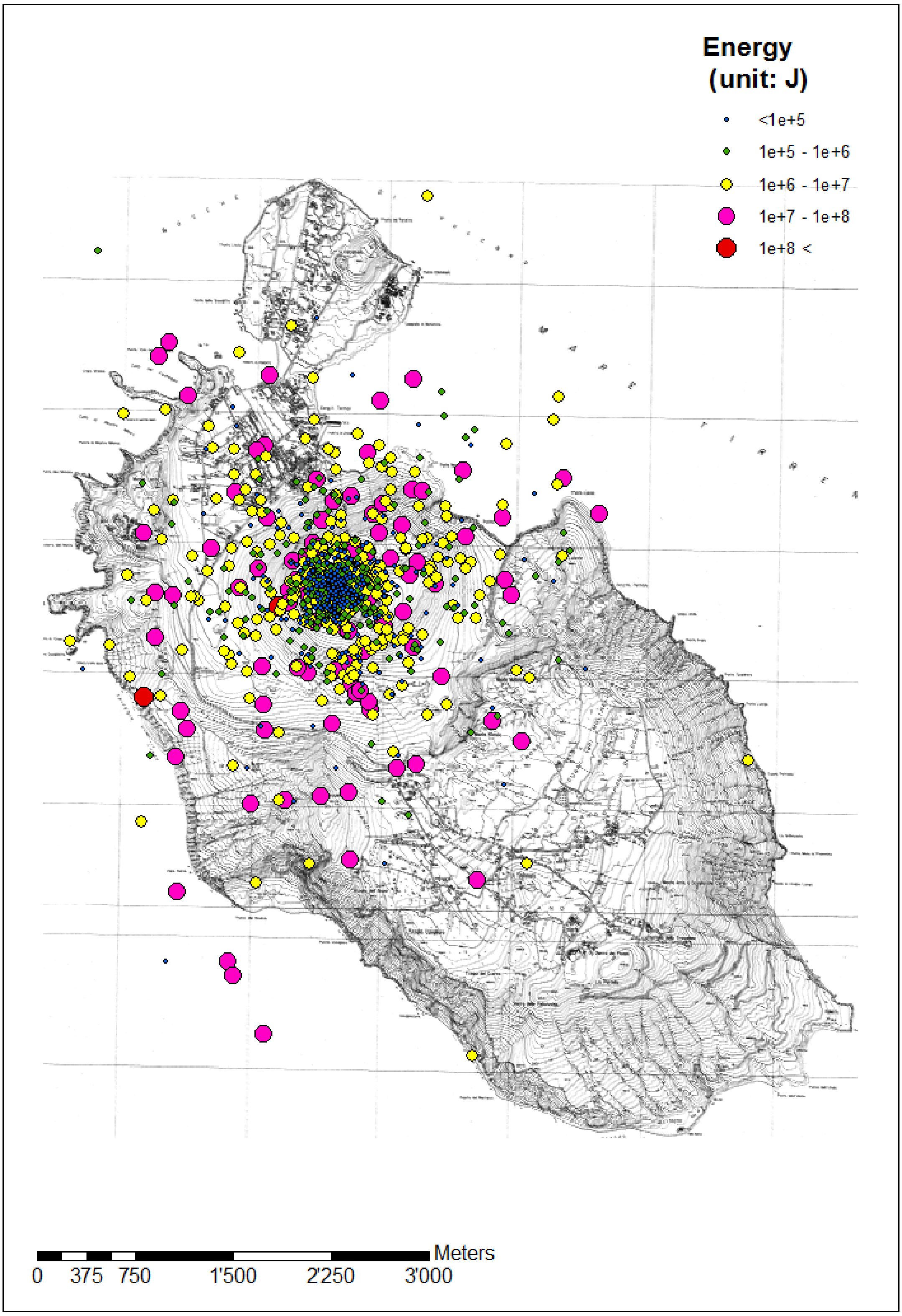


Figure 2.26: *Energy distribution for scenario 1*

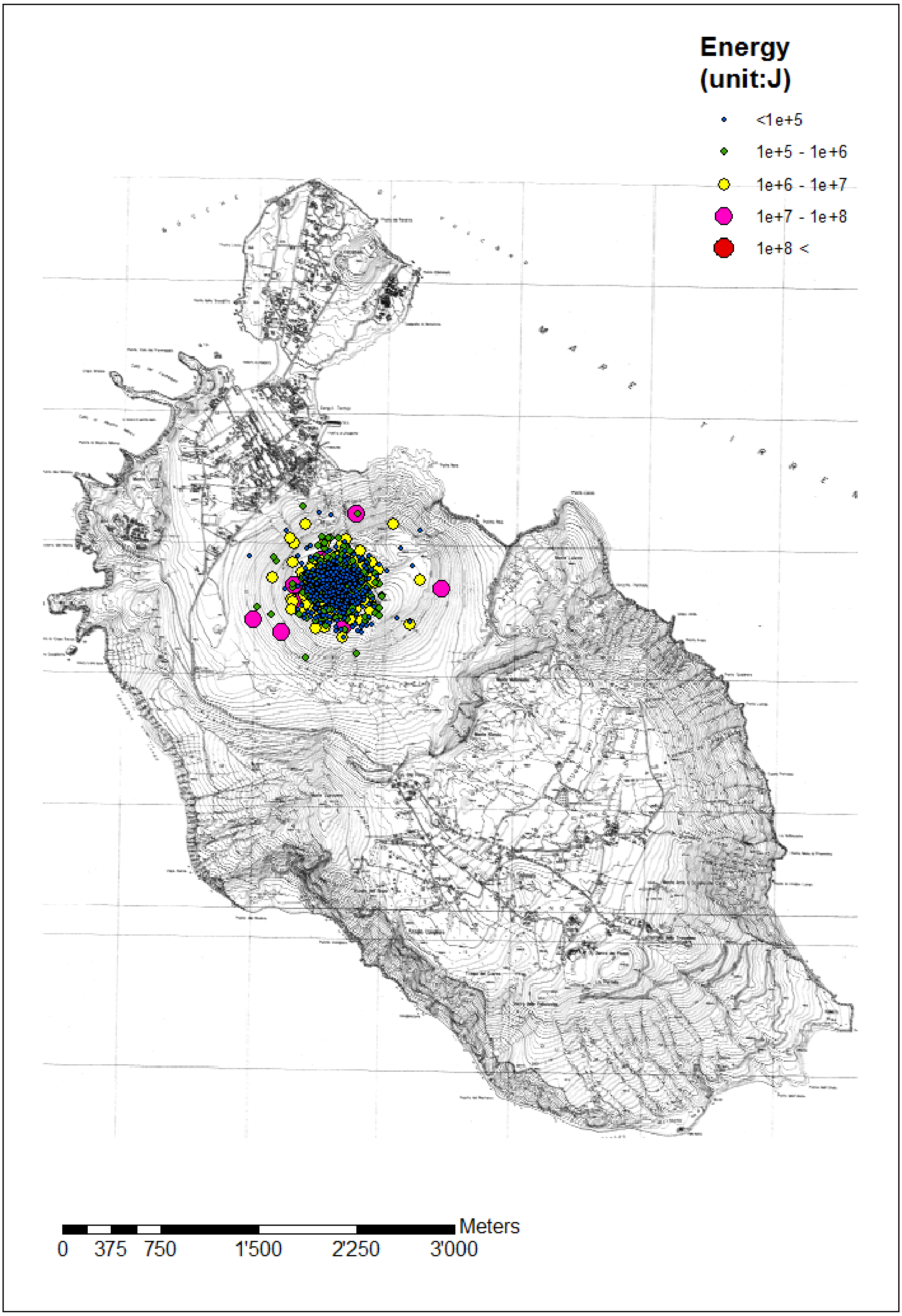


Figure 2.27: *Energy distribution for scenario 2*

2.4 Landslides

The landslide hazard and risk evaluation is based on the “Piano stralcio dell’Assetto Idrogeologico” done by the Sicilia region (Regione Siciliana 2004). Due to a lack of data, the evaluation of the hazard was not based on a probabilistic approach but rather on a deterministic one, i.e on the characteristics of past and present events. Landslides are classified according to a rough evaluation of the speed of the event. Three types of landslide have been identified in the region: T1 type: creep and lateral slow extension; T2 type: complex landslide and other phenomena with a moderate speed; T3 type: rapid rock avalanches and debris flow. The magnitude of an event has been then based on a combination of this typology classification with the extension and the volume of a landslide as shown in table 2.6.

		Landslide typology		
Extension (m^2)	Volume (m^3)	T1	T2	T3
<10^4	<1	M1	M2	M3
10^4:10^5	>1	M2	M3	M4
10^5:10^6	>1	M2	M3	M4
>10^6	>1	M3	M4	M4

Table 2.6 Assessment of landslide magnitude based on landslide typology, extension and volume

Five different hazard classes, i.e. P0 Low, P1 moderate, P2 average, P3 high, P4 very high, are then identified combining the 4 different magnitude classes and 4 different degrees of activity (active, inactive, quiescent, stabilized). As shown in table 2.7.

Hazard assessment	Magnitudo			
Activity	M1	M2	M3	M4
Stabilized	P0	P0	P0	P1
Quiescent	P0	P1	P1	P2
Inactive	P1	P1	P2	P3
Active or reactivated	P1	P2	P3	P4

Table 2.7 Assessment of landslide hazard based on the magnitude and the level of activity

The identified areas interested by landslide hazard on the Vulcano Island are the coast and the volcano flanks as shown in the map in Figure 2.28 from the “Piano di stralcio dell’Assetto Idrogeologico”. While on the west and south coast area, the slopes are more interested by active rock falls and topples, the east side is mainly interested by active instabilities due to rapid erosion. One of the most interesting areas, though, is the north-east flank of the volcano where there is a high level of urbanization (area of expansion of Porto) and a landslide of approximately 200’000 m^3 has taken place the 20th of April 1988 inducing a small tsunami. The Sicilia region identified different phenomena in this area: rapid debris flows, slides and rapid erosion. In addition this flank is interested by intense and continuous fumaroles activity and it is strongly altered. For this reason, this area has been the object of recent studies to evaluate the causes of the 1988 landslide (e.g. Tinti et al 1999; Bonaccorso et al, 2010) and how this event could be related to the volcanic activity.

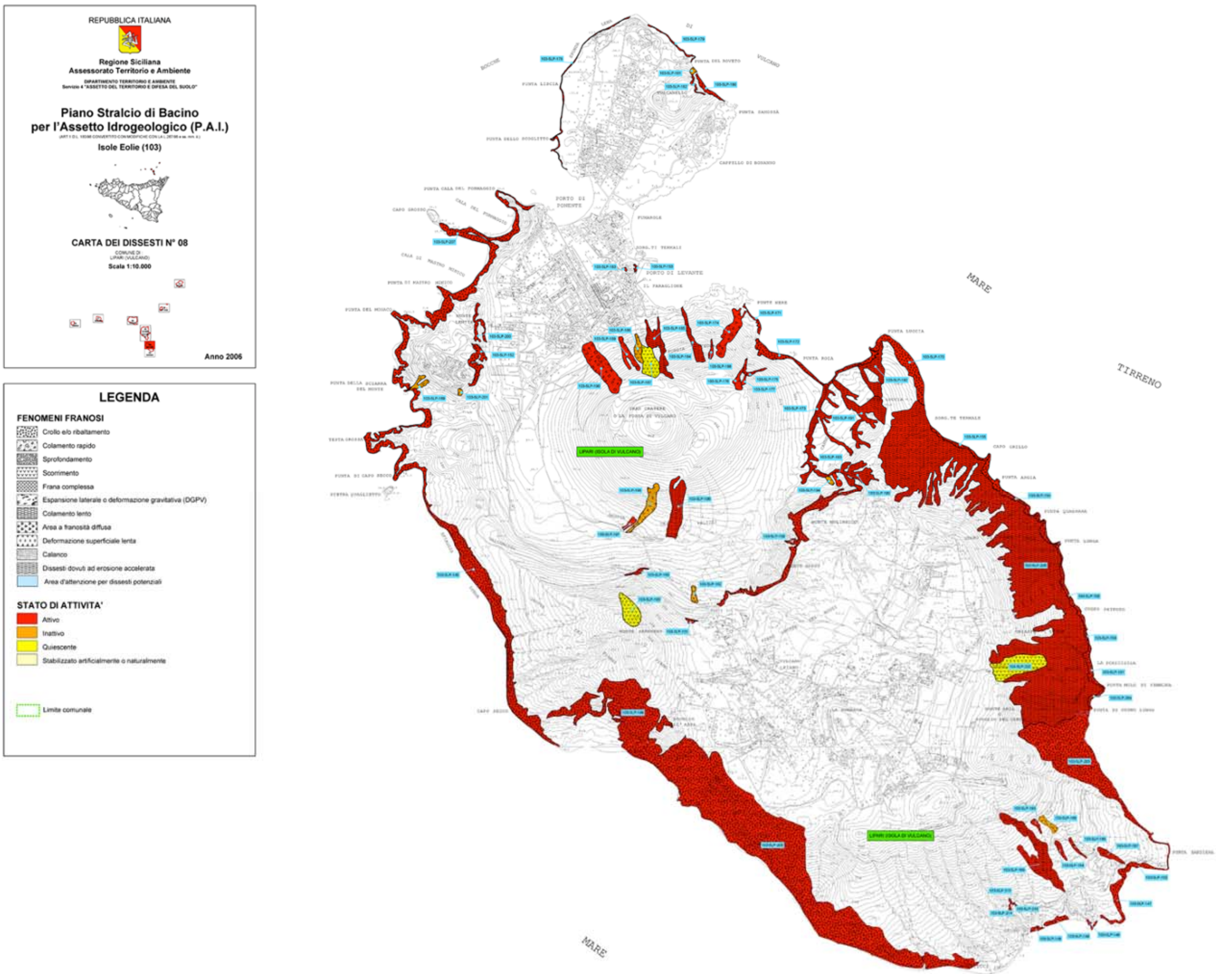


Figure 2.28: *Landslide hazard map of the "Piano di stralcio dell'Assetto Idrogeologico" by Regione Siciliana (2004)*

The risk has been evaluated according to the definition given by the D.P.C.M. 29/9/98 (Atto di indirizzo e coordinamento) where, according to Varnes and Iaeg (1984) the total risk is R=H x E x V, where H is the hazard, E the element at risk, V the vulnerability. For the definition of the elements at risk and the vulnerability 4 classes have been identified from E1 to E4 with increasing vulnerability according to the density and the functionality of the settlements and the networks in the different areas. The risk has been then assessed according to 4 increasing levels of risk from R1 to R4, combining the hazard and the vulnerability classes as shown in Table 2.8. In the "Piano di stralcio dell'Assetto Idrogeologico" of the Regione Siciliana is not specified but here the value of the vulnerability is supposed to be 1.

Risk assessment	Element at risk			
Hazard	**E1**	**E2**	**E3**	**E4**
P0	R1	R1	R1	R1
P1	R1	R1	R2	R2
P2	R2	R2	R3	R4
P3	R2	R3	R4	R4
P4	R3	R3	R4	R4

Table 2.8 Landslide risk assessment based on the element at risk and the hazard

The geomorphological risk has been evaluated in the Vulcano island by the Regione Siciliana as shown in Figure 2.29. Only very small areas have been identified as at risk. However, as clearly stated in the plan itself the classification made by regione Siciliana has a lot of limits and it is useful only to have an idea of the area interested by landslide phenomena. A more accurate analysis is necessary in the future to better evaluate the extent of this kind of phenomena and the related risk.

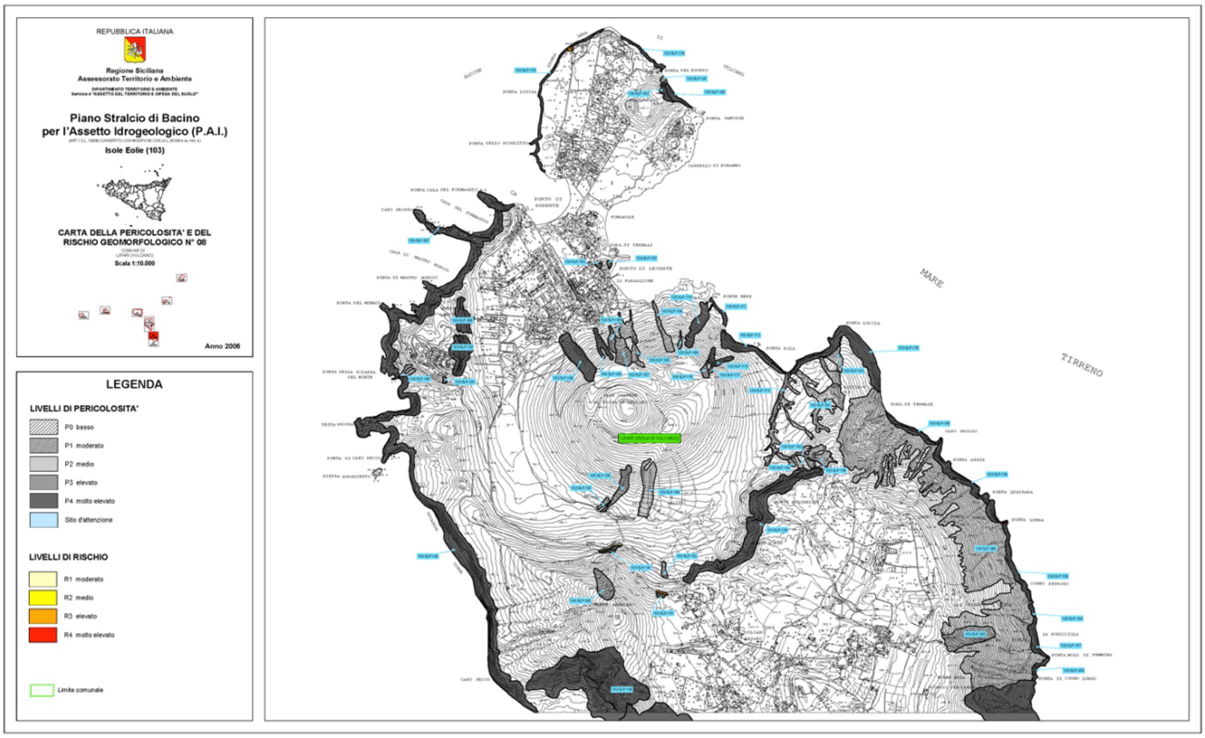


Figure 2.29: *Geomorphological risk map of the "Piano di stralcio dell'Assetto Idrogeologico" by Regione Siciliana (2004)*

2.5 Tectonic earthquakes

Structural and seismotectonic background

The structural and seismotectonic contexts of Siciliy result of the collision between African and European plates. Gioncada (2003) proposes a synthetic structural map for the Eolian Islands area (Fig. 2.30). One of the most seismically active structures seems to be a NNW-SSE-trending dextral strike-slip fault System named Tindari-Letojanni (TL) running from the Central Eolian Islands to the Ionian coast of Sicily northeast.

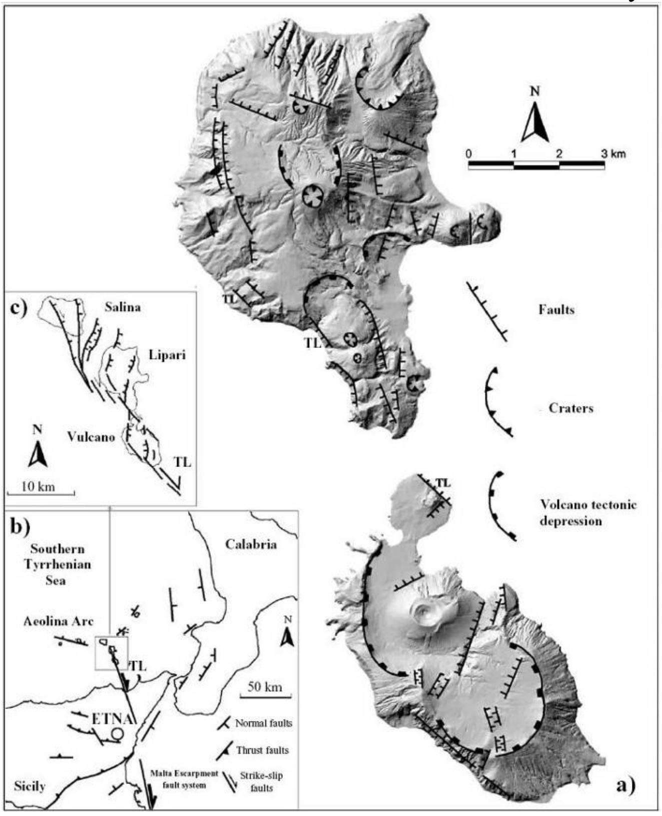


Figure 2.30: Synthetic structural maps of Eolian Islands (from Gioncada, 2003). (a) Simplified structural map of Lipari and Vulcano islands. TL: the Tindari-Letojanni fault system. (b) Main structural features of the southern part of the Tyrrhenian Sea. (c) Cinematic interpretation of the Tindari-Letojanni and related fault systems in the Vulcano-Lipari-Salina islands.

Historical Seismicity

According to the reports of historical earthquakes with origin in the Aeolian Islands area, seismic activity is relatively modest (Falsaperla and Spampinato, 1999). For the period A.D 1000, five main earthquakes, with epicentral intensities VIII to IX, have occurred around 50 km from Vulcano Island (Table 2.9).

Year	Epicentral intensity (MCS)	Latitude (N)	Longitude (E)	Epicentral locality
1494	VIII	38.18	15.55	Messina
1613	VIII	38.12	14.78	Naso
1739	VIII	38.10	14.75	Naso
1786	IX	38.10	15.02	Patti
1978	IX	38.150	14.983	Patti Gulf

Table 2.9: Historical earthquakes in the area of Aeolian Islands for the period A.D 1000 (Source: CPTI, 2004)

Recent Seismicity

Instrumental data confirm a relatively moderate seismic activity (Fig. 2.31). One major episode is the seismic crisis of the Gulf of Patti in 1978. The high seismic rate in the Gulf of Patti is in agreement with literature data that report the important fault system of Tindari-Letojanni. The strongest local earthquake of this region, which occurred on April 15, 1978 (M_S *6.1*) was linked to displacements along this fault.

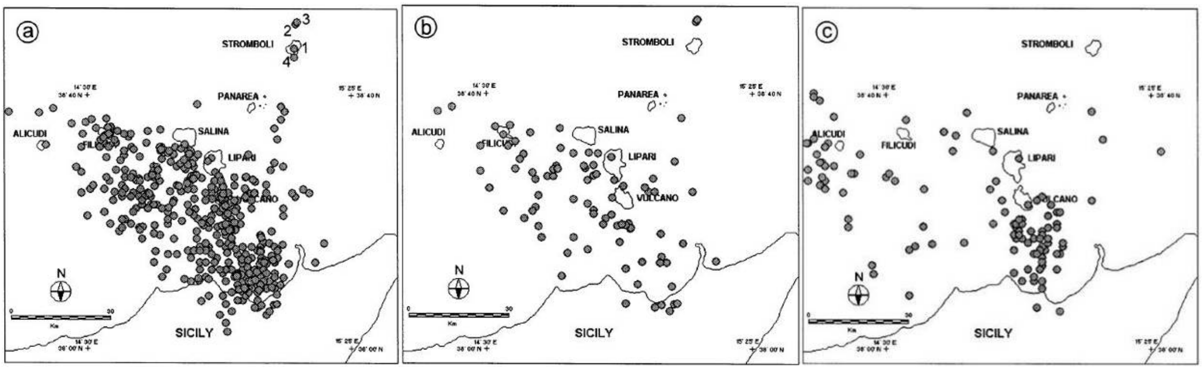


Figure 2.31: Distribution of epicenters around Vulcano Island (from Falsaperla & Spampinato, 1999): (a) with M > 2.5 recorded at the AISN stations from 1985 to 1998; (b) with M ≥ 3 recorded at the AISN stations in the years 1985-1998; and (c) with M ≥ 3 at the ING stations in the years 1977-1984.

Earthquake scenarios

To assess seismic hazard on Vulcano Island, two scenarios of seismic motions were retained:

1) The first scenario is similar to the 1981 earthquake, with a magnitude M_w = 4.7, and a focal depth of 1 km (Fig. 2.32). We chose this earthquake because of his close location to the island and of his shallow depth; the other earthquakes are too far from Vulcano or too deep. To estimate earthquake peak ground acceleration (PGA), we used the empirical ground-motion prediction equations of Sadigh *et al.* (1997).
2) The second scenario is the Peak Ground Acceleration (PGA) derived from Italian building code, 1.8 m/s² for Vulcano Island (Fig. 2.33).

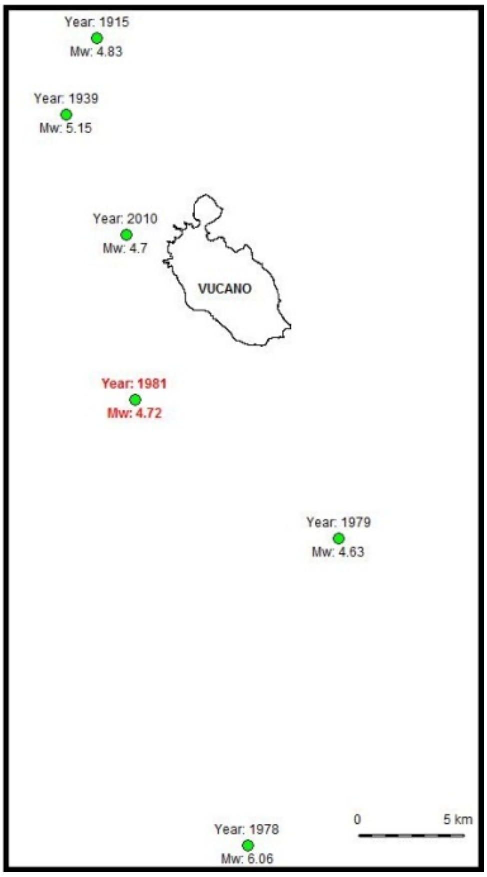


Figure 2.32: Distributions of epicenters close to Vulcano Island: in red the earthquake used for defining seismic hazard in the Ensure Project

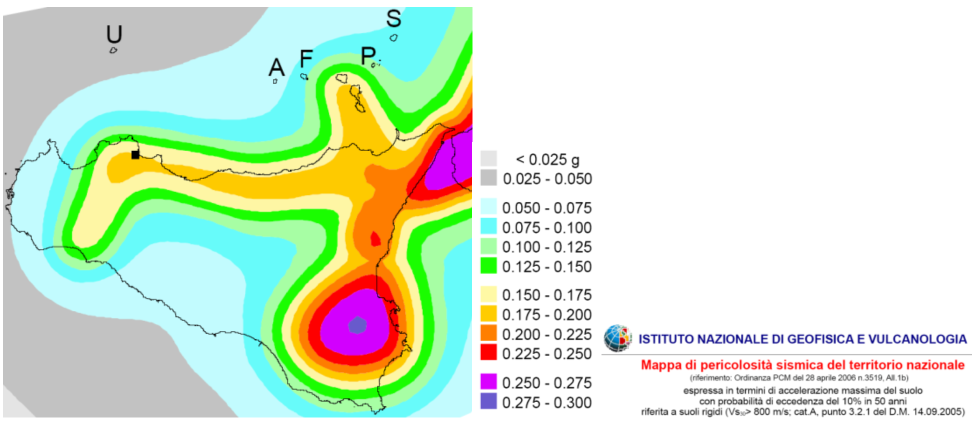


Figure 2.33: Extract of the Peak Ground Acceleration (PGA) map from Italian building code; the value of 1.8 m/s² is used for Vulcano Island

Site effects

The significance of ground-shaking during an earthquake depends on the magnitude, the distance from the fault and the local geological conditions. The most intense shaking experienced during earthquakes generally occurs near the rupturing fault, and decreases with distance away from the fault. In a single earthquake, however, the shaking at one given site can easily be 10 times stronger than the one produced at another site, even when their distance from the ruptured fault is the same. Local geologic conditions are the cause of this difference in shaking intensity known as "site effects". The most critical geological factors defining the seismic response at a site are: the softness of the rock or soil near the surface (shaking is amplified in softer soils) and the thickness of the sediments above hard bedrock (shaking is amplified when soil deposits are thicker). To take into account site effects in Vulcano, we identified, from the geological map of Vulcano (Fig. 2.34), the soil types who can potentially amplify ground shaking. For each soil type, we assign through expert advice, an amplification factor of Peak Ground Acceleration (PGA) increasing with soil softness:

- factor 1.6: alluviums and beach deposits;
- factor 1.3: scories, pyroclastic deposits, hyaloclastic lapilli-tuffs and cinders;
- factor 1: other soils and rock.

Finally, we produced a site effects map relative to amplification factors (Fig. 2.35). As no microzonation map of Vulcano was available during the case study application, we had to use such a simplified approach as a first approximation to quantify the site effects.

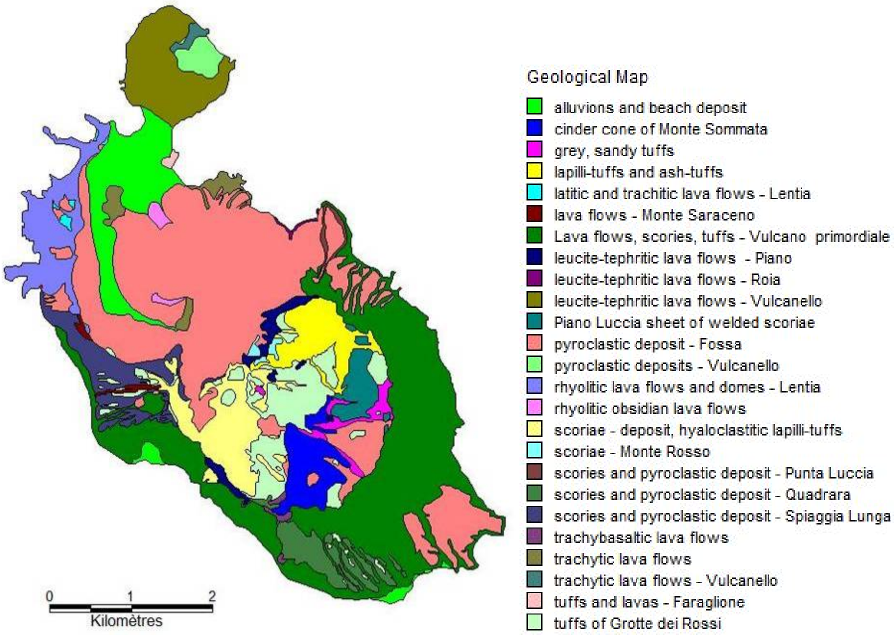


Figure 2.34: Geological Map of Vulcano Island

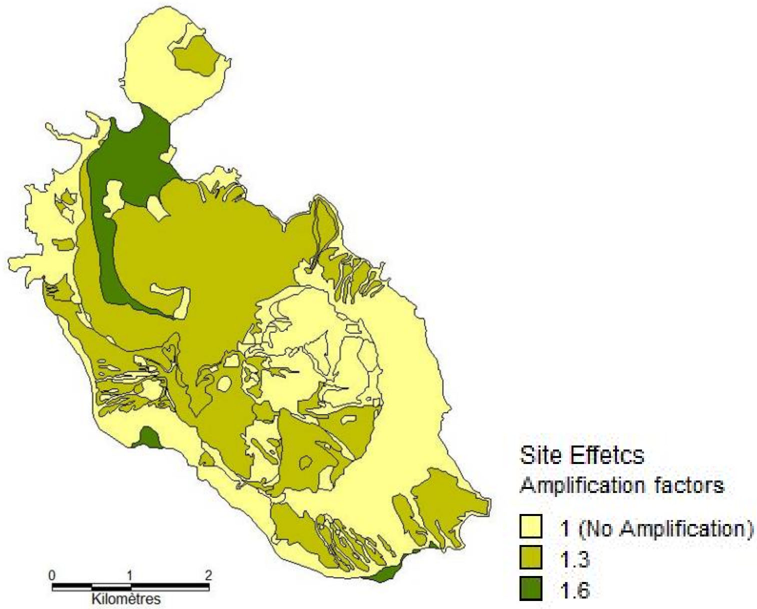


Figure 2.35: Site effects map of Vulcano Island

Seismic hazard maps

The proposed seismic hazard maps of Vulcano (Fig. 2.36) are the result both of the propagation of seismic waves from the source to the Island and the local amplification by site effects. This assessment is issued from the BRGM software of seismic risk assessment (*Armagedom@*).

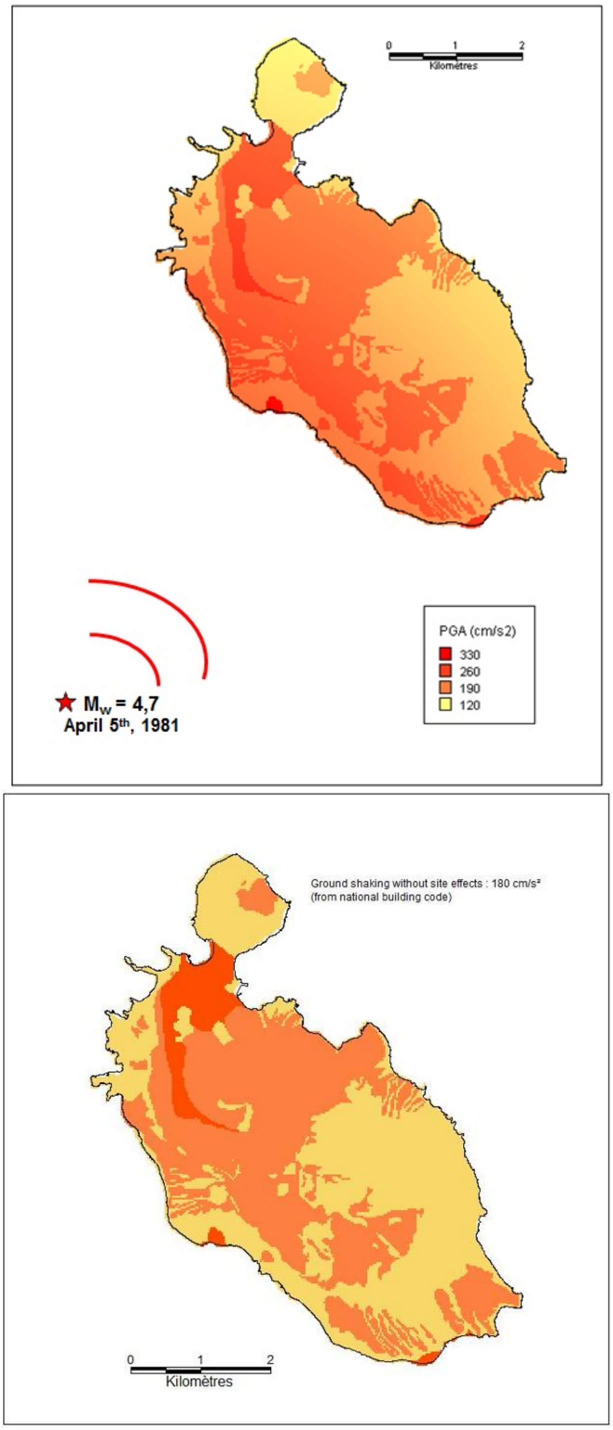


Figure 2.36: Seismic hazard maps of Vulcano island: Left with the earthquake scenario of M_w=4.7 and Right with the Peak Ground Acceleration (PGA) from Italian building code

3 Socio-economic settings of the case study

Vulcano island is administratively dependent on the Comune of Lipari. In 2006, its residential population reached 1080 people (Comune Lipari, 2008). Main characteristics of this population are summarized in Table 3.1. In particular, 54.5% of the population is composed by men with most inhabitants between 18 and 64 years old and 2% of the population being from other countries than Italy (ISTAT, 2005).

Categories	inhabitants	women	men	children < 5 years	people > 65 years
Number	1080	492	588	63	180
Percent [%]	100	45.6	54.4	5.8	16.7

Table 3.1. Main indicators of the population of Vulcano (source : Comune Lipari, 2008)

The number of 1080 represents the official account, however the effective number is closer to 800, especially in winter time, when all touristic activities cease and therefore owners of hotels and residences go back either to Sicily or to the continent. During the high touristic season, in summer from May to October, between 5,000 to 20,000 tourists visit the Island. Italians mainly come in July-August, whereas foreigners and students come in March-June and September-October. Moreover foreigners also come to work for hotels. This variability in origin should be considered when developing awareness on volcanic risk and on emergency procedures. The only one school on Vulcano can receive children from primary to middle school (age of 13). Then children need to go to Lipari and to Siciliy or to mainland Italy to pursue high school and university. The Census2000 (ISTAT, 2005) mentions that 2% of the population is illiterate. The 2000Census (ISTAT, 2005) indicates that the majority of the working population of Vulcano island (72.3%) works for tourism activities, in shops or in public administration, whereas 24.9 % works in the construction and the remaining percentage in agriculture. The working population represents 66% of the resident population; however 25% of this working population is without an economical activity (ISTAT, 2005).

The principal activity on the island until the end of the 19th Century was harvesting wood and mining alum and sulfur. In the middle of the 19th Century a British man named James Stevenson bought the northern part of the island and planted vineyards for grapes that would later be used to make Malvasia wine. However, all these activities were interrupted by the 1888-90 eruption of La Fossa, which, interestingly, occurred without any warning whatsoever, and when the population was relatively small, compared to today situation. All the Aeolian islands became famous in the 1950s after the two movies “Stromboli, terra di Dio” and “Vulcano”, and tourism became the primary economic activity. However, the main urbanization wave on Vulcano took place in the 1980s with no real planning. The population mostly subsists on tourism between April and October when the island’s population swells to around 20,000. Vulcano is mainly popular for its mud baths and also attracts adventurous tourists interested in climbing the simmering La Fossa and its smaller, dormant neighboring volcano called Vulcanello. As a result, tourism on Vulcano is characterized by both “long and medium term tourism” (people that stay on the island one or more weeks) and “daily tourism”. The ~800 permanent residents are equally distributed between the two principal towns on the island, Il Porto and Il Piano, but most tourist infrastructures are located in the Porto area, beneath the lowest flank of La Fossa cone (Fig. 2), the most active volcanic system on the island at present time. This seasonal variation of population size significantly increases the volcanic risk in the summer months. Critical facilities are also equally distributed between Il Porto and Il Piano area, resulting in a complex territorial vulnerability associated with a complex and dynamic range of potential eruptive scenarios (Fig. 2).

In terms of critical facilities, Vulcano island is equipped with one major road that goes from the north to the south part, passing by the La Fossa volcano, three harbors (Porto Levante, Porto Ponente and Gelso), two heliports (Vulcanello and Piano), one medical center (Porto), one school (Piano) and a police station (on the main road between Porto and Piano) (figure 3.1). Among the three harbors, the only one that can receive big boats is Porto Levante, the two others are dedicated to small marine activities or emergency evacuation, but of minor size. Heliports also serve for evacuation purposes. In case of serious health issues or regarding energy and water supply, Vulcano depends on Lipari and Sicily. Vulcano does not have natural reserve of drinkable water. As a result, water is brought by boat and stored in two main reservoirs in Gelso and Monte Saraceno (maximum of 1800 m^3). In terms of energy, Vulcano, as well as the other Aeolian islands, is equipped with an independent diesel power station and is not connected on the electricity grid of the mainland (Cavallaro and Ciraolo, 2005). However on Vulcano, there is also a photovoltaic power station, built in 1984 (Firor et al., 1993). At the beginning it was a stand-alone power station covering energy needs for 54 houses on the island. But in 1995, the photovoltaic power plant was modified in order to run in parallel with the diesel generator to complement the demand when the energy consumption is at high level (Firor et al., 1993), so supposedly during the tourist season. Indeed in summer, if one assumes that there are similarities between Vulcano and Salina, electricity demand reaches peak values (Cavallaro and Ciraolo, 2005).

3.1 Risk perception

Social science interviews of key stakeholders were carried out in 2008 to 2009 and an interview survey of the general public was carried out in 2010 (N=91). Results of the survey indicate that awareness of the last volcanic eruption in the 1800s and expectations of a future eruption in <100 years are good. For example, some 81% of respondents believed an eruption was somewhat likely to very likely within 100 years. However, only 14% believed an eruption was somewhat likely to very likely within the next 12 months. A slight majority think that eruptions will be bad and do not think that the effects of an eruption are exaggerated (53% and 55%, respectively) and most respondents believe they will only have minutes to hours to a few days of forewarning before an eruption. Few, however, have taken simply steps to prepare and people are mixed about what the Civil Protection Authority advises in an eruption. During evacuations, sheltering needs are anticipated both off- and on-island. Major problems of concern on the island were related to provision of public services and a lack of cultural and social activities and strategic development strategy, not “fear” of the volcano or presence of visitors. The most common problem linked to the volcano was effects on quality of water.

Analysis of survey data show that there is an expectation of a future eruption on island, but people’s attention is focused on concerns about short-term economic, social and service issues. These concerns result in people leaving the island for perceived greater opportunity (e.g., better jobs, entertainment and education). Increasing knowledge of protective actions and preparedness for an eruption or other hazards should focus on incentives for preparing. They should, for example, highlight the economic and social benefits and consequences of preparing. Benefits include an increased ability to cope with an eruption and its effects and hence a reduction in risk and personal loss during a volcanic unrest. Consequences are an initial investment of time and resources in exchange for reduced impacts, feeling of greater security and control, and coping abilities in the near to long-term. However, the lack of expectations of an eruption in < 12 months means people are unlikely to use their short-term access to time and monetary and physical resources to undertake preparedness actions because other more pressing matters. Future efforts to connect with island residents as part of any risk reduction strategy will have to counter this position (i.e., that volcanic hazards do not represent a short-term threat) by focusing initial information on matters of island wide importance, such as water quality. This is because many residents attribute the quality of water to effects of the volcano. By focusing on the relationship between the volcano and water supply, something of vital importance and obvious interest to the community at large, a sense of trust could be developed which could serve as a platform for engaging the community in other matters, such as those surrounding risk reduction actions for living with and responding to volcanic hazards on the island.

3.2 Database used for the hazard and vulnerability assessment of Vulcano island (building typology and distribution)

A geographical information system combines a variety of tools that can be very useful in assessing vulnerability and risk. In the frame of the Vulcano case study, a database has been elaborated in order to include key information related to volcanic hazards and exposed elements. This database has been maintained using ArcGis 9.3. The reference system used for data gathering is the Universal Transverse Mercator (UTM) 33N based on the World Geodetic System (WGS) 84 ellipsoid. All data can then be expressed in a metric system. Table 3.2 describes the type of data that was specifically used in this case study. Figure 3.1a shows the shaded relief of the Island as well as the main features, such as streams, roads and buildings.

Name	Content	Resolution	Format	Used for
quickbird_tm2	Quickbird satellite image high resolution of Vulcano island 2005	1m	raster	background
Geol_polyg	Geological units of Vulcano Islands based on Keller (1970) and Gioncada et al., 2003)		vector	seismic hazard assessment
Istat vulcano.shp	Statistics 2001 on Vulcano (Census Units map and related data sets on population and buildings)	Polygon based	vector	physical vulnerability of social system and for building vulnerability assessment
Buildings	Buildings based on aerial photographies of 1996		vector	for building vulnerability assessment
Building_export_new.shp	254 buildings described with specific elements		vector	building vulnerability assessment
Streets.shp	Main streets of Vulcano based on aerial photographies of 1996		Vector	vulnerability assessment of transport lines
Cartography (scale 1:2000)	Digital Cartography (2004) of the Sicily Region urban areas		vector	physical vulnerability of natural, built environment and critical infrastructures

Table 3.2. GIS data used for the Vulcano case study

Regarding the built environment, the Census2000 (ISTAT, 2005), distinguishes three distinctive areas on Vulcano, defined on specific characteristics linked with house distributions and availability of services. These three types of areas are a) inhabited center defined as cluster of houses with public infrastructures and services b) inhabited nucleus with a lower density of houses and with infrastructures less well maintained c) scattered houses with a distance sufficiently large enough not to be considered as a nucleus. Based on figure 3.1b, inhabited centers are localized in Porto, Vulcanello and Piano. The rest of the island is

considered as having scattered houses. Depending on the hazard considered, key building components should be considered. Most often information related to type of materials, building ages and number of floors is considered. In case of tephra fallout, angle of roof, existence of large openings on roofs and main axes of buildings are also key parameters as collapse of buildings under loading depends on strength of roofs.
Data contained in the Census 2000 (ISTAT, 2005) give information related to buildings like the use, the number of floors, the age of construction, but summarized for each pre-defined areas existing in Vulcano. In order to have a more in-deep information, a field campaign was carried out in order to look for specific indicators (table 3.3) for building characterization and to collect some data on roads width and quality of construction. The survey was defined on a grid of 100m x 100m. A representative building of the pixel was selected and assessed as detailed as possible, depending on the accessibility. 254 buildings have been assessed (figure 3.1c).

Indicator	Description
B_use	Use of the building
Period_U	period of the year where the building is occupied/open
Nb_flats	number of apartments/living place inside a building
Nb_storey	number of stories of a building
B_under	presence of underground
B_shape	description of the building shape
B_morpho	morphology of the building 1: hotel with irregular shapes and more than 2 stores ; 2: simple house, one floor, regular; 3: residential buildings with irregular shape 1 or more floors
B_mat	type of material (fieldstones, bloc pumice, concrete, clay bricks, mixed
B_quality	quality of building, good or poor
B_preserva	preservation of the building
R_type	type of roof (flat, pitched, mixed)
R_angle	angle of the roof
R_openings	openings on the roof
R_chimney	chimney on roof
R_water	water supply on roof
R_solar_pa	solar panel on roof
Nb_open	number of openings on the buildings (windows, doors)
W_Shutter	protection of windows
B_slope	slope of the buildings
V_regulari	vertical regularity of the building

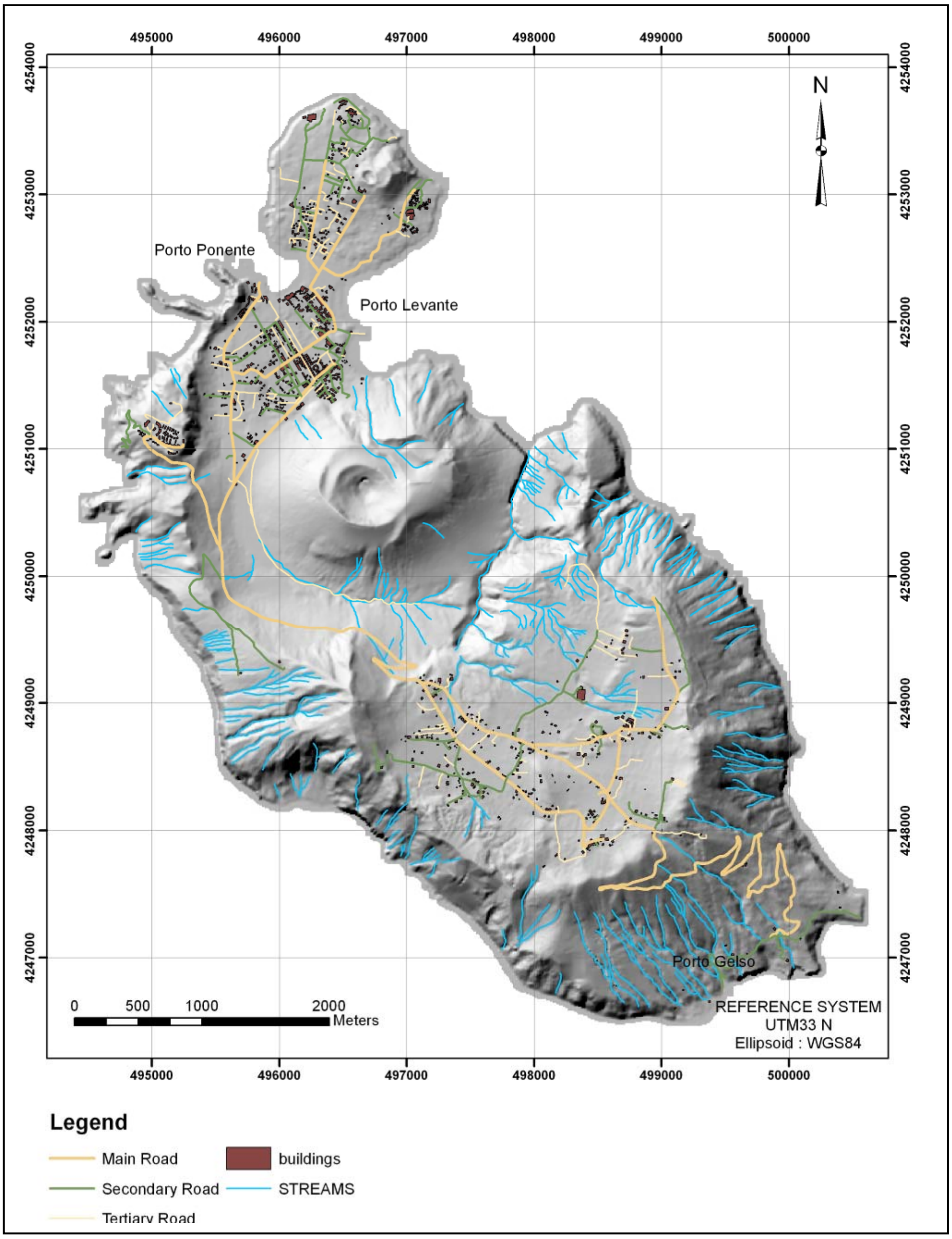
Table 3.3 : main parameters used during the field investigation of buildings

The period of construction was also one of the parameters considered. One of the working hypotheses was to use the type of material used for construction as well as the number of floors. Before 1980, it seems that houses on Vulcano were built, in most of the cases, with a rectangular one floor shape and constructed with volcanic rocks mixed with mortar. However, based on discussion with inhabitants and constructors on the island, it seems that most of the buildings have been renewed or even rebuilt over the years. Consequently, the real period of construction seems difficult to assess without specific in-site tests. Information provided by the 2000Census should also be carefully considered, as it can be seen on figure xb, that most of buildings are considered to have been built between 1972 and 1981.

Description	Type of use	Number of floors	Roof type	Type of material	Morphology
Type	Residential	1	Flat	Unknown	regular
Number of results over 254	209	179	186	224	137
%	82%	70%	73%	88%	54%

Table 3.4. Main results for the 254 investigated buildings

Some of the results are summarized in table 3.4. The field investigation shows that most of these buildings are residential houses, occupied either on a yearly basis or more often during the nice season (May – October). The majority of roofs of investigated buildings were flat. 70% of the buildings are composed of one floor. As it can be seen, the type material was difficult to assess in the field as it was based on visual inspection. In 88% of the cases, the material used was not identified.



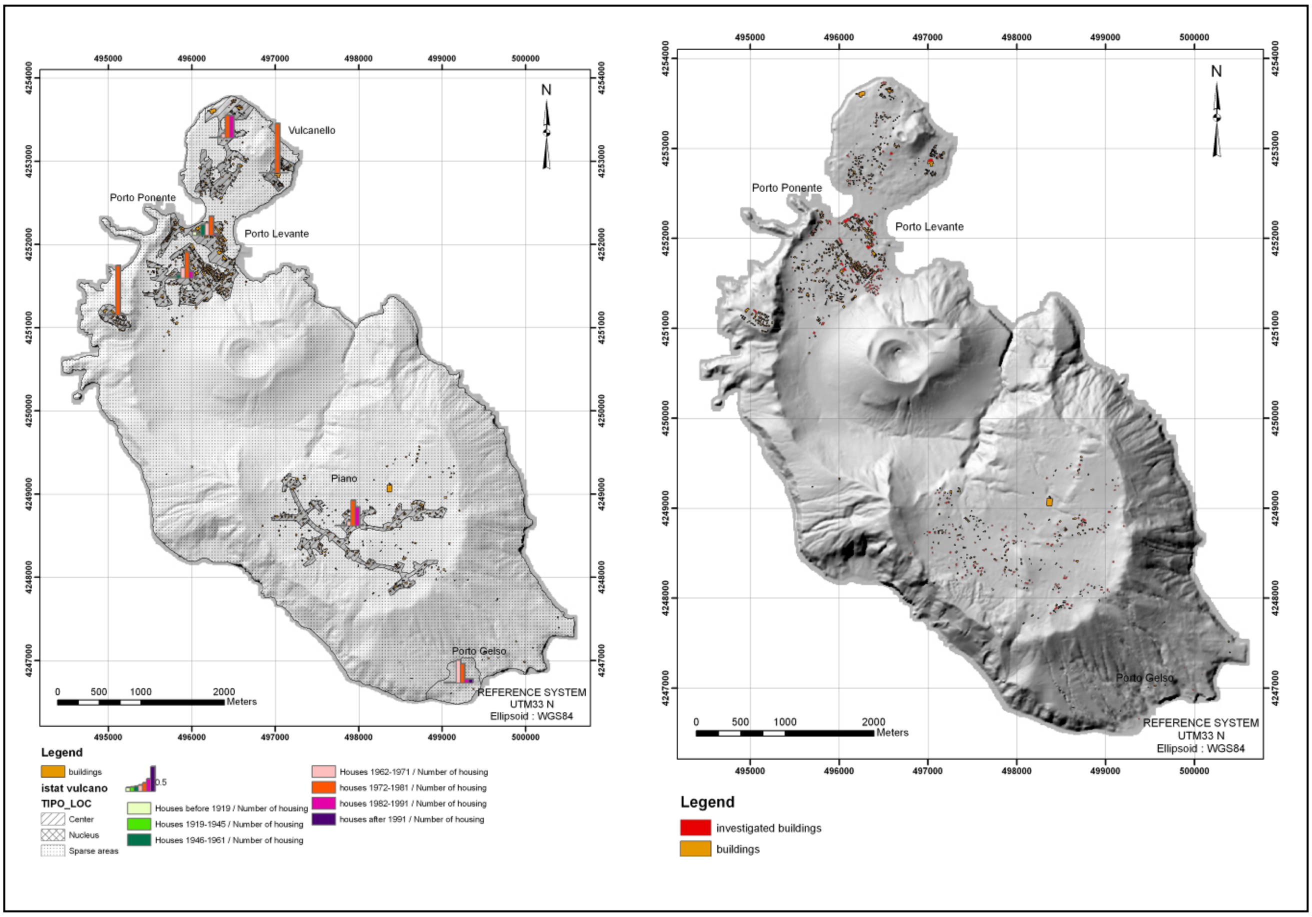


Fig. 3.1 a) Representation of the main features of Vulcano island. b) Area types and houses distribution on Vulcano based on GIS data from ISTAT (2005). c) Investigated buildings

4 Application of the Ensure framework

4.1 Mitigation capacity

Based on the general framework set up in WP4, the first set of matrixes is focused on mitigation capacities and is addressed to evaluate:

- if the different components of risk (hazard and vulnerability of exposed elements and systems) are known and assessed;
- if, according to such knowledge, mitigation measures have been defined or implemented;
- if the different actors (individuals, communities, institutions, economic stakeholders) are adequately prepared or able to face a potential hazardous event.

These aspects do not directly refer to the features, which make a given object or a given actor susceptible to be damaged (vulnerability), focusing on the capacities enabling a system (a city, a community) to be prepared in face of future events, in terms of preventing, mitigating, facing hazardous events. Hence, the first set of matrixes is addressed to evaluate aspects related to the availability of an effective risk knowledge-base, to the capacity to implement prevention and or mitigation measures, etc. which are crucial to face future hazardous events. In the meanwhile, it is worth noting that, in some cases, overconfidence in the possibility to prevent or mitigate expected hazard may lead to increase vulnerability (Normandin, Therrien, Tanguay, 2009): therefore, capacities enabling a community to anticipate and to be prepared in face of future events must be judiciously employed (Fiksel, 2003).

With respect to the practical application of this first set of matrixes to the case study, mitigation capacities have been evaluated with respect to the three main hazards that the Vulcano island is prone to: volcanic, seismic and landslides. To this aim, slight changes and integration to the matrixes set up in the Work Package 4 and some changes to the defined parameters have been required, due both to the peculiarities of the case study and to the available information. In detail, the general framework outlined in WP4 was structured in four macro-systems (natural environment, built environment, infrastructure and production sites and social system). Each of them was characterized by one or more systems; then, with respect to each system, different aspects were investigated through different parameters and the main criteria and descriptors were defined (fig. 4.1).

This main structure has been modified as follows (fig. 4.2):

- the four blocks have been considered as the main systems to which the assessment is referred;
- for each system, different aspects have been considered;
- for each aspect, the key topics which have to be investigated have been identified;
- for each key topic, parameters, criteria for assessment (type of assessment scale, information source, etc.), descriptors and specific notes on the case-study have been provided.

Besides the slight changes to the general framework, the possibility/opportunity of assigning different weights to the different aspects and key topics has been tested in the case study.

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Notes on the Case study
Natural environment	Natural Hazards	Are landslides known and mapped?	Landsilides hazard maps availability	binary; scale of detail	yes/no; local/regional	There is a rather extensive study commissioned by the Province of Bolzano of the different landslides affecting the Corvara area in the Alps
		Is available knowledge updated?	Hazard maps updating	Frequency of updating	on the basis of regular surveys/ only occasionally	Last update of the study is 2006
		Are hazards monitored?	are landlsides adequately monitored?	binary; quality and density of monitoring devices	yes/no; expert judgement	Movements are monitored
		Are monitoring systems connected to forecasting modelling systems?	existence and quality of early warning systems for predictable landslides types	binary; expert judgement upon the quality of models; back analysis	yes/no; match of monitored data to forecasting models	Apparently the monitoring system is not connected to an emergency plan
		structural defence measures	existance and quality of structural defences/drainage works	binary; expert judgement; movement status	yes/no; quality of defences; state of maintenance	Water drainage works should be carried out in the attempt to stabilize the movement but at the moment they are absent
	Exposure and vulnerability of built environment	Is exposure and vulnerability considered and acted upon in plans?	Vulnerability assessment of exposed built stock	binary; updating frequency	yes/no; any time new buildings are built/only occasionally	Only two houses are directly exposed to the Corvara landslides; other buildings are in a less exposed zone
			Risk maps and scenarios, including enchained events	binary	yes/no	the study of the Bolzano Province provides an analysis of the vulenrability of the built environment

Figure 4.1 – Structure of the general framework carried out in WP4

This opportunity can be important for a final evaluation: for example, in the Vulcano case study lava flows are not among the expected phenomena according to the most likely eruptive event selected in section 2.
Therefore, the availability of structural defence measures is less relevant with respect to the availability of monitoring systems connected to forecasting/modelling systems, being structural defence measures relevant only with respect to lahars, but ineffective with respect to other volcanic phenomena, like tephra falls. Hence, in this case, a weight of 0.5 has been assigned to the mentioned key topic.

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Parameters	Criteria for assessment	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring Parameter	Scoring key-topic	Scoring Aspect	Scoring System
Natural environment	Natural Hazards knowledge	1	Are volcanic hazards known and mapped?	1	Volcanic hazard maps availability	binary scale based on data collection	yes/no	YES	The official hazard map of Vulcano island used by the Italian Civil Protection is by Dellino and La Volpe (1997). The map focuses on the distribution of diluted pyroclastic density currents (Dellino P, Volpe LL (1997) and is the result of a research project developed between 1993 and 1995 by the Italian National Council of Research- National Group for Volcanology and titled "Progetto Vulcano". (see: "Stratigrafia, dinamiche eruttive e deposizionali, scenario eruttivo e valutazioni di pericolosità a La Fossa di Vulcano", Felici Editore). Furthermore, it has to be considered that the map is not an "official" one, as in the case of Maps provided by Basin Authorities. Finally, it has to be noticed that, although the scale of the hazard assessment seems to be adequate, the lack of a detailed assessment of some of the volcanic phenomena (ashes, lahars...), which clearly depends on the hypothesis on which the assessment has been carried out, might be insufficient for a correct definition of mitigation measures.	1	0,75 = High	0,44 = Low	0,3 = Low
					Scale of hazad maps adequate to support prevention and mitigation measures	qualitative scale based on expert judgement	adequate, partially adequate, inadequate	PARTIALLY ADEQUATE		0,5			
			Are spatial and temporal dynamics of volcanic hazards and synergies among them and other natural hazards (e.g. tsunami) considered?	1	Hazard scenarios, taking into account spatial and temporal dynamics of volcanic hazards and including enchained events, availability	qualitative scale based on data collection	not available, available but not satisfactory, available	NOT AVAILABLE	No hazard scenarios showing potential synergies among different phenomena and the temporal dynamics of volcanic phenomena are currently available.	0	0 = Absent		
			Is available knowledge updated?	1	Hazard maps updating	binary scale based on data collection	yes/no	NO	There are recent studies, but they do not represent official maps. The most recent study has been published by Dellino et al. (2010). It accounts for a more detailed stratigraphy and a quantification of potential damage on the built environment (Dellino P, De Astis G, La Volpe L, Mele D, Sulpizio R (2010) Quantitative hazard assessment of phreatomagmatic eruptions at Vulcano (Aeolian Islands, Southern Italy) as obtained by combining stratigraphy, event statistics and physical modelling, Journal of Volcanology and Geothermal Research). New stratigraphic work has been developed in the frame of a PhD project at the University of Pisa (Dr Federico Di Traglia) and the project ENSURE as part of a collaboration with Prof. Mauro Rosi. Associated results have not been published yet but they could highlight fundamental differences with the work of Dellino and colleagues.	0	0 = Absent		
					Frequency of update	qualitative scale based on data collection	any time new knowledge is available/ any time activity changes/ occasionally	—					
			Are hazards monitored?	1	Availability of volcanic hazards monitoring systems	binary scale based on data collection	yes/no	YES	According to INGV geochemical phenomena are currently monitored: http://www.pa.ingv.it/sorveglianza/elettronica/elettronica.html; seismic activity is also monitored by INGV and there are currently 4 permanent seismic stations on the island	1	1 = Very High		
					Quality and density of monitoring systems	qualitative scale based on expert judgement	good, medium, scarce	GOOD		1			
	Tools for prevention	0,5	Are monitoring systems connected to forecasting modelling systems?	1	Avalilability of volcanic hazards monitoring systems linked to forecasting systems	binary scale based on data collection	yes/no	NO		0	0 = Absent	0 = Absent	
					Quality of forecasting models connected to hazard monitoring systems	qualitative scale based on expert judgement upon the quality of forecasting models	good, medium, low	—					
					Existence of early warning systems	binary scale based on data collection	yes/no	NO		0			
			Are structural defence measures available and effective?	0,5	Existence of structural defence measure	binary scale based on data collection	yes/no	NO	There is a project related to the canalisation of rainwater to collect water from the volcano flanks and mitigate mud and debris flow, but no data related to the quality (extension, features) of the project and information about its implementation are currently available.	0	0 = Absent		
					Effectiveness of existing structural defence measures	qualitative scale based on expert judgement upon the effectiveness of defences	effective, partially effective, ineffective	—					
					State of maintenance of defences	qualitative scale based on expert judgement upon the state of maintenance	high, medium, low	—					

Figure 4.2 – The framework for assessing Mitigation Capacities

Moreover, the assessment provided with respect to each parameter, generally based on data collection, experts' judgments or results of questionnaires and expressed through a qualitative scale, has been translated into a numerical score varying between 0 (scarce or absent) and 1 (very high). The scoring system is addressed to obtain aggregate values for the different aspects and systems. In detail, starting from the numerical scores assigned to each parameter, aggregate numerical scores have been calculated with respect to each key topic, aspect and system.

In detail, based on the values of each parameter, a numerical score has been assigned to each key topic: to this aim, the parameters considered as not significant for the case-study have been eliminated; the scores obtained for each parameter (each of them variable between 0 and 1) have been summed and the mean value has been calculated.
Then, each key-topic has been weighted in order to determine its role in defining the Aspect. The value of the Aspect is obtained through the sum of the key-topics scores and the results have been normalized between 0 and 1[4].
Finally, the weight of each Aspect in determining the value of the considered System has been defined and the system score has been obtained summing the scores of each aspect and normalizing the result between 0 and 1.

It is worth underlining that no weight has been assigned to each parameter; hence, the scores of key topics represent the average among the values of the parameters; on the opposite key topics and aspects may also have a weight ≠1. Thus, the maximum obtainable value has to be calculated taking into account the weight of the key topic or of the aspect (fig. 4.3)

<table>
<tr><th>Aspect Weight</th><th>Key topic Weight</th><th>Scoring parameter</th><th>Scoring key-topic</th><th>Scoring aspect</th><th>Scoring system</th></tr>
<tr><td rowspan="6">1</td><td rowspan="6">1</td><td>0</td><td rowspan="6">0,25 = Low</td><td rowspan="6">0,25 = Low</td><td rowspan="12">0,4 = Low</td></tr>
<tr><td></td></tr>
<tr><td>0</td></tr>
<tr><td></td></tr>
<tr><td>1</td></tr>
<tr><td>0</td></tr>
<tr><td rowspan="6">0,25</td><td rowspan="6">0,25</td><td></td><td rowspan="6">1 = Very High</td><td rowspan="6">0,25 = Low</td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td>1</td></tr>
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</table>

Figure 4.3 – Scoring and weighting procedure

Aggregate values can be useful in order to compare different systems, whereas disaggregate information related to each aspect or to each key topic can support more effectively the understanding of the main weaknesses and strengths in the mitigation capacities and, therefore, which key topics or aspects have to be reinforced. Then, the final scores (of key-topics, aspects and systems) have been again translated into a qualitative scale.
In order to pass from qualitative judgment to numerical scores and vice-versa, the scale showed in figure 4.4 has been applied.
Before going to a more detailed explanation of the matrixes related to each hazard, it is worth focusing on two main aspects.
First of all, it has to be emphasized that numerical scores and qualitative values do not represent absolute measures but comparative ones: this imply that a High vulnerability level is not an absolute judgment, since vulnerability of a given element or system can be defined as very high (or very low) only in respect to other considered elements or systems.
The second aspect is related to the geographical scale which mitigation matrixes refer to. They have been applied, indeed, to the Municipal Scale, since the latter represents the lowest level on which mitigation policies can be implemented. Nevertheless, in many cases, the investigated key topics refer to different scales. For example, in case of mitigation matrix related to seismic risk, one of the topics refers to the availability of building codes. Such

[4] The normalization is obtained by the formula: Normalized score = (obtained score-minimum possible score)/(maximum possible score-minimum possible score). The values of the scores in the formula are obtained multiplying the value of the key-topics by the relative weight.

codes are provided, in the Italian context, at national scale, at least with some further restrictions at regional scale. Thus the matrix, although referred to a Municipal scale, includes key topics and parameters which have to be investigated with respect to different geographical scales, since mitigation capacities at local scale depend, in some cases, on legislative framework, policies, decisions taken at wider scales.

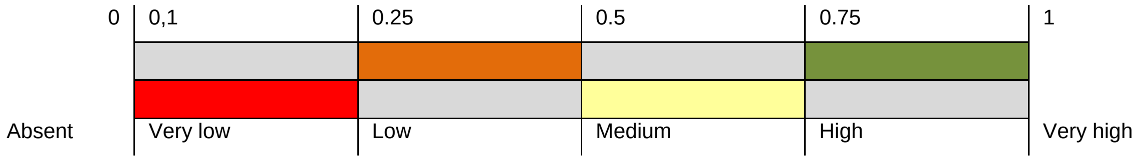

Figure 4.4 - Correspondence between qualitative values and numerical scores

4.1.1. Volcanic Risk

With respect to the first matrix, referred to volcanic risk, it has to be noticed that the obtained values are quite low with respect to all the considered systems: natural and built environment; critical infrastructures and social system.

In detail, with respect to the natural environment, the final scoring of the system translated in a qualitative judgment is low: nevertheless, the final score is an average value resulting from aspects and key topics characterized by high/medium scores and others by very low scores. This is very important in order to identify key topics and aspects on which to act for improving mitigation capacities with respect to the system at stake.
For example, although in the last decades the knowledge of the volcanic phenomena has been significantly improved and hazardous phenomena are effectively monitored on the Vulcano Island, some weaknesses still persist. They can be mainly referred to the lack of detailed maps of the different volcanic phenomena and of hazard scenarios able to take into account the variability of volcanic phenomena over time and in space, both of them indispensible for effectively supporting mitigation measures and emergency management. Moreover, it has to be highlighted the lack of early warning system and also of structural defence measures, which could be very significant for some of the volcanic phenomena, such as lahars. Nevertheless, very recently, a project related to the canalisation of rainwater to collect water from the volcano flanks in order to mitigate debris flows in the area of Porto Levante has been set up; such defence measures, although not specifically related to lahars, could be effective in mitigating these phenomena in the northern area of the island. The importance of the mentioned defence measure has been taken into account in the third matrix, related to landslides.
Nevertheless, these key topics, due to the fact that they are not relevant to all the volcanic phenomena, have been weighted 0.5, reducing their importance with respect to the final scoring of the Natural System.
The final score obtained with respect to the built environment is very low. In this case, two main aspects have been investigated: the first one is related to the knowledge of exposure and vulnerability of built environment; the other is related to the availability and efficacy of rules and tools for mitigation. Both of them show relevant weaknesses. In detail, neither official maps nor studies and research work on exposure and vulnerability of built environment in face of the different volcanic phenomena are currently available and, even though the recently approved Master Plan identifies a volcanic hazard prone area, defining it as: “Volcanic risk: territorial organization linked to civil protection”, no specific constraints for reducing exposure and vulnerability of built environment are explicitly provided.

The final score obtained with respect to the third system, related to critical infrastructure and production sites, is also low; it is worth nothing that in the Vulcano island the existing infrastructures can be considered critical only at local scale and no vulnerability assessment is currently available, whereas some projects for improving the capacity for facing emergency have been developed: a new road connecting the area of Porto Levante, which is the most densely populated mainly in summer and the most exposed to volcanic phenomena, with the safer area of Piano; a new collecting place in the area of Porto and a medical aid with hydro-ambulance for providing first assistance in case of emergency. On the opposite, it has to be noticed that at present no relevant production sites are located on the island (whose main resource is represented by tourism), whereas new sites for production are foreseen by the Master Plan in areas which might be affected by volcanic phenomena (fig. 4.5).

Finally, the social system has obtained a low final score although, also in this case, the different aspects and key topics show very heterogeneous values. Firstly, it is worth noting that, according to the surveys developed by the UNIGE team through questionnaires on a sample of local population (section 3.1), expectation of a future eruption in a long time span (<100 years) is good, but expectation of an eruption in a short time (<12 months) is very low. Thus, preparedness at individual level is very low and it is worsened by the lack of an emergency plan and the absence of media campaigns and education programs aimed at increasing risk awareness.

With respect to the capacity of local economic stakeholders to invest in mitigation measures, it is worth noting that local economy, based on tourism, can be placed at an average level: incomes are all above 15000 € per year, most between 15-30 thousand €/year and no one is below the poverty threshold. Nevertheless, there are no relevant economic stakeholders and the island belongs to a very poor region: the value of the GDP pro-capite in Sicily is one of the lowest in Italy. These features have important repercussions on the local scale in terms of provision of public services, lack of cultural and social activities and strategic development strategies. Moreover, according to this, it could be stated that public resources for mitigation would be difficult to raise, at least at regional level.

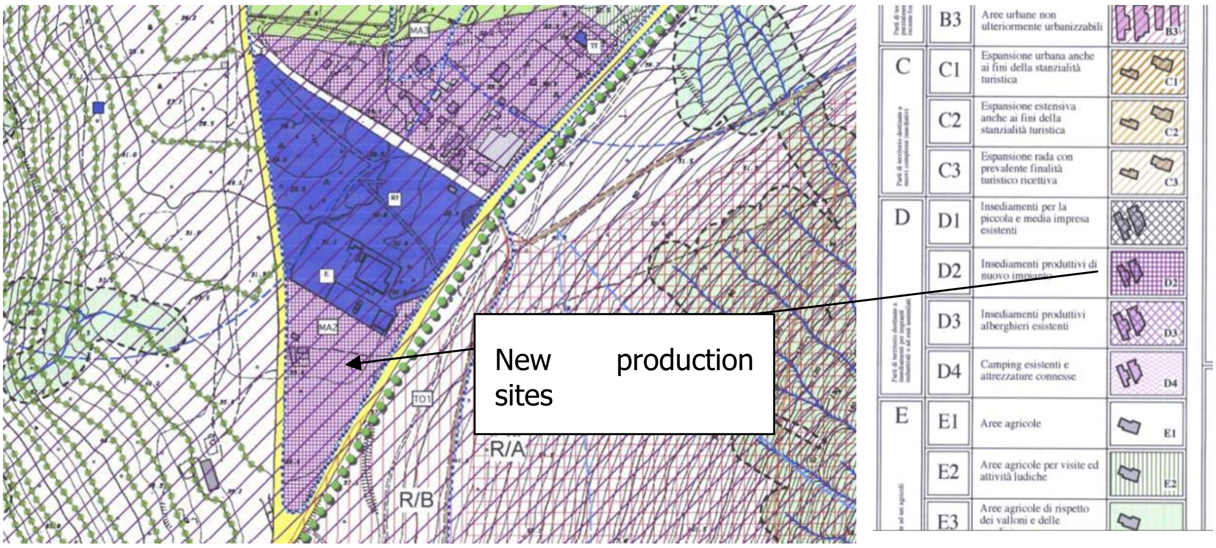

Figure 4.5 – An extract from the Vulcano Master Plan

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Parameters	Criteria for assessment	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring Parameter	Scoring key-topic	Scoring Aspect	Scoring System
Natural environment	*Natural Hazards knowledge*	1	Are volcanic hazards known and mapped?	1	Volcanic hazard maps availability	binary scale based on data collection	yes/no	YES	The official hazard map of Vulcano island used by the Italian Civil Protection is by Dellino and La Volpe (1997). The map focuses on the distribution of diluted pyroclastic density currents (Dellino P, Volpe LL (1997) and is the result of a research project developed between 1993 and 1995 by the Italian National Council of Research- National Group for Volcanology and titled "Progetto Vulcano". (see: "Stratigrafia, dinamiche eruttive e deposizionali, scenario eruttivo e valutazioni di pericolosità a La Fossa di Vulcano", Felici Editore). Furthermore, it has to be considered that the map is not an "official" one, as in the case of Maps provided by Basin Authorities. Finally, it has to be noticed that, although the scale of the hazard assessment seems to be adequate, the lack of a detailed assessment of some of the volcanic phenomena (ashes, lahars...), which clearly depends on the hypothesis on which the assessment has been carried out, might be insufficient for a correct definition of mitigation measures.	1	0,75 = High	0,44 = Low	0,3 = Low
					Scale of hazad maps adequate to support prevention and mitigation measures	qualitative scale based on expert judgement	adequate, partially adequate, inadequate	PARTIALLY ADEQUATE		0,5			
			Are spatial and temporal dynamics of volcanic hazards and synergies among them and other natural hazards (e.g. tsunami) considered?	1	Hazard scenarios, taking into account spatial and temporal dynamics of volcanic hazards and including enchained events, availability	qualitative scale based on data collection	not available, available but not satisfactory, available	NOT AVAILABLE	No hazard scenarios showing potential synergies among different phenomena and the temporal dynamics of volcanic phenomena are currently available.	0	0 = Absent		
			Is available knowledge updated?	1	Hazard maps updating	binary scale based on data collection	yes/no	NO	There are recent studies, but they do not represent official maps. The most recent study has been published by Dellino et al. (2010). It accounts for a more detailed stratigraphy and a quantification of potential damage on the built environment (Dellino P, De Astis G, La Volpe L, Mele D, Sulpizio R (2010) Quantitative hazard assessment of phreatomagmatic eruptions at Vulcano (Aeolian Islands, Southern Italy) as obtained by combining stratigraphy, event statistics and physical modelling, Journal of Volcanology and Geothermal Research). New stratigraphic work has been developed in the frame of a PhD project at the University of Pisa (Dr Federico Di Traglia) and the project ENSURE as part of a collaboration with Prof. Mauro Rosi. Associated results have not been published yet but they could highlight fundamental differences with the work of Dellino and colleagues.	0	0 = Absent		
					Frequency of update	qualitative scale based on data collection	any time new knowledge is available/ any time activity changes/ occasionally	—					
			Are hazards monitored?	1	Availability of volcanic hazards monitoring systems	binary scale based on data collection	yes/no	YES	According to INGV geochemical phenomena are currently monitored: http://www.pa.ingv.it/sorveglianza/elettronica/elettronica.html; seismic activity is also monitored by INGV and there are currently 4 permanent seismic stations on the island	1	1 = Very High		
					Quality and density of monitoring systems	qualitative scale based on expert judgement	good, medium, scarce	GOOD		1			
	Tools for prevention	0,5	Are monitoring systems connected to forecasting modelling systems?	1	Avalilability of volcanic hazards monitoring systems linked to forecasting systems	binary scale based on data collection	yes/no	NO		0	0 = Absent	0 = Absent	
					Quality of forecasting models connected to hazard monitoring systems	qualitative scale based on expert judgement upon the quality of forecasting models	good, medium, low	—					
					Existence of early warning systems	binary scale based on data collection	yes/no	NO		0			
			Are structural defence measures available and effective?	0,5	Existence of structural defence measure	binary scale based on data collection	yes/no	NO	A project related to the canalisation of rainwater to collect water from the volcano flanks in order to mitigate mud and debris flows in the area of Porto Levante has been recently set up. Such defence measures, should be effective also in respect to lahars, Nevertheless, it has been taken into account in the matrix related to landslides.	0	0 = Absent		
					Effectiveness of existing structural defence measures	qualitative scale based on expert judgement upon the effectiveness of defences	effective, partially effective, ineffective	—					
					State of maintenance of defences	qualitative scale based on expert judgement upon the state of maintenance	high, medium, low	—					
Built environment	*Exposure and vulnerability of built environment knowledge*	1	Is exposure and vulnerability known and considered in plans?	1	Risk maps and scenarios, including enchained events availability	binary scale based on data collection	yes/no	NO	The study published by Dellino et al. (2010), providing a quantification of damage on the built environment, should represent a first assessment of risk, although it is not official and exposure and vulnerability assessment has not been explicitly considered.	0	0 = Absent	0 = Absent	0,1 = Very Low
					Vulnerability assessment of exposed built stock availability	binary scale based on data collection	yes/no	NO		0			
					Frequency of update	qualitative scale based on data collection	any time new buildings are built/only occasionally	—					
					Vulnerability and exposure assessment included in ordinary plans (example land use)	binary scale based on data collection	yes/no	NO	The new Master Plan which has been approved only in November 2010 does not include exposure and vulnerability assessment. It only includes, according to the Italian National Law, a geological report. Nevertheless, it has to be noticed that the Sicily Region has a very old law on land use planning. Thus, according to the regional law, local Master Plan are not forced to include risk assessment, whereas in other Italian regions (e.g. Emilia Romagna, exposure and vulnerability assessment are explicitly mentioned as contents of a Master Plan.	0			
	Rules and tools for risk mitigation	1	Do rules for risk mitigation exist? What is their expected efficacy/quality?	1	Building codes/rules availability	binary scale based on data collection	yes/no	NO	There are no building codes in Italy related to volcanic hazards. At local scale no specific rules for buildings in areas affected by volcanic risk have been issued. Local Master Plan and Building Regulations (Regolamento Edilizio) do not include any specific rule for building in volcanic hazard prone areas.	0	0,2 = Very Low	0,2 = Very Low	
					Quality and update of building codes/rules	qualitative scale based on expert judgement	taking into account new knowledge and info/only occasionally updated	—					
					Traditional building practice based on hazard knowledge	binary scale based on expert judgment	yes/no	NO	Traditional eolian architecture seems to be more careful to the problems linked to hot temperatures and water scarcity than to the ones related to volcanis hazards.	0			
					Land use plans embedding risk mitigation measures	binary scale based on data collection	yes/no	YES	In the Master Plan recently approved a large area has been identified as a volcanic hazard prone area. In detail, this large area is defined as: "Volcanic risk: territorial organization linked to civil protection". This area, which includes not only the Volcano itself but the built up areas of Porto Ponente, Porto Levante e Vulcanello, is superimposed to the functional zoning defined by the Master Plan and no specific limitations are defined. Some constraints have been defined for all the areas affected by "geological risks". In detail, according to the technical norms of the MasterPlan, in these areas the re-building of existing houses in case of collapses or demolitions is not allowed; nevertheless, according to the norms for each functional zone, new buildings are allowed after in-depth geognostic surveys. No rules for reducing exposure and vulnerability of built environment are explicitly provided by the new Master Plan, although it recognizes that existing built up areas are at risk.	1			
					Quality of mitigation measures included in land use plans	qualitative scale based on expert judgement	formal/substantial with limitation and specific requirements for new settlements/substantial with limitation and specific requirements for new and existing settlements	FORMAL		0			
					Integration to other measures (insurance)	binary scale based on data collection	yes/no	NO		0			
Infrastructure and production sites	*Exposure and Vulnerability of Critical infrastructures: knowledge and mitigation*	1	Is vulnerability of critical infrastructures assessed and acted upon? Particularly with resepct to na-techs and enchained effects on depending systems?	1	Vulnerability assessment of critical infrastructure availability	binary scale based on data collection	yes/no	NO		0	0,4 = Low	0,4 = Low	0,3 = Low
					Frequency of updating	qualitative scale based on data collection	each time new projects are drawn/only occasionally	—					
					Current Maintenance Programs embedding mitigation	binary scale based on data collection	yes/no	YES	According to the available information all the ports of the island (Levante, Ponente, Gelso) have been secured and upgraded last year, altghough only for Porto Gelso, Civil Protection requirements have been clearly taken into account.	1			
					Frequency of maintenance activities	qualitative scale based on data collection	regularly/frequently/ occasionally	OCCASIONALLY		0			
					New projects based on hazard/risk assessment	binary scale based on data collection	yes/no	YES	The most relevant project is the new main road connecting the area of Porto with the safer one of Piano. The project, which at present has not been realized, is clearly based on the availbale hazard assessment (Dellino, La Volpe 1997). Another relevant project refers to a new square in the area of Porto, as a center for collecting people for civil protection; the latter has been approved but it has not been financed at present. Finally, a medical aid (presidio medico) with hydroambulance for providing first assistance in case of emergency should be established in Volcan starting from this year (2011).	1			
					Level of coordination among stakeholders	qualitative scale based on interviews and expert judgement	low/medium/high	LOW		0			
	Exposure and vulnerability of Production sites: knowledge and mitigation	0,25	Is the vulnerability of production sites assessed and acted upon particularly with respect to potential na-techs?	0,25	Vulnerability assessment of production sites availability	binary scale based on data collection	yes/no	NOT RELEVANT FOR THE CASE STUDY			0 = Absent	0 = Absent	
					Frequency of updating	qualitative scale based on data collection	each time new plants or transformation of existing ones occurs	NOT RELEVANT FOR THE CASE STUDY					
					Retrofitting measures for existing production sites	binary scale based on data collection	yes/no	NOT RELEVANT FOR THE CASE STUDY					
					New projects based on risk assessment	binary scale based on data collection	yes/no	NO	New production sites are foreseen by the new Master plan in areas at volcanic risk. However, according to the detailed hazard assessment developed within the Ensure Project, the new areas for production might be significantly affected by lahars.	0			
					Rules for existing hazardous plants in risky areas aimed at preventing or mitigating na-tech events	qualitative scale based on data collection and expert judgement	special provisions for hazardous plants/generic rules	NOT RELEVANT FOR THE CASE STUDY					
					Na-tech explicitly accounted for in hazardous installations emergency plans	binary scale based on data collection	yes/no	NOT RELEVANT FOR THE CASE STUDY					

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Parameters	Criteria for assessment	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring Parameter	Scoring key-topic	Scoring Aspect	Scoring System
Social system (agents)	*People/individuals Preparedness*	1	Are individuals aware of existing risks, informed and prepared in case of emergency?	1	Risk perception/ awareness	qualitative scale based on questionnaires	low/average/good	**AVERAGE**	According to surveys developed within the Ensure Project, the awareness of timing of most recent eruption (69%) is good. Expectations of a future eruption in <100 years is also good, but lack of expectation of an eruption in < 12 months suggests that people delay in taking preparedness actions, since the issue is not pressing. Interviewed people were largely split down the middle on the idea of taking actions to increase their ability to respond to the next eruption (e.g., 52% disagreeing they would prepare and 47% agreeing they would).	**0,5**	**0,1 = Very Low**	**0,1 = Very Low**	**0,2 = Very Low**
					Level of coverage of Early Warning Systems (if EW Systems are available)	quantitative scale based on data collection	% of coverage in respect to the population	—	According to surveys developed within the Ensure Project, concern about lack of information, no provision for elderly and a lack of drills have been expressed by several interviewed.				
					Individual preparedness in terms of availability of masks and sholves	qualitative scale based on questionnaires	low/average/good	**LOW**	A majority of respondents believe they would have from few minutes to some hours to react before an eruption. But, few people indicated they have an emergency supply kit on hand.	**0**			
					Known evacuation procedures	binary scale based on questionnaires	yes/no	**NO**	At present, the Emergency Plan is not avalible; thus, evacuation procedures are not clearly defined.	**0**			
					Evacuation drill (training) frequency	qualitative scale based on data collection	Regularly (every year)/every few years/occasionally	**OCCASIONALLY**	The only evacuation drill on the island was done in November 1991. They used one ferry (SIREMAR) in Porto Ponente and one ferry (NGI) in Gelso. Moreover, according to the surveys developed within the Ensure Project, many people have not a clear idea of where to go and what to do in case of emergency In detail, the questionnaires reveal that 43% of interviewed, answered that in case of eruption they would have gone to specific meetings points, while 40% declared they don't know what to do.	**0**			
	Mitigation capacity of Institutions	1	Are Institutions able to involve community/ies in mitigation strategies and improve risk awareness? Is the level of cooperation among different institutions in charge of risk prevention/ mitigation satisfactory?	1	Participation in development and prevention/mitigation strategies	qualitative scale based on questionnaires and expert judgment	not existant/average/good	**NOT EXISTANT**		**0**	**0,1 = Very Low**	**0,1= Very Low**	
					Media campaigns	binary scale based on data collection	yes/no	**NO**		**0**			
					Frequency of media campaigns	qualitative scale based on data collection	every two years/only occasionally	—					
					Education programs embedded in school programs	binary scale based on data collection	yes/no	**NO**		**0**			
					Coordination and cooperation among institutions in charge of risk prevention/ mitigation	qualitative scale based on interviews and expert judgement	low/average/high	**AVERAGE**		**0,5**			
	Mitigation capacity of economic stakeholders	1	Do local economic stakeholders have sufficient resources for mitigation?	1	GDP; GVA (Gross added value, measure of productivity and size of economy)	qualitative scale based on data collection	rich/average/poor country	**AVERAGE**	Tourism represents the leading economic activity. Thanks to tourism, local economy is placed at an average level: incomes are surely all above 15000 € per year, most between 15-30 thousand €/year and, according to the surveys developed within the Ensure Project, no one is below the poverty threshold. Nevertheless, the regional economic context is very poor: the value of the GDP pro-capite in Sicily is one of the lowest in Italy. The low level of the regional economy might have relevant repercussions on the local scale in terms of provision of public services, lack of cultural and social activities and strategic development strategies. According to this, it seems possible to state that private stakeholders should have an average capacity to raise funds for mitigation, but public resources would be difficult to raise. National or European funds would be required although the Volcano island should represent not a priority in the Italian situation where other volcanic areas, like the Vesuvius area for example, would require funds for mitigation activities.	**0,5**	**0,75 = High**	**0,75 = High**	
					dimension of poverty/marginalization	qualitative scale based on data collection	low/average/high	**LOW**	As mentioned above, no one is below the poverty threshold; almost all inhabitants own a house. More than 30% of inhabitants has at least an other property to rent in the summer.	**1**			

Fig. 4.6 (Matrix1) Mitigation capacity - volcanic phenomena

4.1.2. Seismic Risk

As seismic risk is concerned, the final scores obtained for each of the considered systems are slightly higher than the ones obtained with respect to volcanic phenomena. Such a result mainly depends on the presence of building codes at national and regional level for reducing vulnerability of existing and new buildings in face of earthquakes, whereas no rules are available neither for volcanic nor, as we will see in the next pages, for landslides. In detail, with respect to the natural system, it is worth noting that a seismic hazard map is available but no in-depth analyses at local scale have been developed and the potential earthquake-induced hazards (landslides, tsunami) are completely neglected. Finally, it has to be noticed that, despite the good level of the earthquake monitoring system, monitoring devices for tsunami have been placed only in the Stromboli island.

With respect to the built environment, up to now the assessment of exposure and vulnerability of the building stock has not been carried out. Nevertheless, traditional eolian architecture is characterized by detached houses with one or two floors and most of them are in a good state of maintenance: therefore, they should have a good response in face of seismic events. Moreover, despite no specific incentive is available for building stock retrofitting, it is worth noting that in 2010, based on a national law for re-launching the building sector, Sicily has issued a regional Law which allows a raise of 20% in volume for detached or semi-detached houses (very common in Vulcano Island), reserving such an opportunity to buildings which have been legally built up to December 2009 and introducing two further conditions: the control of static condition and the seismic retrofitting of buildings. Hence, such a law could have negative effects, since it might induce an increase of building density in areas affected not only by seismic but also by volcanic hazard or by landslides but, in the meanwhile, it represents an opportunity for private interventions addressed to improve physical vulnerability to earthquakes.

The system of critical infrastructures and production sites has obtained a medium score, which mainly depends on the fact that all new buildings in Italy have to be built according to seismic codes. In contrast, it has to be noticed that, although Sicily Region has started a programme for identifying all critical infrastructures of regional importance and assessing their vulnerability, no critical infrastructure of regional importance has been identified on the

Vulcano island. Hence, for existing critical infrastructures, vulnerability assessment should be implemented at local scale.

With respect to the social system, it has to be firstly mentioned that, despite specific surveys have been developed in order to evaluate the preparedness of local population in face of volcanic events, only indirect information was available with respect to seismic risk. However, due to the fact that seismic events are quite frequent on the Island, that the last earthquake, occurred in August 2010, was largely discussed since it involved numerous tourists, it has been argued that the perception of seismic risk is quite widespread on the island. As in the case of volcanic risk, no plan for managing seismic emergency is currently available, even though in 2010, after the seismic event which hit Lipari and Vulcano, in the Lipari Municipality (which includes the Vulcano island), a Municipal Operative Centre was activated in order to guarantee a coherent management of emergency among all the involved Institutions. The Center should guarantee an effective coordination and cooperation among institutions in charge at least of emergency management.

System	Aspect	Aspect Weight	Key topic	Key topic Weight	Parameters	Criteria for assessment	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-topic	Scoring Aspect	Scoring System
Natural environment	*Natural Hazards Knowledge*	1	Is seismic hazards known and mapped?	1	Seismic Hazard map availability	binary scale based on data collection	Yes/no	YES	In Italy, the seismic hazard map of the whole country has been set up. An interactive map of sesimic hazard is also availble on line (http://esse1.mi.ingv.it/). Moreover, grounding on this map, all the Italian Municipality has been classified in respect to 4 classes: Zone 1 – The most dangerous one, which includes 725 municipalities; Zone 2 – In this zone, which includes 2.344 municipalities, quite big earthquakes can occur; Zone 3 – the 1.544 Municipalities included in the zone are prone to earthquakes of average sesmic intensity; Zone 4 – The less dangerous zone, with a low possibility of seismic damages, which includes 3.488 municipalities. Then, each Region has modified this classification, according to more in-depth analyses. According to such a classification, the Municipality of Lipari (which Vulcano is part of), is included in the Zone 2.	**1**	**0,25 = Low**	**0,5 = Medium**	**0,5 = Medium**
					Scale of hazad maps adequate to support prevention and mitigation measures	qualitative scale based on expert judgement	adequate, partially adequate, inadequate	INADEQUATE		**0**			
					Map for potentially fault rupturing at the ground surface	binary scale based on data collection	Yes/no	NO		**0**			
					Site amplification map	binary scale based on data collection	Yes/no	NO		**0**			
			Are hazards monitored?	1	availability of seismographs and accelerometers networks	binary scale based on data collection	Yes/no	YES	There are four sesimc stations on the Volcano Island (http://www.ct.ingv.it/index.php?option=com_wrapper&view=wrapper&Itemid=215&lang=it)	**1**	**1 = Very High**		
					Density of monitoring system	qualitative scale based on data collection	dense/medium/only individual sparse points	DENSE		**1**			
			Are induced/triggered hazards known and controlled?	0,5	Availability of maps of landslides and estimation of their potential movement consequent to earthquakes	binary scale based on data collection	Yes/no	NO	Map of landslides exists, although it does not include any explicit reference to earthquake induced phenomena. Nevertheless, after the seismic events occurred in August 2010, some Ordinances aimed at preventing people from staying, traveling and bathing on some beaches which might be affected by landslides due to seismic events.	**0**	**0 = Absent**		
					Map of potential liquefaction zones	binary scale based on data collection	Yes/no	NO		**0**			
						quantitative scale based on data collection	% of the area of investigation covered by the map	—					
					Map of tsunami hazard	binary scale based on data collection	Yes/no	NO	Some research works are available, but no official maps have been developed. Nevertheless, it is worth noting that the recently approved Master Plan defines the two areas of Porto ponente and Porto levante as tsunami prone areas.	**0**			
					Tsunami monitoring network	binary scale based on data collection	Yes/no	NO	A tsunami monitoring system is available only for the close island of Stromboli.	**0**			

System	Aspect	Aspect Weight	Key topic	Key topic Weight	Parameters	Criteria for assessment	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-topic	Scoring Aspect	Scoring System
Built environment	*Knowledge of exposure and vulnerability of built environment*	1	Is exposure and vulnerability considered and acted upon in plans?	1	Risk maps and scenarios, including enchained events	binary scale based on data collection	Yes/no	NO		**0**	**0 = Absent**	**0 = Absent**	**0,22 = Very Low**
					Vulnerability assessment of exposed built stock	binary scale based on data collection	Yes/no	NO	A sample survey on vulnerability of building stock has been developed for some settlments of the Sicily Region (GNDT, 2000). Nevertheless, Volcano was not included in this survey.	**0**			
					Frequency of update	qualitative scale based on data collection	any time new buildings are built/only occasionally	—					
					Vulnerability and exposure assessment considered in ordinary plans (e.g. land use plans)	binary scale based on data collection	Yes/no	NO	The recently approved Master Plan Ndo not include any assessment on exposure and vulnerability to earthquakes of building stock	**0**			
	Rules and tools for risk mitigation	1	Do rules for mitigation exist? What is their expected efficacy/quality?	1	Building codes/rules availability	binary scale based on data collection	Yes/no	YES	Seismic Building codes have been issued in Italy in 2003 and updated in 2005 and in 2008 (GU n.29 del 04/02/2008). They have to be applied on the whole Italian territoy, according to the seismic hazard values provided by the INGV (http://esse1.mi.ingv.it/ntc.html)	**1**	**0,44 = Low**	**0,44 = Low**	
					Quality and update of building codes	qualitative scale based on expert judgement	Frequently updated and taking into account new knowledge and info/only occasionally updated	Frequently updated and taking into account new knowledge and info		**1**			
					Traditional building practice based on hazard knowledge	binary scale based on expert judgment	Yes/no	NO	Traditional eolian architecture seems to be more careful to the problems linked to hot temperatures and water scarcity than to the ones related to seismic hazards, although traditional building practices is mainly characterized by detached houses of one or two floors.	**0**			
						Expert judgement about the capacity to conform to the "code of practice"	High/Medium/Low	MEDIUM		**0,5**			
					Maintenance level of built stock	qualitative scale based on data collection and expert judgement	High/Medium/Low	MEDIUM	In the Volcano case, the qualitative judgment is based on photos included in the building data-base, although it would require more in-depth analyses.	**0,5**			
					Specific provisons for retrofitting	binary scale based on data collection	Yes/no	NO	No specific provisions for retroffitting are available.	**0**			
					Indirect incentives for retrofitting	binary scale based on data collection	Yes/no	YES	In 2010, based on a national law for re-launching the building sector, Sicily has issued a regional Law which allows a raise of 20% in volume for detached or semi-detached houses (very common in Volcano Island). The opportunity is reserved to buildings which have been legally built up within the dicember 2009 and is subordined to the control of static condition and to the seismic retrofitting of buildings themselves.	**1**			
					Land use plans embedding risk mitigation measures	binary scale based on data collection	Yes/no	NO		**0**			
					Type and quality of mitigation measures included in land use plans	qualitative scale based on expert judgement	formal/substantial with limitation and specificif requirements for new and existing settlements	—					
					Integration to other measures (insurance)	binary scale based on data collection	Yes/no	NO		**0**			

System	Aspect	Aspect Weight	Key topic	Key topic Weight	Parameters	Criteria for assessment	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-topic	Scoring Aspect	Scoring System
Infrastructure and production sites	*Exposure and Vulnerability of Critical infrastructures: knowledge and mitigation*	1	Is vulnerability of critical infrastructures assessed and acted upon? Particularly with resepct to na-techs and enchained effects on depending systems?	1	Vulnerability assessment of critical infrastructure	binary scale based on data collection	Yes/no	NO	In Sicily Region, critical infrastructures of regional relevance have been identified and vulnerability assessment is in progress. Nevertheless, no critical infrastructures of regional relevance have been identified in the Volcan island. Hence, for exinsting critical infrastructures, vulnerability assessment should be implemented at local scale.	0	0,25 = Low	0,25 = Low	0,4 = Low
					Frequency of updating	qualitative scale based on data collection	each time new projects are drawn/only occasionally	—					
					Current Maintenance Programs embedding mitigation	binary scale based on data collection	Yes/no	NO		0			
					Frequency of maintenance activities	qualitative scale based on data collection	regularly/frequently/ occasionally	—					
					New projects based on hazard/risk assessment	binary scale based on data collection	Yes/no	YES	According to National building codes	1			
					Level of coordination among stakeholders	qualitative scale based on interviews and expert judgement	low/medium/high	LOW		0			
	Exposure and vulnerability of Production sites: knowledge and mitigation	0,25	Is the vulnerability of production sites considered particularly with respect to potential na-techs?	0,25	Vulnerability assessment of production sites	binary scale based on data collection	yes/no	**NOT RELEVANT FOR THE CASE STUDY**			1 = Very High	0,25 = Low	
					Frequency of updating	qualitative scale based on data collection	each time new plants or transformation of existing ones occurs	**NOT RELEVANT FOR THE CASE STUDY**					
					Retrofitting measures for existing production sites	binary scale based on data collection	yes/no	**NOT RELEVANT FOR THE CASE STUDY**					
					New projects based on risk assessment	binary scale based on data collection	yes/no	YES	New production sites are foreseen by the new Master plan; they will have to conform to National building codes.	1			
					Na-tech explicitly accounted for in mitigation strategies	Rules for existing hazardous plants in risky areas	special provisions for hazardous plants/generic rules	**NOT RELEVANT FOR THE CASE STUDY**					
					Na-tech explicitly accounted for in hazardous installations emergency plans	binary	yes/no	**NOT RELEVANT FOR THE CASE STUDY**					
Social system (agents)	*People/individuals Preparedness*	1	Are individuals aware of existing risks, informed and prepared in case of emergency?	1	Risk perception/awareness	qualitative scale based on questionnaires	low/average/good	AVERAGE	Questionnaires on the case study have been specifically focused on perpception and awareness of volcanic risk. Nevertheless, due to the fact that seismic events are quite frequent on the Island and the last earthquake occurred in the August 2010 and was largely discussed since it involved numerous tourists, it should be argued that the perception of seismic risk is quite widespread on the island.	0,5	0,25 = Low	0,25 = Low	0,4 = Low
					Individual preparedness	Level of preparedness in respect to specific self protective measures and to measures included in emergency plans	High/Medium/Low	LOW	No specific data are available. Nevertheless, due to the lack of the Emergency Plan for seimic risk, no measures for improving preparedness are currently available and everything is left to individual sensitivity to the problem.	0			
	Mitigation capacity of Institutions	1	Are Institutions able to involve community/ies in mitigation strategies and improve risk awareness? Is the level of cooperation among different institutions in charge of risk prevention/ mitigation satisfactory?	1	Participation in development and prevention/mitigation strategies	qualitative scale based on questionnaires and expert judgment	not existant/average/good	NOT EXISTANT		0	0,25 = Low	0,25 = Low	
					Media campaigns	binary scale based on data collection	yes/no	NO		0			
					Frequency of media campaigns	qualitative scale based on data collection	every two years/only occasionally	—					
					Education programs embedded in school programs	binary scale based on data collection	yes/no	NO		0			
					Coordination and cooperation among institutions in charge of risk prevention/ mitigation/management	qualitative scale based on interviews and expert judgement	low/average/high	HIGH	In 2010, a Municipal Operative Centre for the Lipari Municipality has been activated in order to guarantee a coherent management of emergency among all the involved Institutions.	1			
	Mitigation capacity of economic stakeholders	1	Do local economic stakeholders have sufficient resources for mitigation?	1	GDP; GVA (Gross added value, measure of productivity and size of economy)	qualitative scale based on data collection	rich/average/poor country	AVERAGE	Tourism represents the leading economic activity. Thanks to tourism, local economy is placed at an average level: incomes are surely all above 15000 € per year, most between 15-30 thousand €/year and, according to the surveys developed within the Ensure Project, no one is below the poverty threshold. Nevertheless, the regional economic context is very poor: the value of the GDP pro-capite in Sicily is one of the lowest in Italy. The low level of the regional economy has relevant repercussion on the local scale in terms of provision of public services, lack of cultural and social activities and strategic development strategies. According to this, it seems possible to state that private stakeholders should have an average capacity to raise funds for mitigation, but public resources would be difficult to raise. National or European funds would be required although the Volcano island should represent not a priority in the Italian situation where other volcanic areas, like the Vesuvius area for example, would require funds for mitigation activities.	0,5	0,75 = High	0,75 = High	
					extent of marginalized groups	qualitative scale based on data collection	low/average/high	LOW	As mentioned above, no one is below the poverty threshold; almost all inhabitants own a house. More than 30% of inhabitants has at least an other property to rent in summer.	1			

Fig. 4.7 (Matrix 2) Mitigation capacity – earthquakes

4.1.3 Landslides

With respect to the third matrix (Fig. 4.8), focused on landslides, the qualitative value obtained for the natural systems, or better for the knowledge and the prevention of hazard factors, is medium, mainly in force of three points: the approval in 2006 of the Extract Plan for the Hydrogeological Setting, issued by the Basin Authority, which represents an update of the previous one; the availability of a monitoring system for the northern sector of the Vulcano at least, and the setting up of some, although minor, structural defence measures for rock falls and of a drainage system for mitigating debris flows in the area of Porto Levante.

On the opposite, the final qualitative value obtained with respect to the built environment is very low. It has to be noticed, indeed, that the Extract Plan for the Hydrogeological Setting does not provide any survey on vulnerability of the exposed building stock although, in theory, vulnerability of exposed elements has been considered, and risk maps have been developed. This is one of the main problems of the landslide hazard and risk maps currently carried out in Italy: they generally single out the triggering areas, neglecting the run out areas. Therefore, they force to undervalue the quantity and quality of exposed elements and their vulnerability. Hence, in many cases, hazard and risk maps differ only slightly one from each other.

Such a consideration can affect also future developments: if new projects have, according to the Italian Law, to respect prescriptions provided by the Extract Plan, the lack of information related to the likely run out areas could drive toward the localization of new residential settlements but also critical infrastructures or industries in such areas.
Questionnaires on the case study have been specifically focused on perception and awareness of volcanic risk. Nevertheless, due to the recent Ordinances of the Major (35 and 36, issued on 20/08/2010) aimed at prohibiting the access to some areas along the coast affected by instability phenomena, it should be argued that the inhabitants have a quite good awareness of the problem, since it has great impacts on the main local economic activity: tourism. Finally, it is worth noting that no emergency plan for landslides is available.

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Parameters	Criteria for assessment	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring Parameter	Scoring key-topic	Scoring Aspect	Scoring System
Natural environment	*Natural Hazards knowledge*	1	Are landslide hazards known and mapped?	1	Hazard maps availability	binary scale based on data collection	yes/no	**YES**	The Extract Plan for the Hydrogeological Setting has been issued by the Basin Authority in 2006. Maps related to landslides phenomena, to hydraulic and geomorphological hazards are available.	1	0,75 = High	0,83 = High	0,74 = Medium
					Scale of hazad maps adequate to support prevention and mitigation	qualitative scale based on expert judgement	adequate, partially adequate, inadequate	**PARTIALLY ADEQUATE**	The scale of the landslide map is 1:10.000; no detailed maps are currently available	0,5			
			Is available knowledge updated?	1	Hazard maps updating	binary scale based on data collection	yes/no	**YES**	The current Plan already represents an update of a previous one.	1	1 = Very High		
					Frequency of update	qualitative scale based on data collection	any time new knowledge is available/ any time activity changes/ occasionally	**ANY TIME NEW KNOWLEDGE IS AVAILABLE**	In the Extract Plan for the Hydrogeological Setting regular updates following further studies or future events or new interventions are foreseen.	1			
			Are hazards monitored?	1	Availability of landislide monitoring systems	binary scale based on data collection	Yes/no	**YES**	According to Tinti et al 1999 there is a electronic distant measurement (EDM) trilateral network called VULNORD which is used to monitor the northern sector of vulcano under the responsability of the "Istituto Internazionale di Vulcanologia" IIV of Catania (now INGV). This together with seismic monitoring and measurements related to the variation in temperature and gas emission from the fumaroles, which can monitor the alteration of the flank constitute the monitoring system in place for landslide of the northern sector. Furthermore a metereological station is available on the Volcano Island.	1	0,75 = High		
					Quality of the monitoring system	qualitative scale based on expert judgement	good, medium, scarce	**MEDIUM**	We don't have updated information on the state of maintenance and the frequency of data collection related to the monitoring system. Nevertheless, according to Tinti et al (1999) it is routinely used	0,5			
	Tools for prevention	1	Are monitoring systems connected to forecasting modelling systems?	1	Availability of landslide hazards monitoring devices linked to forecasting systems	binary scale based on data collection	yes/no	**YES**	According to the National Civil Protection, the warning system for hydraulic and hydro-geological risk is assured by the Civil Protection Department and the Regions through the network of Functional Centre which collects and integrates: qualitative and quantitative data collected by the hydro-meteorological and rain gauge networks, radar meteorology from the national network, available from various satellite platforms for earth observation; spatial data, hydrological, geological, geomorphological and those arising from the monitoring of landslides; the weather patterns, hydrology, hydrogeology and water (http://www.protezionecivile.it/jcms/it/funzionale_idro.wp). Therefore, the meteorological station on the island should be linked this system.	1	0,3 = Low	0,65 = Medium	
					Reliability of forecasting models connected to hazard monitoring systems	qualitative scale based on expert judgement upon the quality of forecasting models	good, medium, low	**LOW**	Since there is only one Functional Centre in each Italian Region, I think that available models at regional scale do not take into account specific local condition	0			
					Existence of early warning systems	binary scale based on data collection	yes/no	**NO**		0			
			Are structural defence measures available and effective?	1	Existence of structural defence measure	binary scale based on data collection	yes/no	**YES**	There are some minor structural defense most for rock falls. A drainage system is in place for debris flow mitigation	1	1 = Very High		
					Effectiveness of existing structural defence measures	qualitative scale based on expert judgement upon the effectiveness of defences	effective, partially effective, ineffective	**PARTIALLY EFFECTIVE**	rockfall fences are effective, but they are quite rare. The drainage system is new.	0,5			
					State of maintenance of defences	qualitative scale based on expert judgement upon the state of maintenance	high, medium, low	**MEDIUM**	rockfall fence seem in quite is in a good state. The drainage system is new.	0,5			
Built environment	*Exposure and vulnerability of built environment*	1	Is exposure and vulnerability considered and acted upon in plans?	1	Vulnerability assessment of exposed built stock	binary scale based on data collection	Yes/no	**NO**	The Extract Plan for the Hydrogeological Setting does not provide any survey on vulnerability of exposed built stock, although in theory, vulnerability of exposed elements has been considered.	0	0 = Absent	0 = Absent	0,12 = Very Low
					Frequency of update	qualitative scale based on data collection	any time new buildings are built/only occasionally	—					
					Risk maps and scenarios, including enchained events	yes/no		**NO**	The Extract Plan for the Hydrogeological Setting includes some risk maps, although very few areas at risk are identified.	0			
					Vulnerability and exposure assessment considered in ordinary plans (example land use)	binary scale based on data collection	Yes/No	**NO**	The recently approved Master Plan does not include exposure and vulnerabiility assessemnt of built stock to landslides and does not clearly mention the analyses developed for the Extract Plan for Hydrogeological Setting.	0			
	Rules and tools for risk mitigation	1	Do rules for mitigation exist? What is their expected efficacy/quality?	1	Building codes/rules	binary scale based on data collection	yes/no	**NO**		0	0,25 = Low	0,25 = Low	
					Quality and update of building codes/rules	qualitative scale based on expert judgement	taking into account new knowledge and info/only occasionally updated	—					
					Traditional building practice based on hazard knowledge	binary scale based on expert judgment	yes/no	**NO**	It's worth noting that most of the settlement in the area of Porto Ponente are located under a slope affected by active phenomena of fast debris flows, as clearly shown in the Extract Plan.	0			
					Level of maintenance of building stock	qualitative scale based on data collectiom	High/Medium/ Low	**MEDIUM**		0,5			
					Land use plans embedding risk mitigation and vulnerability reduction	binary scale based on data collection	yes/no	**YES**	According to the Italian Law, the Master Plan have to take into account all the prescriptions of the Extract Plan for Hydrogeological Setting, Nevertheless, it has to be noticed that the Master Plan does not include any reference to the Extract Plan for Hydrogeological Setting.	1			
					Quality of mitigation measures included in land use plans	qualitative scale based on expert judgement	formal/substantial with limitation and specific requirements for new settlements/substantial with	**FORMAL**	No further developments are foreseen in the risky areas, but no measure for reducing exposure and vulnerability of existing sellments and infrastructures are mentioned.	0			
					Integration to other measures (insurance)	binary scale based on data collection	yes/no	**NO**		0			
Infrastructure and production sites	*Exposure and Vulnerability of Critical infrastructures: knowledge and mitigation*	1	Is vulnerability of critical infrastructures assessed and acted upon? Particularly with resepct to na-techs and enchained effects on depending systems?	1	Vulnerability assessment of critical infrastructure	binary scale based on data collection	yes/no	**NO**	In the risk maps of the Extract Plan for Hydrogeological Setting some streches of road networks are indicated as elements at risk, although detailed analyses are not available.	0	0,25 = Low	0,25 = Low	0,25 = Low
					Frequency of updating	qualitative scale based on data collection	each time new projects are drawn/only occasionally	—					
					Current Maintenance Programs embedding mitigation	binary scale based on data collection	yes/no	**NO**		0			
					Frequency of maintenance activities	qualitative scale based on data collection	regularly/frequently/ occasionally	—					
					New projects based on hazard/risk assessment	binary scale based on data collection	yes/no	**YES**	According to the Italian Law, all the new projects have to take into account prescriptions of the Extract Plan for Hydrogeological Setting	1			
					Level of coordination among stakeholders	qualitative scale based on interviews and expert judgement	low/medium/high	**LOW**		0			
	Exposure and vulnerability of Production sites: knowledge and mitigation	0,25	Is the vulnerability of production sites considered particularly with respect to potential na-techs?	0,25	Vulnerability assessment of production sites availability	binary scale based on data collection	yes/no	**NOT RELEVANT FOR THE CASE STUDY**			1 = Very High	0,25 = Low	
					Frequency of updating	qualitative scale based on data collection	each time new plants or transformation of existing ones occurs	**NOT RELEVANT FOR THE CASE STUDY**					
					Retrofitting measures for existing production sites	binary scale based on data collection	yes/no	**NOT RELEVANT FOR THE CASE STUDY**					
					New projects based on risk assessment	binary scale based on data collection	yes/no	**YES**	According to the Italian Law, all the new projects have to take into account prescriptions of the Extract Plan for Hydrogeological Setting	1			
					Rules for existing hazardous plants in risky areas aimed at preventing or mitigating na-tech events	qualitative scale based on data collection and expert judgement	special provisions for hazardous plants/generic rules	**NOT RELEVANT FOR THE CASE STUDY**					
					Na-tech explicitly accounted for in hazardous	binary scale based on data collection	yes/no	**NOT RELEVANT FOR THE CASE STUDY**					

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Parameters	Criteria for assessment	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring Parameter	Scoring key-topic	Scoring Aspect	Scoring System
Social system (agents)	*People/individuals Preparedness*	1	Are individuals aware of existing risks, informed and prepared in case of emergency?	1	Risk perception/awareness	qualitative scale based on questionnaires	low/average/good	**AVERAGE**	Questionnaires on the case study have been specifically focused on perpception and awareness of volcanic risk. Nevertheless, due to the recent Ordinances of the Major (35 and 36, issued on 20/08/2010) aimed at prohibiliting the access to some areas along the coast affected by instability phenomena, it should be argued that the inhabitants have a quite good awareness of the problem, since it has relevant impacts on the main economic activity of the island: tourism.	0,5	0,25 = Low	0,25 = Low	0,42= Low
					Individual preparedness	Level of preparedness in respect to specific self protective measures and to measures included in emergency plans	High/Medium/Low	**LOW**	No specific data are available. Nevertheless, due to the lack of the Emergency Plan for landslides, apart from the mentioned prohibitions, no measures for improving preparedness are currently available and everything is left to individual sensitivity to the problem.	0			
	Mitigation capacity of Institutions	1	Are Institutions able to involve community/ies in mitigation strategies and improve risk awareness? Is the level of cooperation among different institutions in charge of risk prevention/ mitigation satisfactory?	1	Participation in development and prevention/mitigation strategies	qualitative scale based on questionnaires and expert judgment	not existant/average/good	**NOT EXISTANT**		0	0,25 = Low	0,25 = Low	
					Media campaigns	binary scale based on data collection	yes/no	**NO**		0			
					Frequency of media campaigns	qualitative scale based on data collection	every two years/only occasionally	—					
					Education programs embedded in school programs	binary scale based on data collection	yes/no	**NO**		0			
					Coordination and cooperation among institutions in charge of risk prevention/ mitigation/management	qualitative scale based on interviews and expert judgement	low/average/high	**HIGH**	In 2010, a Municipal Operative Centre for the Lipari Municipality has been activated in order to guarantee a coherent management of emergency among all the involved Institutions.	1			
	Mitigation capacity of economic stakeholders	1	Do local economic stakeholders have sufficient resources for mitigation?	1	GDP; GVA (Gross added value, measure of productivity and size of economy)	qualitative scale based on data collection	rich/average/poor country	**AVERAGE**	Tourism represents the leading economic activity. Thanks to tourism, local economy is placed at an average level: incomes are surely all above 15000 € per year, most between 15-30 thousand €/year and, according to the surveys developed within the Ensure Project, no one is below the poverty threshold. Nevertheless, the regional economic context is very poor: the value of the GDP pro-capite in Sicily is one of the lowest in Italy. The low level of the regional economy has relevant repercussion on the local scale in terms of provision of public services, lack of cultural and social activities and strategic development strategies. According to this, it seems possible to state that private stakeholders should have an average capacity to raise funds for mitigation, but public resources, mainly at regional level, would be difficult to raise.	0,5	0,75 = High	0,75 = High	
					extent of marginalized groups	qualitative scale based on data collection	low/average/high	**LOW**	As mentioned above, no one is below the poverty threshold; almost all inhabitants own a house. More than 30% of inhabitants has at least an other property to rent in summer.	1			

Fig. 4.8 (Matrix 3) Mitigation capacity – landslides

4.1.4 Final Remarks

The assessment of the mitigation capacities in face of the three main hazard factors affecting the Vulcano island clearly highlights how knowledge and mitigation policies are still mainly focused on hazard: in the three matrixes (Figs 4.6, 4.7, 4.8), the scores obtained with respect to the natural system are generally higher than the ones obtained with respect to the built environment, since exposure and vulnerability analyses are still largely neglected and, consequently, structural defence measures are generally favoured with respect to those aimed at reducing exposure and vulnerability.

The Master Plan of Vulcano mirrors the widespread difficulty to pay attention to risk prevention/mitigation which characterizes land use planning in Italy: although land use plans take formally into account hazard and risk analyses, they do not generally provide measures for reducing exposure and vulnerability of existing settlements and, in some case cases, foreseen developments lead to increase current risk features.

Also the aspects related to the level of preparedness of individuals and to the capacity of institution to improve risk awareness are generally low; some attempts to achieve a better coordination among the different institutions in charge of risk management can be recognized, although they are limited to the emergency management and are clearly due to specific contingencies (the occurring of a given hazardous event).

4.2 Physical and systemic vulnerability

4.2.1 Tephra

Two main areas have been evaluated: as far as the vulnerability of tephra is concentrated in Porto Levante and Piano, respectively northern and southern area of the Volcano island (Fig. 4.9).

The evaluation has been carried out with regard to physical and systemic propensity to damage of natural and built environment, of critical infrastructures and social system.

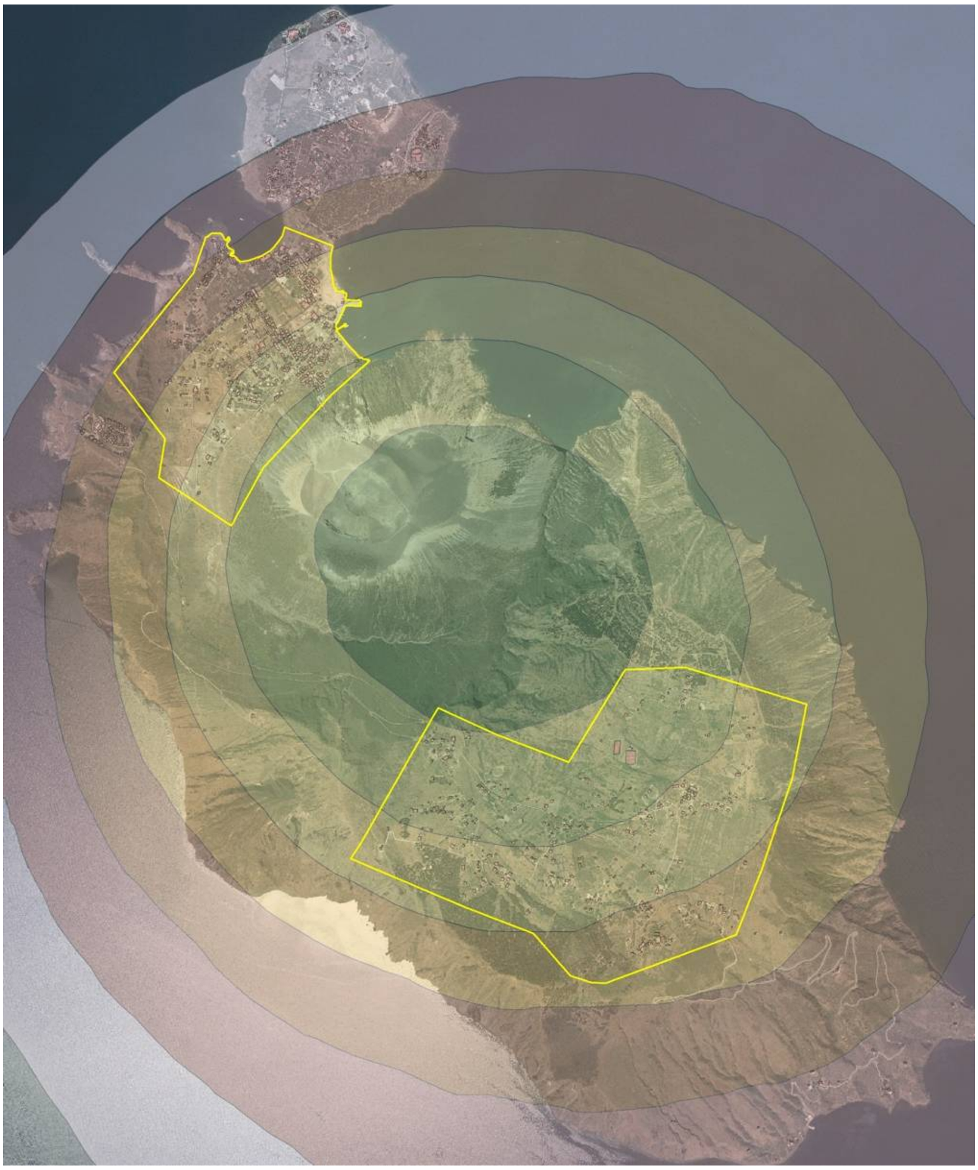

Fig. 4.9 – Case study area

The Scoring System

The scoring system applied to assess the physical and systemic vulnerability is based on the weighted sum approach. For each criteria two value have been assigned: one is to assess the weight (from 1, high, to 0, not relevant) of each parameter with reference to the aspect; the other one is to assess the degree of vulnerability (from 1, low, to 5, high) related to that parameter. Thus, in order to assess the vulnerability of the system, each weighted value of vulnerability is summed to the others and then compared with the reference scale whose limits are identified by the minimum and the maximum achievable value of vulnerability.

	System	Aspect		Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring (3 high - 1 low)	Weight (1 high - 0 not relevant)		Total Score
Natural system	Natural ecosystems	Are natural ecosystems fragile to the potential effects of hazard(s)?		presence of vegetation and forests on the volcanic slopes	binary, coverage and type	yes/no, % and type		2	0.5	1	2-Low
		Can natural systems interact with hazard(s)?		type of soil, vegetation	soil/rock analyses of (loose soil, trees with long and extended roots, vegetation or with superficial roots)	qualitative, scenario dependent		2	0.5	1	
		Are natural ecosystems vulnerable to mitigation measures taken particularly during the emergency phase?		presence of ecosystems that may be endangered by lava flows deviations	binary, type	yes/no, type of vegetation and other species			NOT RELEVANT		

Fig. 4.10 - The scoring system

Physical Vulnerability

Natural System

The assessment of physical vulnerability to tephra of natural environment has been accomplished identifying and classifying open spaces within the investigation area. It has to be underlined that, as mentioned above, the Corine Land Cover was not usable in the selected case-study: also the most detailed level of the mentioned database was, indeed, not enough detailed in respect to the scale of analysis. Thus, the identification and classification of the open spaces have been carried out through cartographies (update cartography scale 1:2000), orthophotos and in situ surveys. Hence, the classification of open spaces is based, firstly, on the morphological features of the site and on the analysis of orthophotos, cartographies and in situ survey. Due to the characteristic on the tephra hazards, open spaces have been classified in permeable and impermeable areas (such as paved surfaces, such as roads, etc.) (Fig. 4.10). The former consist mainly of volcanic soil, vegetable gardens, vineyards or uncultivated zones, open spaces with trees (such as fruit trees, acacias and so on). Further, slope areas defined by widespread vineyards, orchards and Mediterranean scrubs have been distinguished by level plane, characterized by the presence of numerous private gardens, vegetable gardens and by pasture and uncultivated land with isolated trees or scrubs, because it is more likely that tephra will slide on the steep areas and thicken on the plain ones. Hence, according to this classification of open spaces both the ecosystem's fragility and the capacity of the natural system to interact with hazard have been considered. Regarding the first aspect, the effect of tephra covering the leaves of different plants and its acid nature will determine a decrease of their capacity of photosynthesis and mainly in those plants placed on the plain. In addition, tephra may bury herbs and brushes stronger effects on the vegetation show up when layers are thicker. Whereas, with reference to the capacity of natural system to interact with hazard, in the literature, it has been underlined that in the short-terms some positive effect may emerge, such as a reduction in the required amount of fertilizer, while negative impacts may be induced on soil, such as soil acidification, and on livestock.

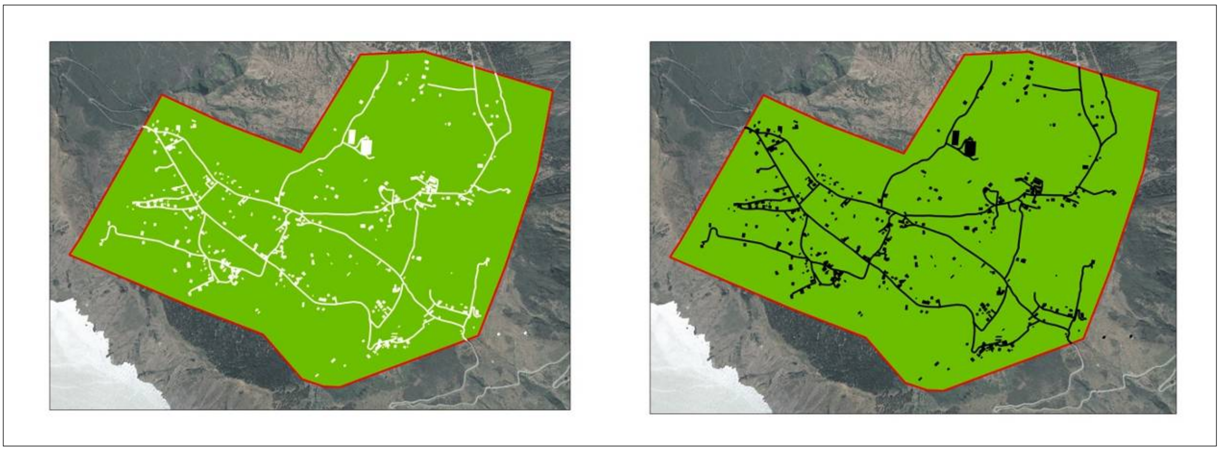

Fig. 4.11 - Permeable and Impermeable areas

Built Environment

The second part of the matrix is related to the vulnerability of the built environment to tephra.

Grounding on the available data, (such as orthophotos, photographic database and updated maps scale 1:2000) and according to the features of the considered hazard, buildings in the area of investigation have been classified according to the following features:

- Roof
- Shape
- Maintenance
- Position

Therefore, buildings have been classified in relation to the features of roofs, distinguishing roofs (plane or pitched) from patios, lean-to roof (tettoie) and pergolas (Fig. 4.11). Then, they have been classified with reference to the quality of the maintenance level (from vey high to low). In addition, specific study on Vulcano's roofs carried out by Prof. Lestuzzi at University of Losanna pointed out that with a probability of accumulation of 300kg/m2 of tephra the lower degree of vulnerability regarding a roof is with a pitch of 30°. Thus considering the main typology present on the island, for this parameter is generally high. Furthermore, those parameters, which are not relevant for tephra, are highlighted in grey; on the other hand, those parameters colored in orange are relevant, but due to lack of data they have been excluded from the evaluation process.

Fig. 4.12 – Roof types

Physical vulnerability assessment has been developed applying the parameters included in the modified matrix (Figure 4.16). Grounding on the photographic database, the number and quality of openings, the level of maintenance have been assessed for each building. Whereas, in order to analyze the level of buildings' vulnerability with respect to their position, wind direction as well as different levels of probability of reaching an accumulation of 300kg/m^2 and four different distances have been considered:

- in case of infrastructures located at a distance of 1 kilometer from the crater slope, vulnerability level has been considered high;
- in case of infrastructures located at a distance of 1.5 kilometer from the crater slope, vulnerability level has been considered high-medium;
- in case of infrastructures located at a distance of 2 kilometers from the crater slope, vulnerability level has been considered medium-low;
- in case of infrastructures located at a distance of 2.5 kilometers or more from the crater slope, vulnerability level has been considered low;

In addition, the physical vulnerability of historical buildings, pointed out accordingly to the survey carried out by the Master Plan, and of public facilities (churches and schools) have been assessed taking into account the criteria of distance from hazardous sources.

Fig. 4.13 - Historical buildings

Fig. 4.14 - Historical buildings

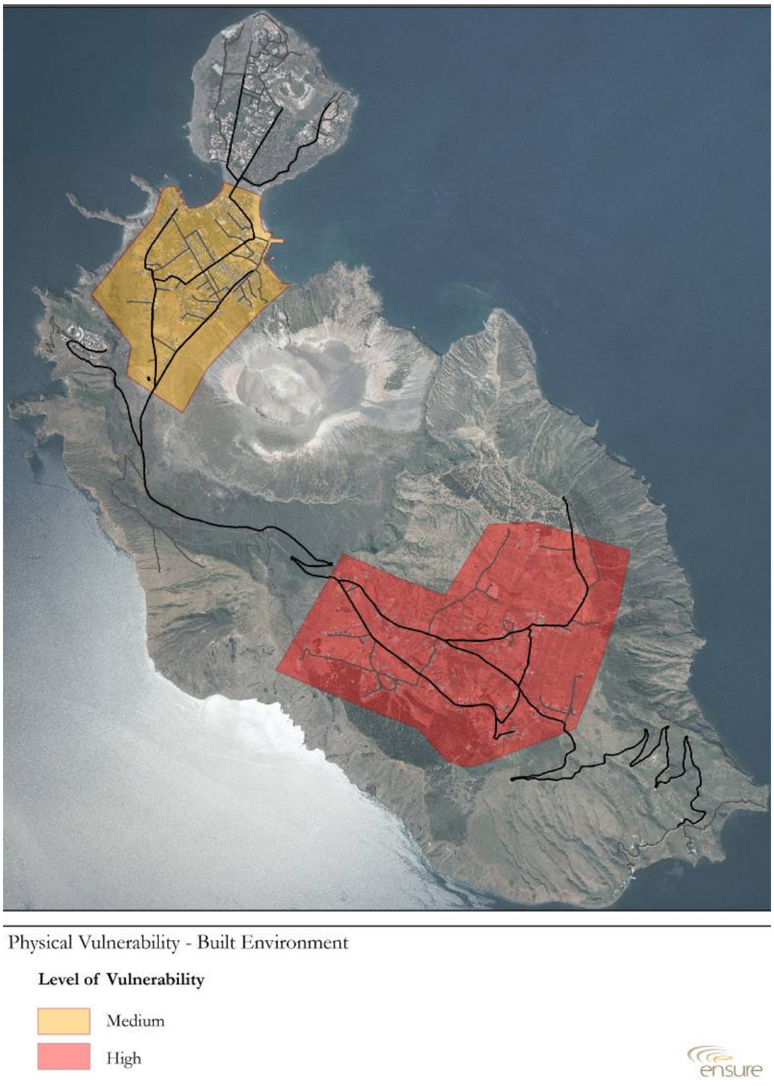

Fig. 4.15 - Physical Vulnerability of Built Environment

	System	Aspect		Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring (5 high - 1 low)	Weight (1 high - 0 not relevant)		Total Score
Built environment	*Exposure and vulnerability of built environment*	What are the factors that make buildings, the urban fabric and public facilities vulnerable to the stress?	Buildings	roof	connection to structure	good/poor	no data available				30,5=High
					weight	heavy/light	no data available				
					shape and material	large inclination/plane	The proposed classification of European roof types for tephra fall resistance (Spence et al., 2005) : WEAK: Sheet roofs, old or in poor condition. Tiled roof, old or in poor condition. Masonry vaulted roof. MEDIUM/WEAK:Sheet roof on timber; average quality; average or good quality tiled roof on timber rafters or trusses. Steel or precast reinforced concrete joists and flat terrace roof. MEDIUM: Flat reinforced concrete roof not all above characteristics; sloping rein- forced concrete roof. Sheet roof on timber rafters or trusses, good quality and condition, de- signed for cyclone areas. S TRONG: Flat reinforced concrete roof designed for access; recent, good quality construction, younger than 20 years. Furthermore, when the VEI are equal to 300 kg/m2 picthed roofs (with a sharp less than 30°) act as a plain one.	5	1	5	
				structure	material	iron, reinforced concrete, masonry (different types), other		NOT RELEVANT			
					homogeneity	large/largely disomogenous	no data available				
					type of connection among parts	good/poor	no data available				
					floors rigidity	rigid/non rigid	no data available	NOT RELEVANT			
				foundation	depth and type	non-existent, deep, superficial		NOT RELEVANT			
				spans between resistant elements	distance in m.	> 3 mt; < 3 mt (for masonry mainly)		NOT RELEVANT			
				shape	openings	number and dimension of windows/doors		5	1	5	
					quality of openings	may be easily sealed/not		5	0,5	2,5	
					basement	existant/non existant		NOT RELEVANT			
					inflammable objects	existant/non existant	no data available	4			
					sources of radiation or toxic chemicals	existant/non existant	no data available				
				maintenance	building conditions	very poor/ good		3	1	3	
				position	soil on which the building is built (crest, alluvial deposits, etc.)	amplification soils yes/no		NOT RELEVANT			
					with respect to dangerous channels	parallel/perpendicular		INADEQUATE			
					distance from dangerous areas	inside/outside potentially affected areas (scenario dependent)		5	1	5	
			Historical buildings		building conditions	very poor/ good	no data available				
					distance from dangerous areas	inside/outside potentially affected areas (scenario dependent)	presence of historical building in Porto Levante area	4	1	4	
			Vulnerability assessment of public facilities		internal machinery sensitive to the volcanic hazards	yes/no; type of machinery	no data available				

	System	Aspect		Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring (5 high - 1 low)	Weight (1 high - 0 not relevant)		Total Score
Built environment	*Exposure and vulnerability of built environment*	What are the factors that make buildings, the urban fabric and public facilities vulnerable to the stress?	Buildings	roof	connection to structure	good/poor	no data available				24,5=Medium
					weight	heavy/light	no data available				
					shape and material	large inclination/plane	The proposed classification of European roof types for tephra fall resistance (Spence et al., 2005) : WEAK: Sheet roofs, old or in poor condition. Tiled roof, old or in poor condition. Masonry vaulted roof. MEDIUM/WEAK:Sheet roof on timber; average quality; average or good quality tiled roof on timber rafters or trusses. Steel or precast reinforced concrete joists and flat terrace roof. MEDIUM: Flat reinforced concrete roof not all above characteristics; sloping rein- forced concrete roof. Sheet roof on timber rafters or trusses, good quality and condition, de- signed for cyclone areas. S TRONG: Flat reinforced concrete roof designed for access; recent, good quality construction, younger than 20 years. Furthermore, when the VEI are equal to 300 kg/m2 picthed roofs (with a sharp less than 30°) act as a plain one.	5	1	5	
				structure	material	iron, reinforced concrete, masonry (different types), other		NOT RELEVANT			
					homogeneity	large/largely disomogenous	no data available				
					type of connection among parts	good/poor	no data available				
					floors rigidity	rigid/non rigid	no data available	NOT RELEVANT			
				foundation	depth and type	non-existent, deep, superficial		NOT RELEVANT			
				spans between resistant elements	distance in m.	> 3 mt; < 3 mt (for masonry mainly)		NOT RELEVANT			
				shape	openings	number and dimension of windows/doors		5	1	5	
					quality of openings	may be easily sealed/not		5	0,5	2,5	
					basement	existant/non existant		NOT RELEVANT			
					inflammable objects	existant/non existant	no data available	4			
					sources of radiation or toxic chemicals	existant/non existant	no data available				
				maintenance	building conditions	very poor/ good		3	1	3	
				position	soil on which the building is built (crest, alluvial deposits, etc.)	amplification soils yes/no		NOT RELEVANT			
					with respect to dangerous channels	parallel/perpendicular		INADEQUATE			
					distance from dangerous areas	inside/outside potentially affected areas (scenario dependent)		5	1	5	
			Historical buildings		building conditions	very poor/ good	no data available				
					distance from dangerous areas	inside/outside potentially affected areas (scenario dependent)	presence of historical building in Porto Levante area	4	1	4	
			Vulnerability assessment of public facilities		internal machinery sensitive to the volcanic hazards	yes/no; type of machinery	no data available				

Fig. 4.16 - Matrix related to physical vulnerability of Built Environment

Critical Infrastructures

The only critical infrastructures were assessed as far as the third section of the matrix developed in WP4 is concerned as no relevant production site is located on the Volcano island. As can be seen by the matrix, physical vulnerability of critical infrastructures to tephra depends mainly on factors related to features of the infrastructures and their position in relation to tephra fall down. The assessment has been accomplished on the base of the modified matrix for the entire island due to the characteristic of tephra hazards. Thus, firstly, all the critical infrastructures have been highlighted (Fig. 4.17). The matrix (Figure. 4.18) has been modified distinguishing among different kind of critical infrastructures and between linear (networks) and point-shaped elements. Furthermore, those parameters, which are not relevant for tephra, are highlighted in grey; on the other hand, those parameters colored in orange are relevant. Due to lack of data referring to features and position of networks the water system was not been assessed. On the base of articles found in literature regarding the effects of tephra fallout on these kind of lifelines in some other eruptive events, interactions between electricity and communication lines have been assessed. Furthermore, the assessment of physical vulnerability has been focused on point-shaped elements and on the position of the primary and secondary road network. The former, considered as critical at least at local scale, are located in the area of investigation: the INGV building, the medical center, the police force (Carabinieri), the two power plant (solar and electrical), the telecommunication center the two ports (Porto Ponente and Levante), the gasoline station. For each element, the assessment has been accomplished taking into account some parameters related to physical vulnerability of buildings in which they are placed and their position in respect to tephra.

Fig. 4.17 - Critical Infrastructures on the Vulcano island

Hence, regarding to the last parameter, the assessment has been taking into account the position of each infrastructure in respect to tephra spread and its distance from the hazard source. According to this, four relevant different distances, wind direction and different levels of probability of reaching an accumulation of 300kg/m^2 have been taken into account in order to graduate the level of vulnerability:

- in case of infrastructures located at a distance of 1 kilometer from the crater slope, vulnerability level has been considered high;
- in case of infrastructures located at a distance of 1.5 kilometer from the crater slope, vulnerability level has been considered medium-high;
- in case of infrastructures located at a distance of 2 kilometers from the crater slope, vulnerability level has been considered medium-low;
- in case of infrastructures located at a distance of 2.5 kilometers or more from the crater slope, vulnerability level has been considered low;

The assessment physical vulnerability of the buildings occupied by these infrastructures has been carried out considering the following parameters: roof, level of maintenance.

	System	Aspect		Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring (tephra hazrd)	Parameter Weight		Total Score
Infrastructure and production sites	Critical infrastructures	What are the factors that make critical infrastructures vulenrable (mainly lifelines)	Network	electricity	lines	aerial lines/underground	Volcanic ash, particularly when fine-grained and/or wet, effectively adheres to most surfaces it lands upon, often forming a coating several mm thick. The ash coat is highly conductive and acidic in combination with moisture, due to its high content of salts adhering to the ash particles (Cronin et al., 1998). The composition and grainsize of the ash contaminant is critical to determining whether possible flashover may occur. Flashover of contaminated insulators is a well known phenomena from many locations, due to sea spray (e.g., Higashhiyama et al., 1999), industrial dust (Aulia et al., 2006) and natural dust (Rizk and Assaad, 1971). Typically a combination of fine-grained (< 100 ! m) dust, together with high salt concentrations (up to 1.25 wt.% salts) has shown the greatest potential for contamination (e.g., Chen and Chang, 1996 J.-Y. Chen and R.J. Chang, Field experience with overhead distribution equipment under severe contamination, IEEE Trans. Power Deliv. 11 (1996), pp. 1640–1645. View Record in Scopus | Cited By in Scopus (6)Chen and Chang, 1996).	5	1	5	50,5=Medium
				communication	lines	aerial lines/underground	Interference from ash: Large quantities of electrically-charged ash can be generated in an eruption column. This charged ash can cause interference to radio waves and render radio and telephone systems inoperative. However, there are examples of radio and telephone communications continuing to function around an erupting volcano and in areas receiving ash falls. Overloading of system: During most natural disasters telephone and radio communications are susceptible to overloading by public and emergency services use. Response organizations report frequent overloading of their telephone lines even in cases where the general system remains operative. (http://volcanoes.usgs.gov/ash/commun/index.php#interference)	5	1	5	
				gas	position of gas conducts	across hazardous zones		NOT RELEVANT			
					connection to buildings	vulnerable buildings/not vulnerable)		NOT RELEVANT			
				water	position of water pipes	across hazardous zones	no data available				
					pipes condition	obsolete/new	Corrosive nature of ash can damage and corrode metallic structures				
			Punctual Infrastrutures	sewerage		yes/no;		NOT RELEVANT			
					position of water pipes	across hazardous zones		NOT RELEVANT			
					pipes condition	obsolete/new		NOT RELEVANT			
				INGV	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	2	1	2	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance	Qualitative judgement based on available data	1	0,5	0,5	
				Medical Centre	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	3	1	3	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance	Qualitative judgement based on available data	1	1	1	
				Carabinieri	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	4	1	4	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance	Qualitative judgement based on available data	5	1	5	
				Porto Ponente	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	2	1	2	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance	Qualitative judgement based on available data	1	0,5	0,5	
				Porto Levante	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	4	1	4	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance	Qualitative judgement based on available data	1	0,5	0,5	
				Solar Power Plant	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	5	1	5	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance					
				Electrical Power Plant	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	4	1	4	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance	Qualitative judgement based on available data	2	1	2	
				Water tanks	Roof-fed water tank	yes/no; covered/uncovered	A covered water tank will be safe from direct ash fall contamination, and it may provide valuable water supply during periods ash fall if water use is carefully conserved. Water inflow should be closed before ash lands on the source (the house roof in this case), and the top must be regularly swept/shoveled free of ash to avoid collapse. The inflow should not be opened again until the chemical effect of the ash on water supply is determined safe, or the source is cleared of ash. (USGS webpage, last update Jan 2010, http://volcanoes.usgs.gov/ash/water/index.php#quality)	2	1	2	
				Telecommunication Centre	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	4	1	4	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance	Qualitative judgement based on available data	2	1	2	
				Gasoline Station	position	inside/ouside potentially affected areas and distance from hazard source (scenario dependant)	The assessment has been developer grouding on cartography	3	1	3	
					type of materials; typology; specific vulnerability assessment	construction material; level of maintenance	no data available				
		What are the factors that make production sites vulnerable		presence of flammable materials	binary; amount	yes/no; quantities	no data available				

Fig. 4.18 - Matrix related to physical vulnerability of Critical Infrastructures

Socio-economic system

The Vulcano Island’s economy is mainly based on tourism and this determines and high rate of fluctuation of people living on the island among seasons. Accordingly to ISTAT data (2001), 1000 are the residents on the island, but on the based of the information provided by

Local Authorities, only around 500 are permanent residents which means that they live the entire year on the island; while during summer (in particular during July and August), the number of people thanks to tourist flow increases up to 5-10.000 on the island and those are mainly gathered in the areas of Porto and Vulcanello. Consequently, the aspect that the matrix account as more relevant to assess the physical vulnerability of the social system are individuals and community, and in particular their preparedness and susceptibility to suffer damage (Figure 4.19). Hence, the main factors have been taken into account are: on one hand, preparedness (such as training, exercises and information on what to do) and sensitivity to health effects; on the other hand distribution and features (age and impairment) of population. With reference to preparedness activity, any emergency plan has not been drawn up, but an evacuation drill and information leaflets to tourist regarding volcanic risk are available. Whereas, considering those factors, which may lead to large number of victims, the factors, which have been taken into account in order to assess the vulnerability, are related to age and mobility capacity of population and to its concentration in hazardous areas.

	System	Aspect		Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring (5 high - 1 low)	Weight (1 high - 0 not relevant)		Total Score
Social system (agents)	*People/individuals*	What are the factors that may lead to injuries and fatalities?		Preparedness	prior training and exercises; information about what do do	yes/no; frequency of training;	no data available				13=Medium
						information leaflet to tourist	3-4000 tourist a day in high season (june september)	3	0,75	2,25	
						Check point for climbing the volcano	Around 450 people climb the volcano every day between August and September. About 7,000 people were ticketed every month (aug-spet) and round 2,000 people climb with no ticket, thus around 9,000people may be on the volcano every day.	3	1	3	
				Sensistivity to health effects of volcanic hazards	means of self protection	yes/no;	yes	3	1	3	
	Community and Instituions	What are the factors that may lead to large number of victims?		concentration	resident and present population in dangerous areas	inside/outside potentially affected areas (scenario dependent)	The assessment has been developer grouding on cartography	4	0,5	2	
				Age; mobility impairment, other impairment	difficulties to comply with evacuation orders; difficulties in escaping	yes/no; number of people	Yes, 180/1080 people are over the threshold of 65 years old and 63/1080 children between 0-5 years old; no specific data about impairment is available	3	0,75	2,25	

Fig. 4.19 - Matrix related to physical vulnerability of Socio-system

Systemic Vulnerability

Natural Environment

The first part of the assessment matrix refers to the natural ecosystem. The systemic vulnerability assessment to tephra has been carried out only in respect to two aspects: fragility of ecosystems to secondary effects and capacity of a natural system to interact with hazards (Figure 4.20). The classification of open areas is the starting point for answering to the first question posed by the matrix related to the fragility of a natural ecosystem. As it has been described earlier, open areas are characterized by pasture land, vegetable and private gardens, vineyards or by trees, Mediterranean scrub and orchards, which are highly vulnerable to lahars effects. Hence, the natural ecosystem is highly affected by the combination of tephra with water, as secondary effects of tephra hazards. Furthermore, as it has been highlighted by the study concerning lahars, due to the features of the natural system of Vulcano island, it could interact with lahars in two way: positively, due to the deep roots of vegetation which may increase soil compactness and consequently improve its capacity of facing the impact of lahars; or negatively due to the falling down of trunks of trees which provokes a decrease in the quality of the natural system. Nevertheless, the vegetation along the slope does not have deep roots; any shrubs and trees are not widespread in the plain area. Therefore the interaction between natural ecosystem and hazard can be considered low.

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring (5 high - 1 low)	Weight (1 high - 0 not relevant)	Total Scoring
Natural environment	*Natural ecosystems*	Are natural ecosystems fragile to the potential secondary effects of hazard(s)?	induced lahars; induced landslides	binary; extent	yes/no; maps	yes	1	1	2=Low
		Can natural systems interact with hazard(s)?		yes/no; meteorological assessment in the days after the initial crisis	rainy/dry	yes	1	1	
		Are natural ecosystems vulnerable to mitigation measures taken particularly during the emergency phase?	presence of forests and ecosystems in the path where lava flows are going to be deviated	binary	yes/no; types and % of coverage		NOT RELEVANT		

Fig. 4.20 - Matrix related to systemic vulnerability of Natural Environment

Built Environment

The second part of the matrix related to the systemic vulnerability of built environment to tephra hazard has not been assessed due to the lack of an emergency plan and thus to a shelter system whose importance to be protected by tephra fallout is underlined in the literature (Baxter, 1994; Pomonis et al, 1999). Hence, the system vulnerability of Vulcano's built environment has been considered high.

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring (5 high - 1 low)	Weight (1 high - 0 not relevant)	Total Scoring
Built environment	*Exposure and vulnerability of built environment*	What are the factors that make buildings, the urban fabric and public facilities vulnerable to losses?	Quality of temporary shelters (first emergency)	with heating or conditioning; sanitation; density	yes/no; a>1/50 people/ a < 1/50 people; d < 1tent per family/d > 20 persons/tent				
			Quality of more permenent temporary shelters	dimension; availability of services	d > 14 mq/4 persons/ d < 10 mq/4 persons; yes/no				
			Accessibility to potentially damaged areas from temporary shelters	on foot; transportation	d < 500 m/ d> 500 m; available/not available; frequent/not frequent				
			Accessibility to work sites from temporary shelters	on foot; transportation	d < 500 m/ d> 500 m; available/not available; frequent/not frequent				
			Accessibility to public facilities	on foot; transportation	d < 500 m/ d> 500 m; available/not available; frequent/not frequent				

Fig. 4.21 - Matrix related to systemic vulnerability of Built Environment

Critical Infrastructures

The first part of the assessment matrix refers to the infrastructures. The systemic vulnerability assessment to tephra has been carried out in respect to what factors may determine a break in functioning of critical infrastructures. Two main elements are object of the evaluation are: accessibility and infrastructures. The former has been analyzed distinguishing between: internal and external accessibility to critical infrastructure. Hence, as starting point for the assessment, for each of the identified critical infrastructures located on the island the number of accesses has been evaluated, then the specific features of access ways have been analyzed (Fig. 4.22). As internal accessibility to critical infrastructures has been considered a buffer area equal to 500m in order to take into account both a walking distance and a movement of a vehicle (Fig. 4.23). With reference to the external accessibility, or in other words how to reach the island from outside in case of emergency, heliports and ports play a key role in doing this being the only ways of access to the island.

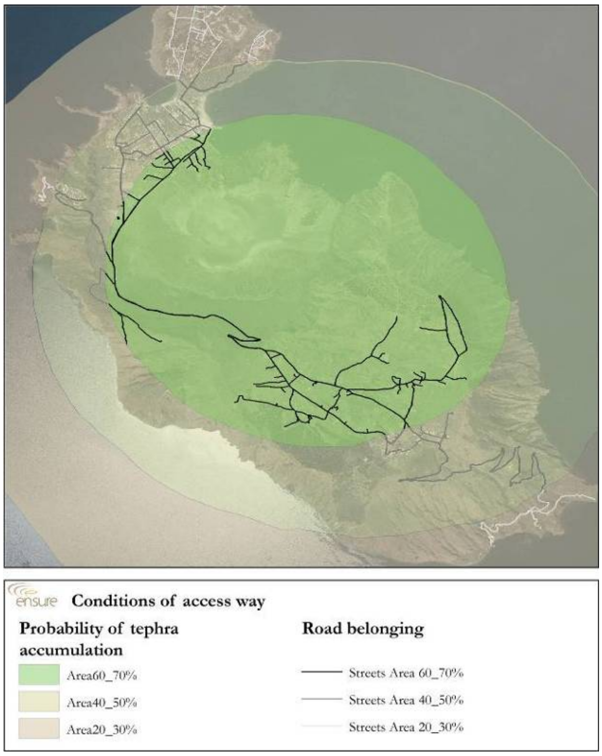

Fig. 4.22 – Condition of access way

The systemic vulnerability to tephra hazard has been assessed taking into account the transferability of functions, in the case of ports, and the criteria of redundancy relatively to the heliports system. While for both of them the criteria of accessibility have been assessed. It is worth to notice that the heliport on the volcano cannot be used as exit way during an emergency phase due to its high vulnerability unless its location is strategic in terms of direct-survey of the conditions of the volcano. However, the more vulnerable areas in terms of external accessibility identified by this study are Piano and Porto Gelso although for different issues, respectively position and accessibility from settlement. Concerning critical infrastructures, as point-shaped elements part of a whole, the assessment has been taken into account factors, such as redundancy and dependency, as key criteria to analyzed the systemic vulnerability of each system (water, communication, electricity, monitoring, health, police force). In case of emergency, Vulcano island needs a relevant external supports, as in the case of water or fuel. In addition, a high level of dependency of each system from the others and a low level of redundancy within the systems can be highlighted. Thus, the vulnerability level is high.

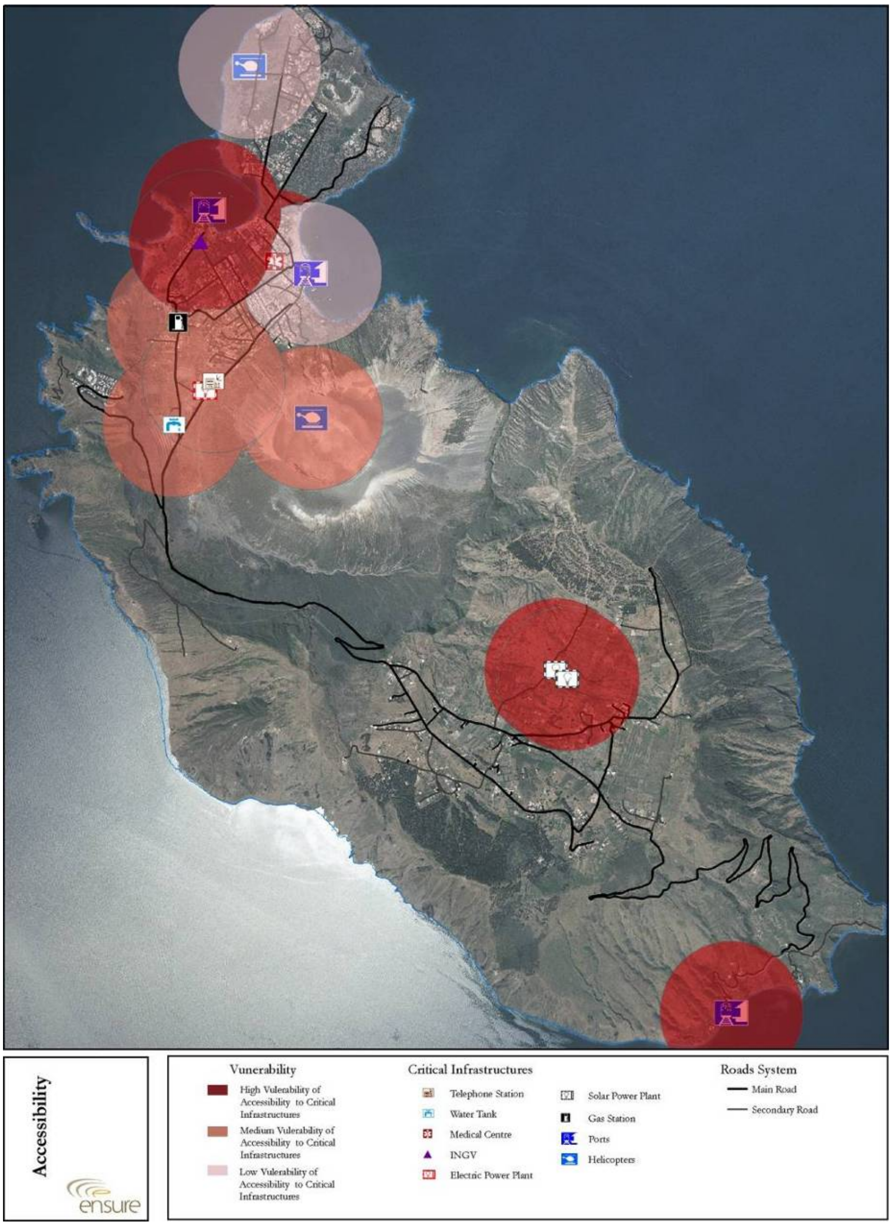

Fig. 4.23 – Level of vulnerability of internal accessibility

	System	Aspect	Parameters			Criteria for assessment	Descriptors	Application to case study	Scoring (5 high - 1 low)	Weight (1 high - 0 not relevant)	Total Scoring
Infrastructure and production sites	Critical infrastructures	What are the factors that make critical infrastructures stop functioning?	Infrastructures (gas, water, electricity, telecom)	puntual infrastructures	gas	redundancy	more than 1/ 1/ 0		NOT RELEVANT		
						dependency from other systems	dependent/autonomous		NOT RELEVANT		
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available	NOT RELEVANT		
					water	redundancy	dependent/autonomous	yes, three water tanks are on the island	2	1	
						dependency from other systems	dependent/autonomous	yes	5	1	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					telecom	redundancy	more than 1/ 1/ 0	no	5	1	
						dependency from other systems	dependent/autonomous	yes	5	1	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					electricity	redundancy	more than 1/ 1/ 0	no, each power plant provide energy to a part of the island	5	1	
						dependency from other systems	dependent/autonomous	yes	5	1	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					INGV	redundancy	more than 1/ 1/ 0	yes, monitoring system available even out of the island	2	1	
						dependency from other systems	dependent/autonomous	yes	5	1	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					Medical Centre	redundancy	more than 1/ 1/ 0	no	5	1	
						dependency from other systems	dependent/autonomous	yes	5	1	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					Carabinieri	redundancy	more than 1/ 1/ 0	no	5	1	
						dependency from other systems	dependent/autonomous	yes	5	1	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
			Accessibility	accessibility from damaged areas		to strategic facilities	more than 1 access/1 access/0 access		NOT RELEVANT		
						physical vulnerability of access ways	vulnerable/not vulnerable	no data available	NOT RELEVANT		
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt)		NOT RELEVANT		
				internal accessibility	gas	redundancy	more than 1/ 1/ 0		NOT RELEVANT		
						dependency from other systems	dependent/autonomous		NOT RELEVANT		
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available	NOT RELEVANT		
					water	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	5	1	
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	4	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					telecom	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	1	1	
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	3	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					electricity	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	1	1	
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	3	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					INGV	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	1	1	
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	3	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					Medical Centre	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	1	1	26,25=Medium
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	3	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					Carabinieri	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	1	1	
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	4	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					Porto Ponente	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	5	1	
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	1	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					Porto Levante	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	2	1	
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	1	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
					Porto Gelso	redundancy	more than 1 access/1 access/0 access	The assessment has been developed grouding on cartography	5	1	
						condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt); position (scenario dependant)	The assessment has been developed grouding on cartography	5	0,75	
						fucntional vulnerability to physical damage (physical vulnerability)	vulnerable components crucial for functioning: yes/no	no data available			
				external accessibility	heliports	Vulcano	existent/non existent	Yes	1	1	
							redundancy	Yes	1	1	
							accessibility from settlements (as accessiblity to strategic facilities)	NO	5	1	
							position	The assessment has been developed grouding on cartography	5	1	
							gathering zones close	no data available			
							metereological assessment				
						Vulcanello	existent/non existent	Yes	1	1	
							redundancy	Yes	1	1	
							accessibility from settlements (as accessiblity to strategic facilities)	The assessment has been developed grouding on cartography	3	1	
							position	The assessment has been developed grouding on cartography	1	1	
							gathering zones close	no data available			
							metereological assessment				
						Piano	existent/non existent	Yes	1	1	
							redundancy	Yes	1	1	
							accessibility from settlements (as accessiblity to strategic facilities)	The assessment has been developed grouding on cartography	3	1	
							position	The assessment has been developed grouding on cartography	4	1	
							gathering zones close	no data available			
							metereological assessment				
					Ports	Porto Ponente	transferability of functions	yes, one ferry (SIREMAR) is used in Porto Ponente and one ferry in (NGI) in Porto Gelso	1	1	
							accessibility from settlements (as accessiblity to strategic facilities)	The assessment has been developed grouding on cartography	2	1	
							position	The assessment has been developed grouding on cartography	3	1	
							gathering zones close	no data available			
						Porto Levante	transferability of functions	Yes	1	1	
							accessibility from settlements (as accessiblity to strategic facilities)	The assessment has been developed grouding on cartography	2	1	
							position	The assessment has been developed grouding on cartography	4	1	
							gathering zones close	no data available			
						Porto Gelso	transferability of functions	Yes	1	1	
							accessibility from settlements (as accessiblity to strategic facilities)	yes, but the features of the road	5	1	
							position	The assessment has been developed grouding on cartography	2	1	
							gathering zones close	no data available			
	Production sites	What are the factors that may lead to halting production?	Degree of dependance of production sites from lifelines			binary; degree of presence of autonomous devices	yes/no; %		NOT RELEVANT		
			Accessibility to the plant and to markets			see internal and particulary external accessibility of the area			NOT RELEVANT		
			Contingency plan for na tech			binary	yes/no; considers all potential threats/does not		NOT RELEVANT		
			Business continuity plan			binary	yes/no		NOT RELEVANT		

Fig. 4.24 - Matrix related to systemic vulnerability of Critical Infrastructures

Socio-economic

The fourth part of the matrix is dedicated to assess to systemic vulnerability of the social system. It is worth to notice that vulnerability is analyzed with reference to two elements: on one hand people, and on the other hand community and institutions. With reference to the former, it has been assessed what are the factors that may reduce the coping capacity during a crisis. Thus, criteria as information on risk, trust in authorities and self-protection means, further impairment and age have been analyzed. As we said earlier, Vulcano island is characterized by a low the number of people living on the island during winter season and by a pretty high flow of tourist during summer seasons and if the level of self protection means is already low for inhabitants it is even lower for tourist. On the other, an information point of INGV is located close to the main port to provide information on risk to residents and tourists. While, regarding the latter, the factors that may hamper effective crisis management have been assessed. Accordingly to this, the lacks of a civil protection plan of training and of training and of any proper communication plan highly affect the effective crisis management unless a continuing monitoring and a drill system are available.

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Scoring (5 high - 1 low)	Weight	Total Scoring
Social system (agents)	*People/individuals*	What are the factors that may reduce coping capacity during crisis?	self protection means	yes/no	masques; shovels	no	5	1	31=Medium
			information on risk	enough/sufficient/none	There is an information point of INGV, which provides informations to resident and tourist, near to Porto Levante		2	1	
			trust in authorities	yes/no	si		2	1	
			age	(elderly/young)			3	0.75	
			impairmanent	yes/no	no data available	no data available			
	Community and Institutions	What are the factors that may hamper effective crisis management?	permanent staff	yes/no	Fire brigades only in Lipari (don't like to intervene in Vulcano). Bertween June and September there are two small fire brigades stations (Forest Rangers) in Porto Gelso and Monte Saraceno		4	0.75	
			continuouing monitoring (>weight if early warning possible)	yes/no	There is a continuose monitoring system at INGV in Palermo.		2	1	
			available equipments	yes/no	Evacuation drill system is available.		2	1	
			potable water storage	yes/no	There are three water tanks for drinkable water (Monte Saraceno, Lentia, Gelso); drinkable water is carried to the island with ferries once a week.		2	1	
			civil protection plan	yes/no	No, but it is in progress.		4	1	
			training and exercise	frequent/not frequent; involving the population /not involving	no		5	0.75	
			communication plan (multilingual)	yes/no	There is not a proper plan, but some information are given to who are doing trekking on the volcano		4	0.75	

Fig. 4.25 - Matrix related to systemic vulnerability of Socio System

4.2.2 Lahars

In this paragraph, the test of the matrixes set up in the workpackage 4 for assessing physical and systemic vulnerability to volcanic phenomena is presented. In detail, the test has been here focused on the physical and systemic vulnerability to lahars, one of the phenomena which might follow a volcanic eruption, affecting relevant areas of the Vulcano island.

Physical vulnerability

Physical vulnerability of the four considered systems (natural environment, built environment, critical infrastructures and social system) to lahars has been assessed in respect to the investigation area shown in Figure 4.26. This area has been defined according to the lahar analyses developed in section 2 and addressed to identify the areas potentially inundated by lahars in the northern area of the Vulcano island.

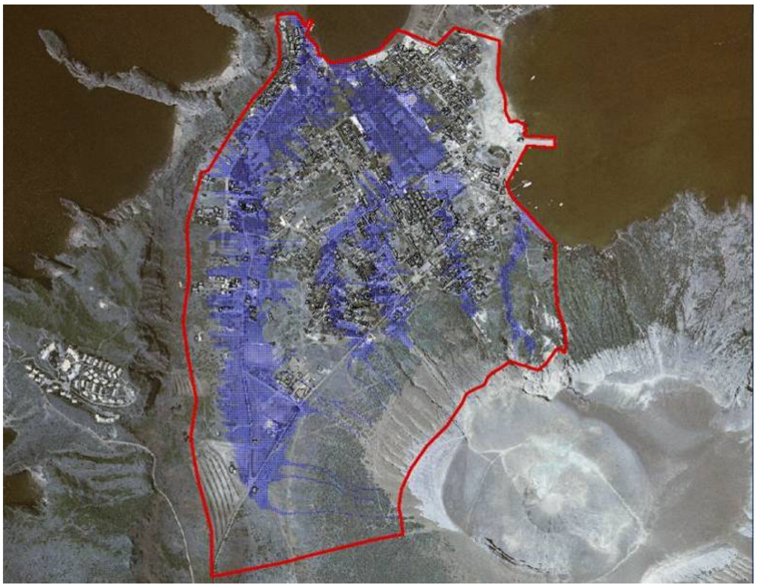

Figure 4.26 – The investigation area (red) and the likely flooded areas (blue)

According to the general framework set up in WP4, the second set of matrixes is related to physical vulnerability and addressed to evaluate physical propensity to damage of natural and built environment, of critical infrastructures and social system. All factors that may increase the potential damage are considered, including the possibility of enchained effects, both between natural hazards (like for example landslides triggered by earthquakes) and between natural and vulnerable built systems (like for example na-tech).

As already mentioned in respect to the first set of matrixes related to the mitigation capacities, slight changes and integration to the structure of the general framework and some changes to the parameters have been required.

The main structure of the matrix defined in WP4 has been modified as shown in Figure 4.27 and in detail:

- the four blocks have been considered as the main systems to which the assessment is referred;
- for each system, different aspects have been considered;
- for each aspect, the key topics which have to be investigated have been identified;
- for each key topic, different key factors have been taken into account (mainly in respect to built environment since different spatial elements have to be considered, as we will see in the following);
- parameters, criteria for assessment (type of assessment scale, information source, etc.), quality of data, descriptors and specific notes on the case-study have been provided.

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	*Exposure and vulnerability of* ***Urban Fabric n. 1***	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,8 = VERY HIGH	0,77 = VERY HIGH	0,77 = VERY HIGH	0,77 = VERY HIGH
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	High	The assessment has been developed grounding on in-situ surveys and photos	0,75				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	High	The assessment has been developed grounding on in-situ surveys and photos (see fig. 16)	0,5				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	Very high	The assessment has been developed grounding on carthography and lahars run out analysis (see fig. 18)	1				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Very high	The assessment has been developed grounding on carthography and lahars run out analysis (see fig. 17)	1				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography (see fig. 20-21)	0,75				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics features	1	rainproof level of the settlement	covered surface/surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Very high	The assessment has been developed grounding on carthography (see fig. 23)	1	0,75 = HIGH			
								rainproof surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	Medium	The assessment has been developed grounding on carthography and orthophoto (see fig. 23)	0,5				
							activities at ground floor	surface of residential building placed at road level/covered surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	High	The assessment has been developed grounding on in-situ surveys and carthography (see fig. 24)	0,75				
								surface of basement/covered surface of the urban fabric	not available								

Figure 4.27 – The matrix for physical vulnerability assessment (modified in respect to the general framework set up in WP4)

Besides the slight changes to the general framework, the possibility/opportunity of assigning different weights to the different aspects and key topics has been applied to the case study and different scores have been calculated (from the scores related to each parameter to a final score related to each system).

Furthermore, it is worth noting that the general framework was structured in respect to all the volcanic phenomena, although the relevance of each parameter in respect to each volcanic phenomenon has been clearly highlighted. Hence, in order to assess physical vulnerability to lahars of the considered systems, only the parameters relevant to such a phenomenon have been taken into account, integrating them, in some cases, with other parameters listed in the framework related to landslides. It has to be considered, indeed, that lahars phenomenon may be compared with mudflows, which have been more deepened in scientific literature.

Finally, it has to be underlined that parameters related to each system have been calculated in respect to different spatial units: as it will be better explained in the following pages, spatial units may vary from the whole area of investigation up to its partitions (urban fabrics, census units) or to individual elements, according to the peculiarities of the investigated systems and to the data availability.

Natural System

The first part of the assessment matrix refers to the Natural System. First of all, it's worth noting that in the Vulcano case-study, due to the lack of a detailed land use map, the assessment matrix has been carried out in respect to two areas, singled out in respect to the morphological features of the site: the plain area and the slope area.

Nevertheless, if a land use map is available, vulnerability assessment of natural system should be more properly referred to the different land uses, in order to obtain comparative measures of vulnerability for each land use.

The assessment of physical vulnerability to lahars of natural environment has required the identification and classification of open spaces within the investigation area. It has to be underlined that, as mentioned above, the Corine Land Cover, one of the most useful data sources to identify land uses, was not usable in the selected case-study: also the most detailed level of the mentioned database was, indeed, not enough detailed in respect to the scale of

analysis. Thus, the identification and classification of the open spaces have been carried out through cartographies (update cartography scale 1:2000), orthophotos and in situ surveys.
Open spaces have been classified in natural and artificial surfaces. The first class consists of emerging rock and lava, pasture lands, vegetable gardens, vineyards or uncultivated areas, open space with trees (fruit trees, acacias, holm oaks, downy oaks, and so on). The second one includes roads, paved open spaces surrounding houses, and so on. In the plain area, under the volcano slopes, vegetable gardens, pasture lands and uncultivated areas with shrubs or isolate trees (mainly acacias and Holm oaks), beside numerous private gardens, can be found. In the area closer to the volcano slopes and along them, orchards and vineyards are mainly widespread and the Mediterranean shrub becomes more frequent (figs. 4.28, 4.29).
The classification of open spaces represents the starting point for answering the two questions posed by the matrix for assessing physical vulnerability of natural environment to lahars. The first aspect is related to the fragility of natural ecosystem in face of the potential effects of hazards. To answer this question it has to be noticed that the vegetation in the plain area mainly consists of Mediterranean shrub, orchards, vineyards and vegetable gardens, which are highly vulnerable to lahars effects. So, with the exception of few isolated groups of trees, the overall fragility of the natural ecosystem can be considered high.

Figure 4.28 – A view of the vegetation in the plain area and along the crater slopes

The second aspect is related to the potential interactions between natural system and hazard. These interactions should be different along the crater slopes and in the plain area, according to the different features of the hazardous phenomenon and of the existing vegetation. Thus, to better understand such interactions we will firstly focus on the slope area. In this area existing vegetation could play a twofold role:

- a positive one, in that it could act as preventative factor in respect to lahars due to the deep roots which may increase soil compactness;
- a negative one, in that trunks of trees, carried downstream by lahars, could worsen the effects of the event.

The type of vegetation along the slope (which, as mentioned above, is characterized by orchards, vineyards and mainly by the Mediterranean shrub) has no deep roots; hence, its effect on the soil compactness is negligible. Furthermore, due to the size and features of the existing vegetation, no big elements, worsening the impacts of lahars, can be carried downstream. Therefore, it can be argued that the interaction between natural systems and hazard can be considered low in the case of the slope area.
Then, looking at the plain area, it has to be underlined that shrubs and trees, which could protect buildings in face of lahars, are not very widespread: thus, also in the plain area the interaction between hazard and natural system can be considered low.

Figure 4.29 and Table 4.1 show the main data related to the natural system in the investigation area. Figure 7 shows the filled in matrix related to the physical vulnerability of natural system to lahars.

The third key-topic reported in the physical vulnerability matrix and referred to the natural environment is related to the vulnerability of the natural ecosystems due to the mitigation measures and, particularly, to measures taken during the emergency. In the case-study, this question has been neglected since no relevant mitigation measure has been up to now set up in face of lahars. As mentioned in the paragraph 3, indeed, some structural defence measures addressed to the canalisation of rainwater in order to mitigate debris flows in the area of Porto Levante have been recently set up. Nevertheless, these measures do not ground on a detailed study of lahars phenomena and are limited to a small area in respect to the one which is potentially affected by the phenomenon.

Area	**Surface (sqm)**	**Percentage on the total (%)**	**Natural areas (sqm)**	**Percentage on the total (%)**	**Shrub areas (sqm)**	**Percentage on the total (%)**
Slope area	444.530	26,00	430.633	25,18	366.740	21,45
Plain area	1.265.398	74,00	842.097	49,25	249.181	14,57
Area of investigation	**1.709.928**	**100,00**	**1.272.730**	**74,43**	**615.921**	**36,02**

Table 4.1 – Natural areas and areas characterized by shrub in the plain area and along the crater slope

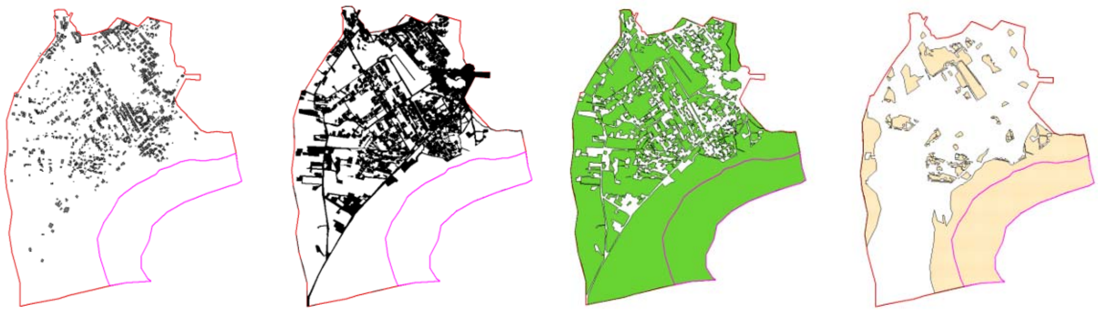

Figure 4.29 – Built up surfaces, artificial surfaces, natural surfaces and shrub areas

After the scoring of the parameters for the two considered areas, it is possible to define the scoring of key-elements and key-topics, basing on an adequate scale of correspondence between qualitative and numeric values (fig. 4.30).

Finally, the Aspects can be defined through the average of the three considered key-topics values and, consequently, the final score of the natural system can be obtained through the average of the numeric values of the Aspects in the two considered areas (fig. 4.31).

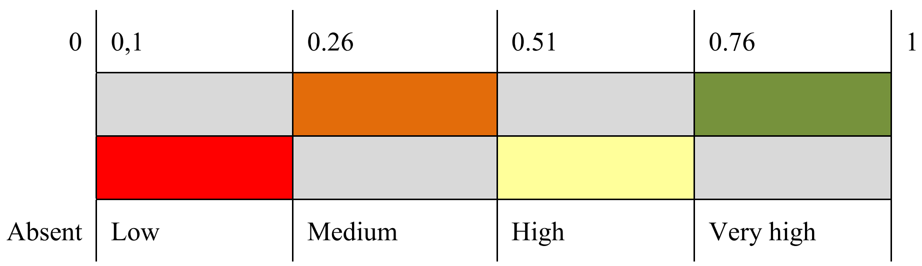

Figure 4.30 – Scale of correspondence between qualitative and numeric values

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Natural ecosystems	*Vulnerability and interaction of natural ecosystem* ***in the slope area***	1	Are natural ecosystems fragile to the potential effects of hazard?	1	presence of vegetation and forests	1	binary; coverage and type	yes/no; % and type	Medium	Four classes obtained through a qualitative judgement based on type and percentage of vegetation (low, medium, high, very high)	**Very high**	The assessment has been developed grounding on qualitative judgement bsed on type and percentage of vegetation	1	1 = Very high	1 = Very high	0,42 = Medium	0,37 = Medium
			Can natural systems interact with hazard?	1	type and quantity of interacting vegetation (distinguishing between positive or negative interaction)	1	trees with long and extended roots/no vegetation or with superficial roots	qualitative	Medium	Four classes obtained through a qualitative judgement based on type and percentage of vegetation (low, medium, high, very high)	**Low**	The assessment has been developed grounding on qualitative judgement bsed on type and percentage of vegetation	0,25	0,25 = Low	0,25 = Low		
			Are natural ecosystems vulnerable to mitigation measures taken particularly during the emrgency phase?	1	presence of ecosystems that may be endangered by lahars flows deviations	1	binary; type	yes/no; type of vegetation and other species	Medium	yes/no; type of vegetation and other species	**No**	No mitigation measures for lahars have been set up and no measures are currently foreseen	0	0	0		
	Vulnerability and interaction of natural ecosystem ***in the plain area***	1	Are natural ecosystems fragile to the potential effects of hazard?	1	presence of vegetation and forests	1	binary; coverage and type	yes/no; % and type	Medium	Four classes obtained through a qualitative judgement based on type and distribution of vegetation (low, medium, high, very high)	**High**	The assessment has been developed grounding on qualitative judgement bsed on type and percentage of vegetation	0,75	0,75 = High	0,75 = High	0,33 = Medium	
			Can natural systems interact with hazard?	1	type and quantity of interacting vegetation (distinguishing between positive or negative interaction)	1	trees with long and extended roots/no vegetation or with superficial roots	qualitative	Medium	Four classes obtained through a qualitative judgement based on type and percentage of vegetation (low, medium, high, very high)	**Low**	The assessment has been developed grounding on qualitative judgement bsed on type and percentage of vegetation	0,25	0,25 = Low	0,25 = Low		
			Are natural ecosystems vulnerable to mitigation measures taken particularly during the emergency phase?	1	presence of ecosystems that may be endangered by lahars flows deviations	1	binary; type	yes/no; type of vegetation and other species	Medium	yes/no; type of vegetation and other species	**No**	No mitigation measures for lahars have been set up and no measures are currently foreseen	0	0	0		

Figure 4.31 – Physical vulnerability of natural system to lahars

Built Environment

The second part of the matrix refers to the built environment and it is probably the most difficult part to be filled in, since the assessment can be referred to different spatial units (buildings, urban fabrics, the whole area of investigation, etc.). Furthermore, the different parameters, according to the selected spatial units, can be applied in different ways and, above all, a large amount of data and information is required.

Spatial units and knowledge-base

According to the matrix developed in WP4, physical vulnerability of the built environment depends on the numerous factors that make an urban fabric vulnerable to the stress; these parameters are related to the features of individual buildings, of urban facilities and of urban fabrics themselves.

Nevertheless, it is worth noting that, in order to assess physical vulnerability of built environment, data and information have to be collected and elaborated in respect to defined spatial elements or units. According to the objectives and the scale of the analysis, spatial units can vary from a Regional or a Municipal area up to a partition of a Municipality (urban fabrics) or to census units, and different elements, such as buildings, public facilities or lifelines, can be taken into account.

Moreover, vulnerability assessment is generally expressed through quantitative or qualitative values but they always represent comparative measures.

Therefore, in a given area, vulnerability assessment has to be addressed to provide a comparison among the exposed spatial elements or units, showing the elements or the units that, in the context at stake, are more vulnerable than the others.

In the area of investigation, according to the objectives of the analysis (to assess physical vulnerability of built environment in respect to a very localized phenomenon as lahars) and to the scale (a partition of a Municipality which comprises both the Vulcano and the Lipari islands), we will refer to the different urban fabrics which can be singled out in the area of investigation, taking into account that their vulnerability is due to the features of buildings and public facilities included in each fabric and to the features of each fabric itself.

Physical vulnerability analyses have been developed within a GIS environment, structured according to three types of spatial elements and units: the whole area of investigation, the different urban fabrics which can be recognized in this area, buildings and public facilities. Beside these elements and units, the main and secondary road networks have been identified.

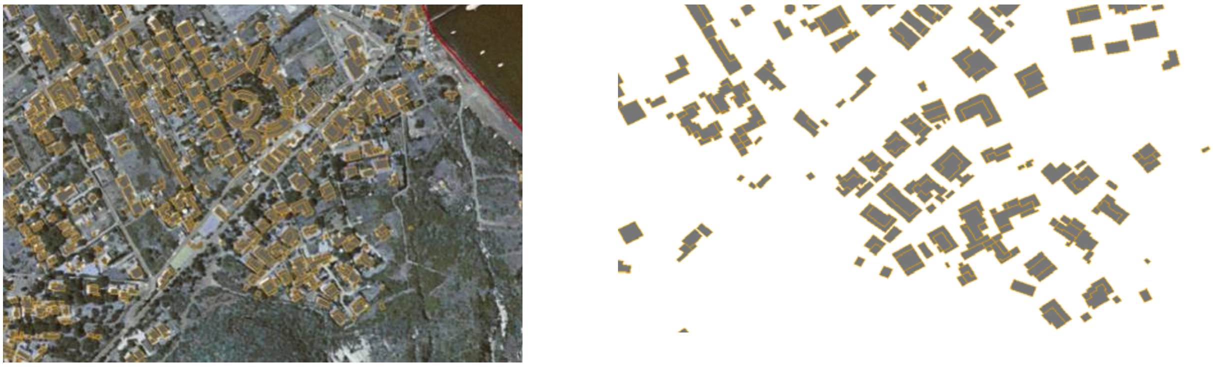

Figure 4.32 – One of the GIS layers providing detailed information on buildings

In detail, the layer referred to buildings (fig. 4.32) has been structured taking into account the different elements which buildings are made of: buildings themselves, patios, balconies and other accessory spaces related to each building. All information has been derived from the updated cartography in scale 1:2000. Such a characterization of the buildings within the GIS has allowed us to carry out an in depth identification of typological features of buildings and an accurate calculation of building volumes.
Furthermore, it is worth noting that vulnerability of buildings or urban fabrics can be analyzed through extensive surveys on each building or each fabric but also through sampling techniques. In the latter case, first of all buildings and urban fabrics showing the same features have to be classified; then, vulnerability assessment carried out in respect to sample buildings or fabrics can be extended to the class they belong to. Grounding on this idea, first of all a classification of buildings and urban fabrics in the area of investigation has been carried out. Since the classification of buildings and urban fabrics may represent a common base for assessing physical vulnerability in respect to different hazards, they have been classified taking into account all their relevant features in respect not only to lahars but also to the other volcanic phenomena (tephra falls), to earthquakes and landslides.
In detail, grounding on the available information (updated maps scale 1:2000; photographic database; orthophoto), buildings in the area of investigation have been classified according to the following features:

- type of use;
- number of floors;
- roof features (plain, pitched);
- construction technique (masonry, reinforced concrete, mixed);
- morphology (regular and irregular);
- building typology (isolated building, serial buildings, building block, etc.).
- historical importance;

Therefore, buildings in the area of investigation have been firstly classified with reference to their main use (fig. 4.33), such as residential, commercial or mixed (residential and commercial), public facilities (churches, medical center, etc.), hotels, technological equipments, etc.
Then, they have been classified with reference to the number of floors, distinguishing one-storey buildings from two or more-storey ones (fig. 4.34); to the features of roofs, distinguishing roofs from patios, lean-to-roofs and pergolas; to the construction techniques (masonry or concrete buildings); to the morphological features of buildings (regular or irregular) (fig. 4.35); to their typology (isolated building, serial building, building block, etc.).
Finally, based on the surveys carried out by the Master Plan recently approved, historical buildings have been singled out (fig. 4.36).

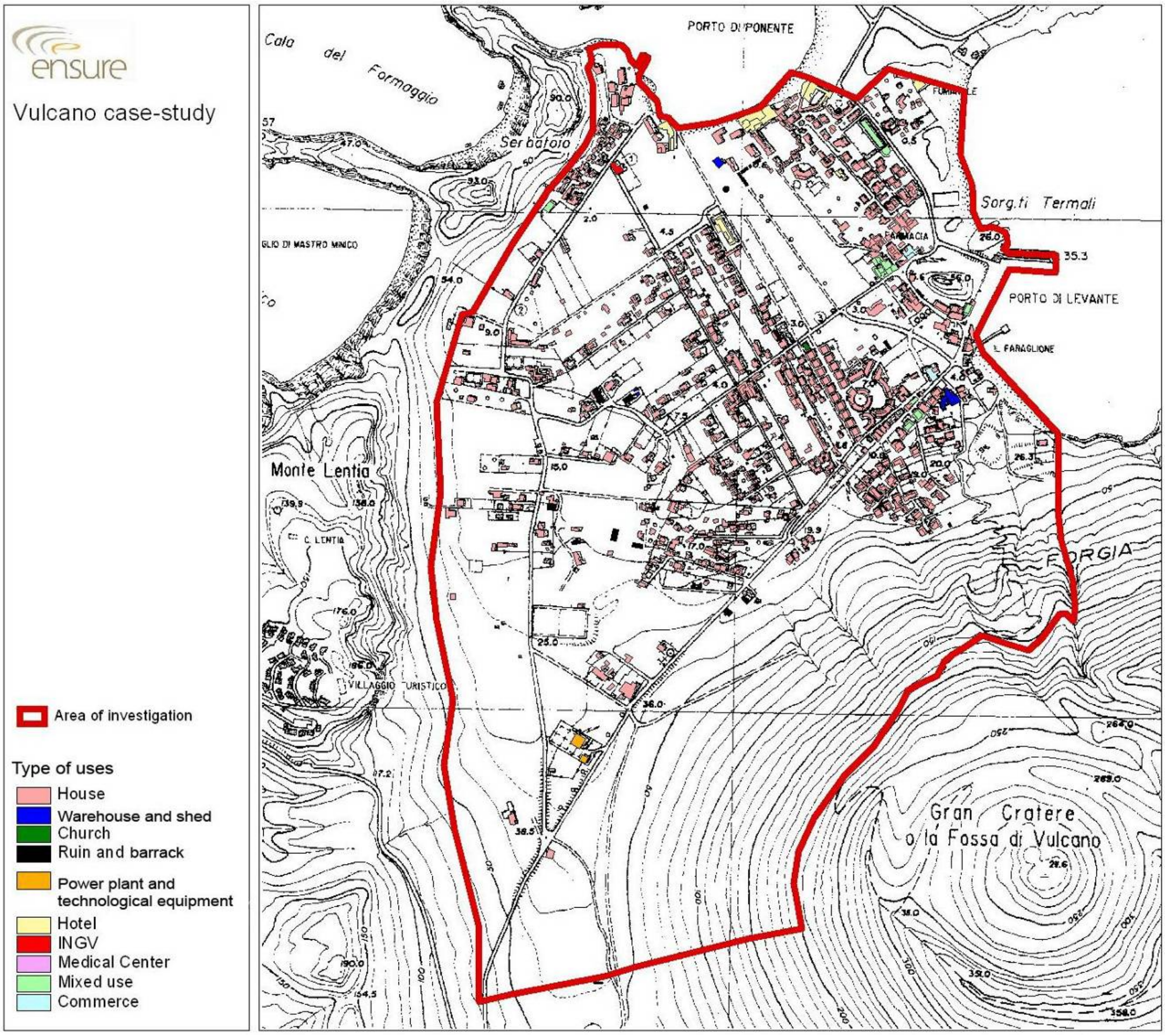

Figure 4.33 – Building classification: type of use

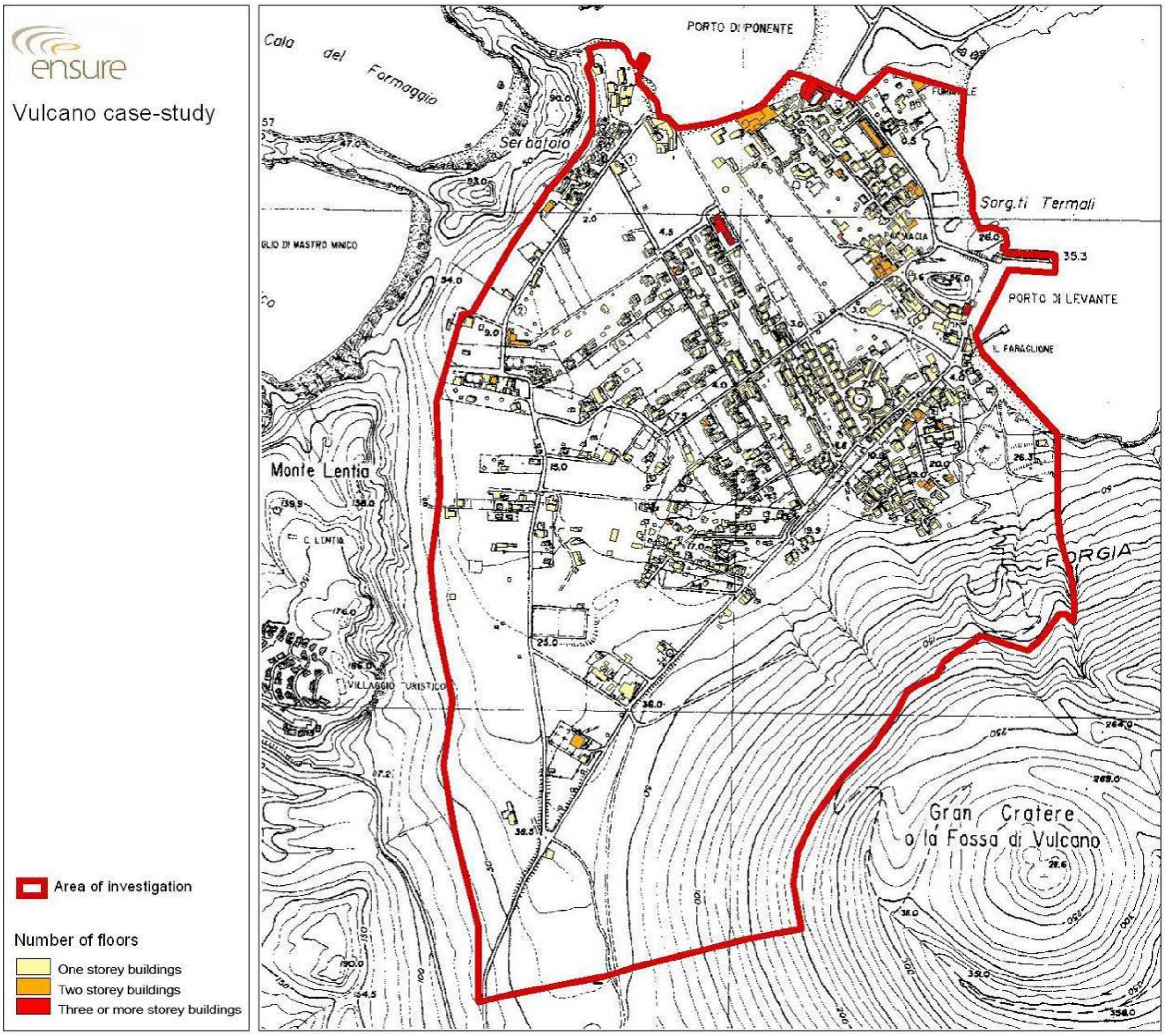

Figure 4.34 – Building classification: number of floors

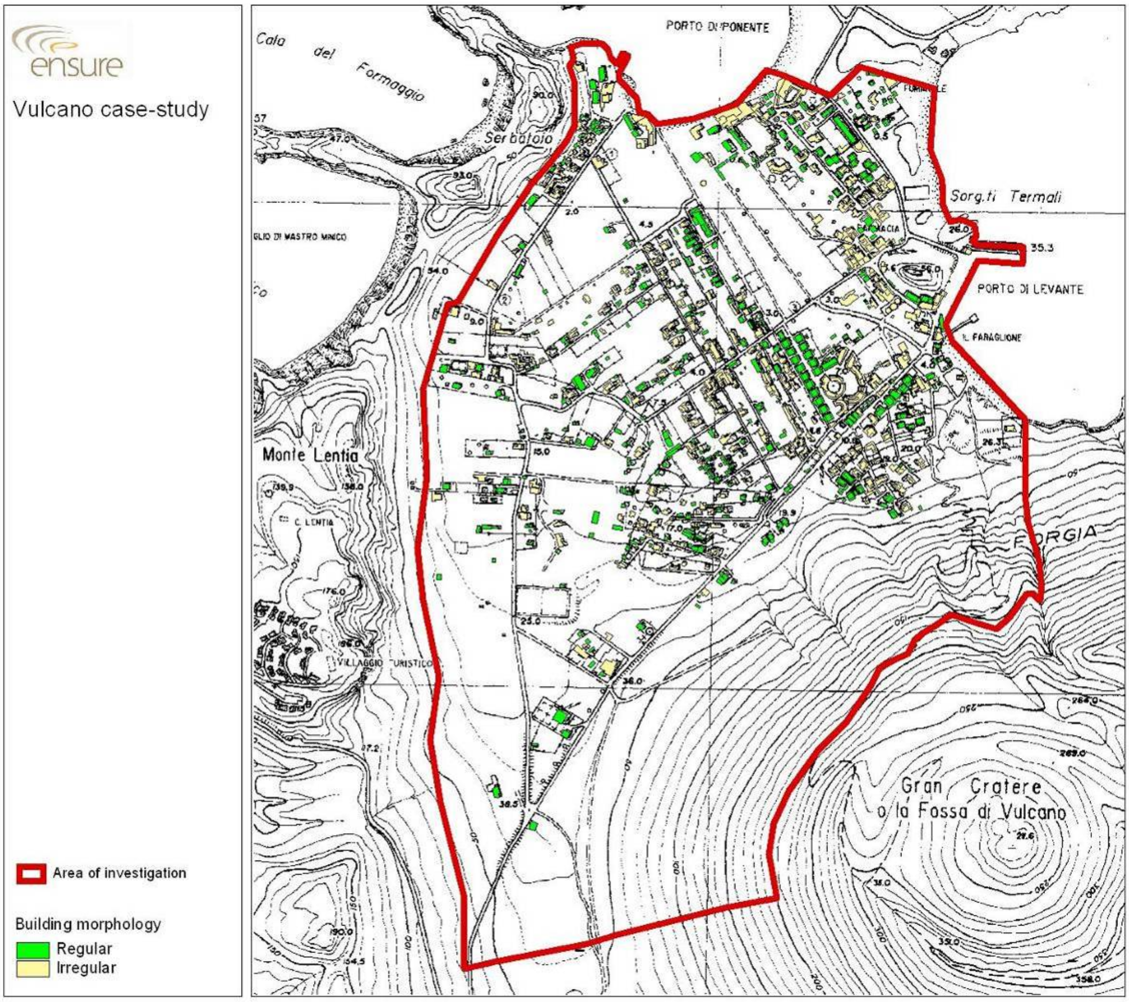

Figure 4.35 – Building classification: morphology

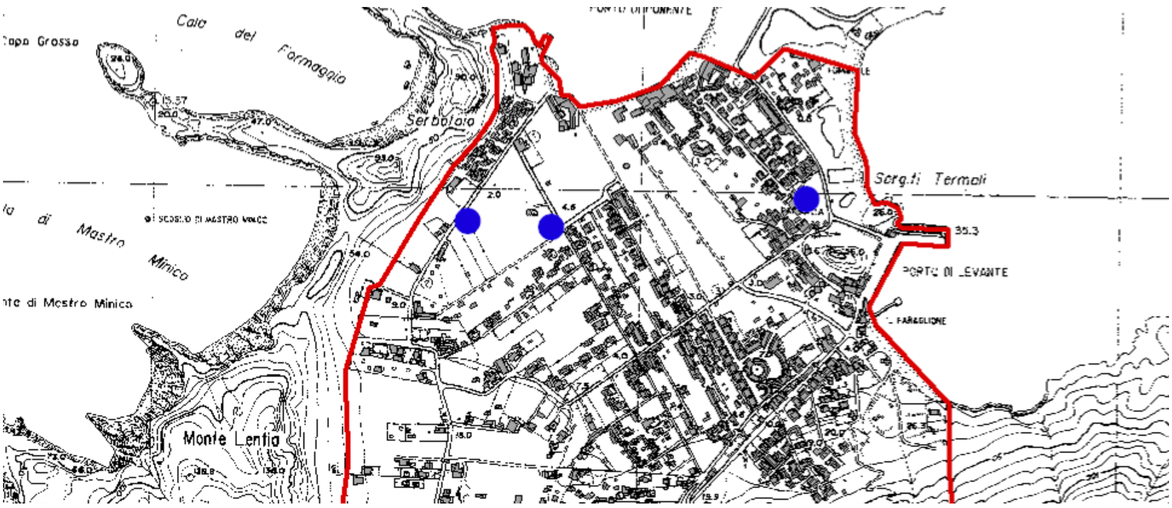

Figure 4.36 – Historical buildings singled out by the Master Plan (blue points)

According to the selected features, all the buildings in the area of investigation have been classified as follows:

Ta Residential buildings

- Ta1 Isolated one or two-storey historical masonry buildings, with horizontal steel or wood elements and flat roofs;
- Ta2 Isolated one-storey masonry buildings, with mixed horizontal elements (such as steel and tile or reinforced concrete and tile floors), flat roofs, with patios or pergolas.
- Ta3 Isolated or serial two or more-storey concrete buildings, with flat roofs.
- Ta4 Serial one or two-storey masonry buildings, with mixed horizontal elements and flat roofs, with patios or pergolas.
- Ta5 One or two-storey masonry building block, with mixed horizontal elements and flat roofs.
- Ta6 Ruins and barrack.

Tb Public facilities
- Tb1 Public facilities located into special typology buildings (church, sport facilities, schools, etc.);

Tc Productive and commercial buildings
- Tc1 One-storey warehouses, storages for handcraft activities and boathouses with flat or pitched roofs;
- Tc2 One-storey buildings devoted to bar, restaurants and leisure activities;
- Tc3 One or two-storey masonry buildings with flat roofs in which hotels or bed&breakfast are located;

Td Energy facilities
- Td1 One or two-storey concrete buildings with flat roofs, in which energy plant and accessory equipments are located.

As mentioned above, the provided classification may be relevant in respect to all the type of hazards affecting the Vulcano island, although not all the selected features are relevant in respect to lahars (for example the type of roofs) (fig. 4.37).
The classification of urban fabrics in the area of investigation has represented the second step for building up the knowledge-base for vulnerability assessment. The classification, as well as the one developed for buildings, has been based on the features of urban fabrics which can be relevant to the different hazards that the investigation area is prone to.
In a large urban context, both fabrics and census units (the smallest spatial units which Census Data generally refer to) are generally numerous and the boundaries of the former can be defined in respect to the boundaries of the latter: such an opportunity might allow us to refer vulnerability assessment of built environment and social system to the same spatial units.
Nevertheless, in the Vulcano case study, and above all in the selected area of investigation, it was not possible to find out such a correspondence, due to the fact that census units are very large, including different types of urban fabrics.
Thus, in order to single out and classify the urban fabrics in the area of investigation, all the built-up areas, the included open spaces and the network of secondary roads have been taken into account. Of course, single houses or buildings have been neglected.
The classification has been based on three main criteria: the site morphology, related to the position of the settlement in the plain area or along the slopes of the crater; the building density, which is generally crucial for defining the level of compactness of a fabric; the morphology (linear, regular, irregular) of the built up area, which largely depends both on the morphology of buildings and on their aggregation rules.

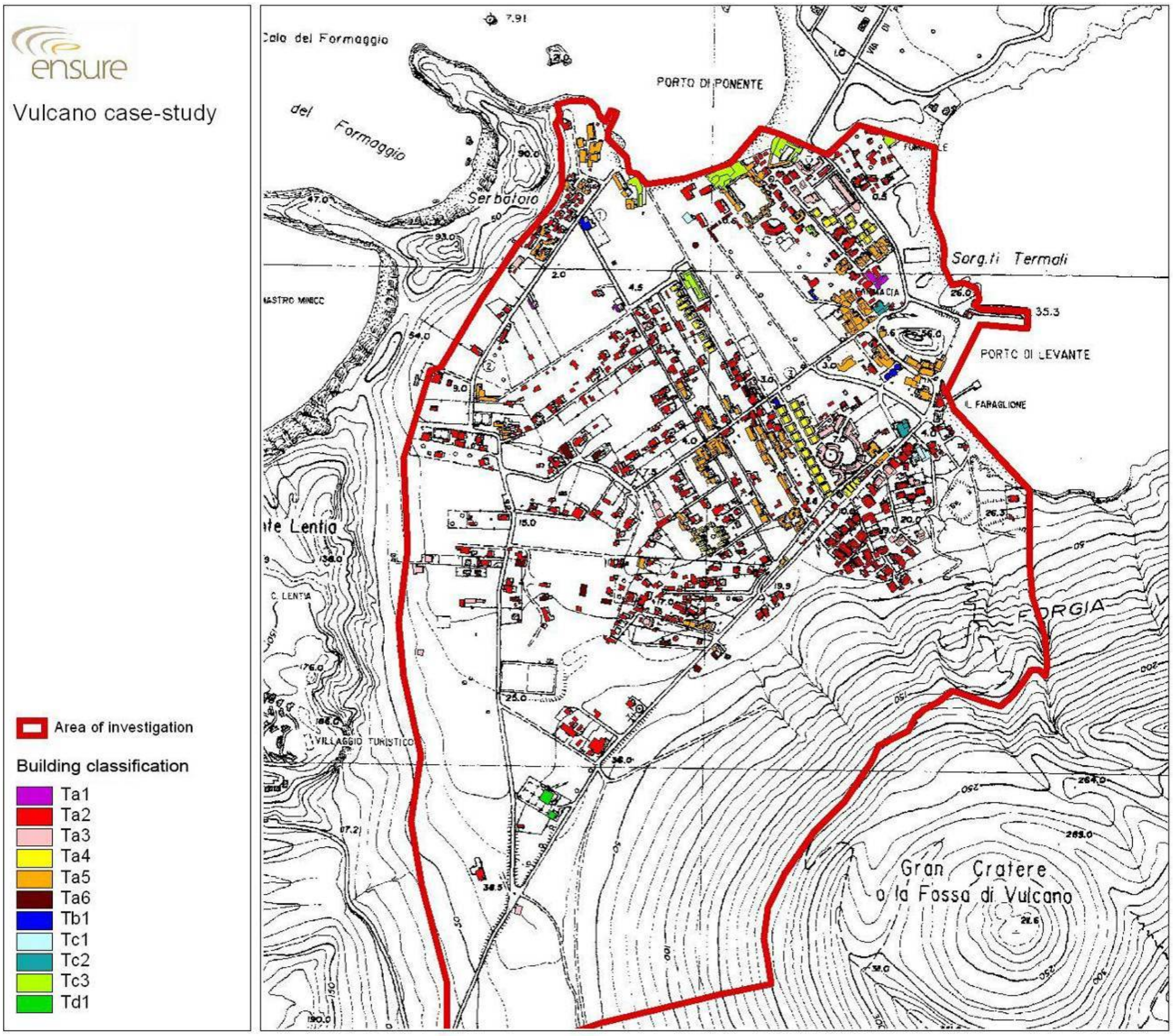

Figure 4.37 –Building Classification

According to these criteria, the following typologies of fabrics have been defined:

A. Fabrics along the slopes
  1 – Regular and compact (high density)
  2 – Nucleus or irregular (low/medium density)

B. Fabrics in the plain area
  1 – Regular and compact (high density)
  2 – Nucleus or irregular (low/medium density)
  3 – Irregular and compact (high density)

Grounding on these criteria, the built-up area has been subdivided into 9 fabrics (fig. 4.38), whose features are synthesized in the table 4.2. In some cases, urban fabrics belonging to the same typology but not contiguous have been distinguished.

Id	Surface (sqm)	Site morphology	Building density (comparative measure)	Built-area Morphology	Typology
1	44.146	Slope	High	Regular	A1
2	65.331	Plain area	High	Regular	B1
3	284.901	Plain area	Low	Irregular	B2
4	110.727	Plain area	Medium	Irregular	B2
5	16.884	Plain area	High	Irregular	B3
6	25.188	Slope	High	Linear	A1
7	7.648	Plain area	Low	Nucleus	B2
8	4.005	Slope	Medium	Nucleus	A2
9	15.779	Plain area	Medium	Irregular	B2

Table 4.2 – Features and typology of urban fabrics

Figure 4.38 – Urban fabrics in the area of investigation

Physical vulnerability of built environment

Up to now, spatial units and elements, which physical vulnerability assessment has to be referred to, have been defined and the knowledge base for carrying out such assessment has been set up.

In the Vulcano case-study, the assessment of the built environment physical vulnerability has been referred, as mentioned above, to urban fabrics: vulnerability of each fabric depends on the physical vulnerability of buildings and public facilities belonging to the fabric and on the features of the fabric itself, which may contribute to make it susceptible to be damaged by a given hazard.

In detail, the level of vulnerability to lahars of the 9 fabrics identified in the area of investigation has been calculated in respect to:

– the vulnerability of each building type (including public facilities);
– the vulnerability of each type of fabric;

Physical vulnerability assessment has been developed applying the parameters included in the modified matrix (fig. 4.27).

The values obtained for each building and public facility have been subsequently referred to the urban fabrics through appropriate indexes. These indexes have been obtained through the following procedure (Table 4.3):

– for each fabric, the quantity of buildings classified in respect to the considered levels (very high, high, etc.) of a given parameter (e.g. the distance from dangerous areas) has been translated into a percentage of built-up surface of buildings belonging to each class/total of the built-up surface of the fabric;
– the obtained percentages have been multiplied by a coefficient (very high level = 1; high level = 0,75; medium level = 0,50; low level = 0,25) and then summed, in order to obtain, for each fabric, an index variable between 0 and 100 (the value 100 of the indicator means that, in respect to a given parameter, all the buildings of the considered fabric have been classified as very high level).

The obtained indexes have been ranked again into four classes and the correspondent level of vulnerability has been assigned to the fabrics.

	Levels of vulnerability of buildings										
	Very high		High		Medium		Low				
Fabric	Covered surface (sqm)	% respect to the total covered surface	Covered surface (sqm)	% respect to the total covered surface	Covered surface (sqm)	% respect to the total covered surface	Covered surface (sqm)	% respect to the total covered surface	Total covered surface (sqm)	Index for fabrics	Qualitative assessment of fabrics
1	8481	73,72	3023	26,28	0	0,00	0	0,00	11504	93,43	Very high
2	351	1,77	15734	79,51	3618	18,28	85	0,43	19788	70,66	High
3	871	2,59	4190	12,47	10886	32,41	17646	52,53	33593	41,28	Medium
4	0	0,00	5734	18,23	6641	21,11	19084	60,66	31459	39,39	Medium
5	0	0,00	0	0,00	0	0,00	31295	100,00	31295	25,00	Low
6	0	0,00	0	0,00	0	0,00	2330	100,00	2330	25,00	Low
7	0	0,00	0	0,00	0	0,00	5040	100,00	5040	25,00	Low
8	548	100,00	0	0,00	0	0,00	0	0,00	548	100,00	Very high
9	0	0,00	0	0,00	125	4,80	2480	95,20	2605	26,20	Low

Table 4.3 - From buildings vulnerability to the vulnerability of urban fabrics: an example related to the parameter “distance of buildings from dangerous areas”

In the matrix (fig. 4.27), the rows in grey represent parameters which are not relevant to lahars vulnerability; the ones in orange refer to parameters which, although relevant, would have required detailed in situ surveys: hence, they have been not considered in the Vulcano case study.

Moreover, it has to be noticed that, in respect to lahars, some parameters can be referred to the identified building typologies (such as the one related to the construction material); others have to be referred to each building (such as position, maintenance, etc.) included into the considered urban fabric.

In detail, for what concerns the construction materials, basing on the surveys carried out for classifying building typologies, a medium level of vulnerability has been assigned to reinforced concrete buildings, a high level of vulnerability to the masonry buildings and a very high level of vulnerability to the steel and wood buildings. According to a precautionary approach, we did not assign a low level of vulnerability to any construction type, since the quality of building construction, mainly in the South of Italy, is often not very reliable.

In respect to the parameters related to individual buildings, the following parameters have been analyzed:

– maintenance;
– building position in respect to the lahars source and directions of flows;
– enclosures (type and position in respect to the lahars directions).

The level of maintenance of each building included in each fabric has been analyzed grounding on the available photographic database. The qualitative judgment has been based on the quality of plasters and paintings of the wall faces, quality of the roofs and patios, of the windows and doors frames and on the signs of structural decay visible to the naked eye. Then, the values obtained for each building have been reported, through the described procedure, to the related urban fabric (fig. 4.39).

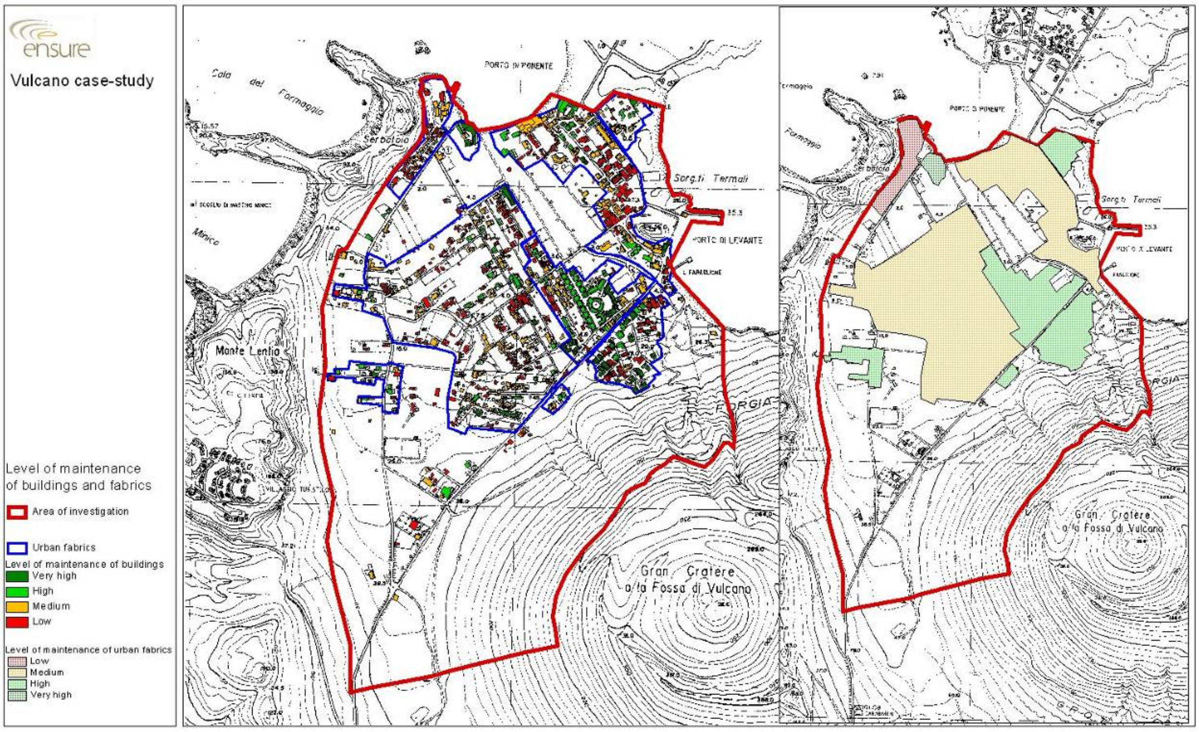

Figure 4.39 –Maintenance levels of buildings and fabrics

The position of each building included in each urban fabric has been analyzed taking into account both the distance from the lahars potential source and the position of the buildings with respect to the lahars channels.
As the distance from the lahars source is concerned, three different distances have been considered, in order to graduate the level of vulnerability of buildings (fig. 4.40):

- in case of buildings located along the crater slopes or in the plain area, at a distance of 100 meters from the slope, vulnerability level has been considered very high;
- in case of buildings located in the plain area, at a distance included between 100 and 150 meters from the slope, vulnerability level has been considered medium;
- in case of buildings located in the plain area, at a distance greater than 150 meters from the slope, vulnerability level has been considered low.

Also in this case, the values referred to each building have been reported to the related fabric (fig. 4.40).
As the position of the buildings with respect to lahars flows is concerned, the analysis has been based on the simulation carried out by the T6 team through Laharz. In respect to each considered channel, three buffers have been considered: a central area 20 meters in width and two belts for each side (a middle one and a lateral one), each of them 10 meters in width (fig. 4.41).
The buildings placed in the central zone have been considered as perpendicular to the flows (in that they are placed along the flows trajectories) with a very high level of vulnerability; the buildings in the middle zone have been considered as lateral to the flows trajectories with a high level of vulnerability; the buildings in the external lateral zone have been considered as only partially involved, with a medium level of vulnerability. Buildings placed out of these three zones have been neglected. In case of buildings located across two different zones, the higher level of vulnerability has been assigned.
Then, the values obtained for each building have been reported to the urban fabric which the building belongs to (fig. 4.42).

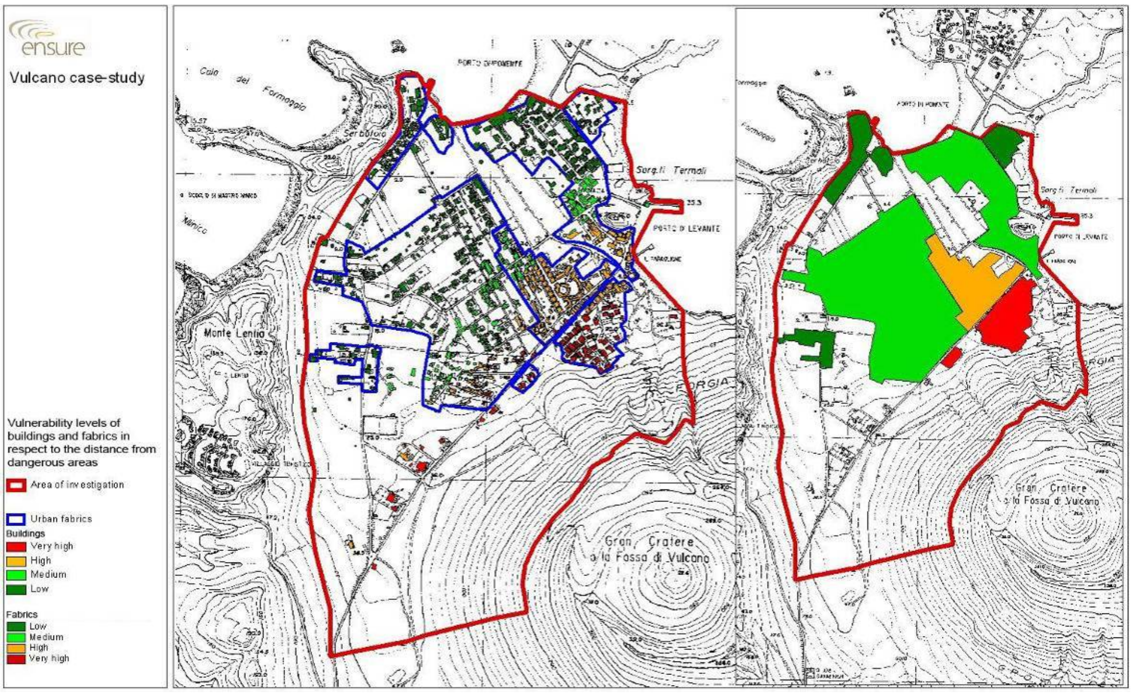

Figure 4.40 – Vulnerability levels of buildings and fabrics in respect to their distance from dangerous areas

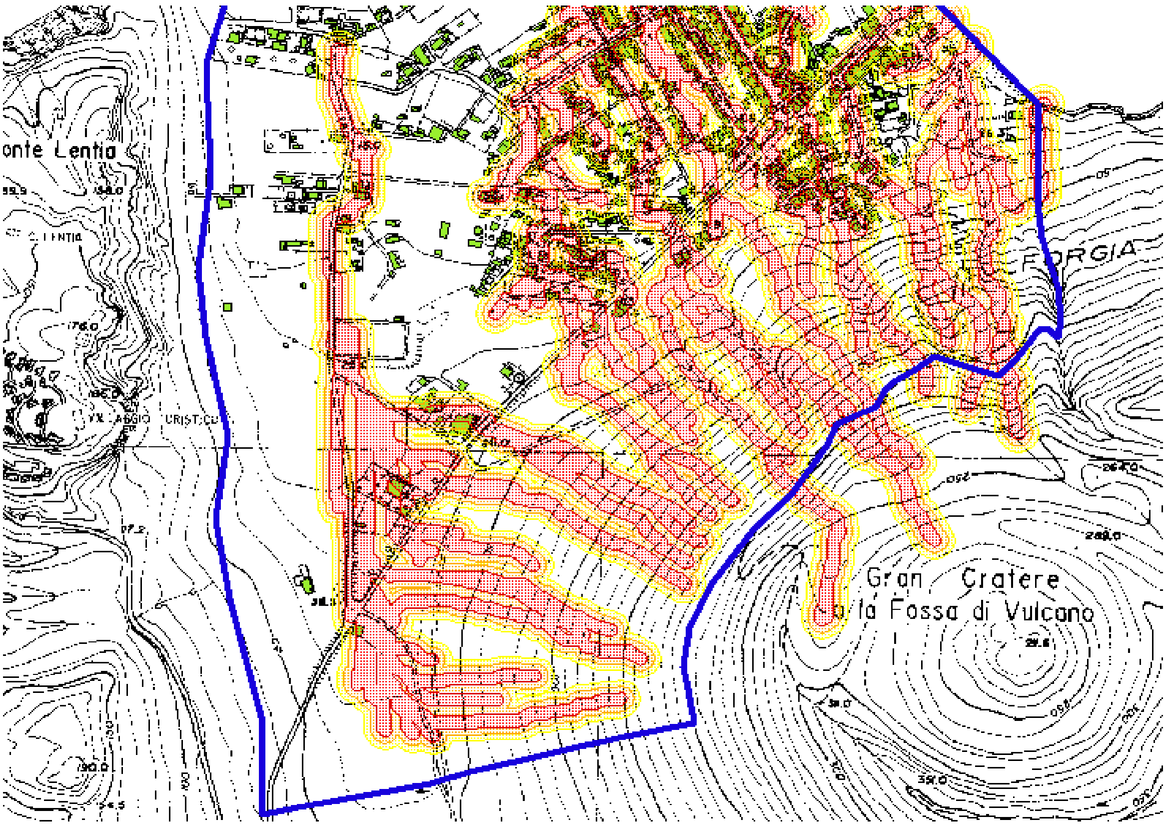

Figure 4.41 – Distances from lahars flows: the buffering zones of the channels

(red 20 meters, orange 10 meters, yellow 10 meters)

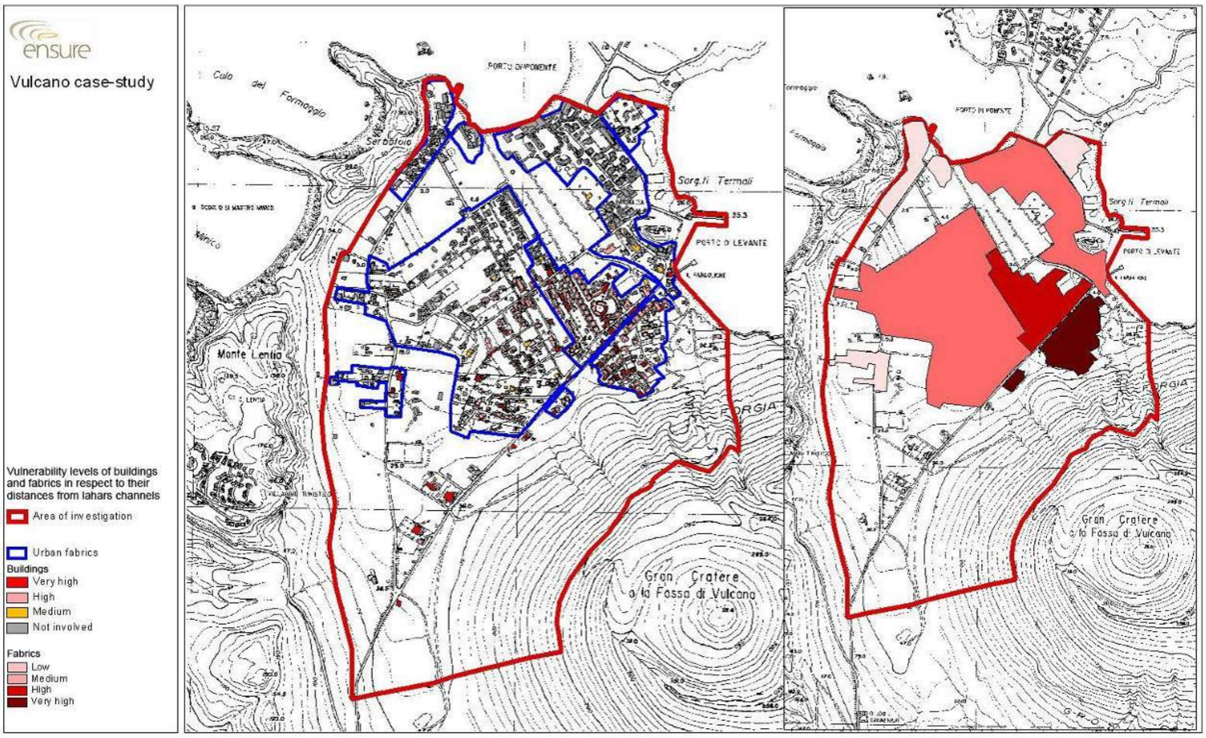

Figure 4.42 – Vulnerability levels of buildings and fabrics in respect to their distances from lahars channels

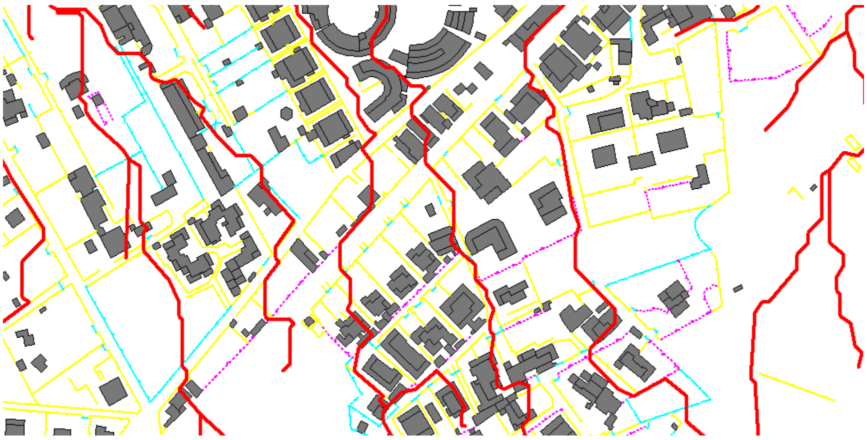

Figure 4.43 – Type of enclosures with respect to lahars flows: hedges (green), gates (cyan), partition walls (yellow), bearing walls (magenta).

With reference to the enclosures, type and position of enclosures in respect to the lahars directions have been considered, highlighting their function of barriers or obstacles (fig. 4.43). In many cases, existing enclosures around the buildings are ineffective, being located beyond or besides the buildings. The different levels of protection of buildings have been assigned as follows: Low (no protection, bearing walls along the slope, protective barriers parallel to lahars flows); Medium (gates, fences and hedges); High (partition walls); Very high (partition walls combined with other protective barriers).

In case of buildings placed along more than one channel, the average of the values has been considered. Then, the values of protection, obtained for each building, have been reported to the urban fabrics (fig. 4.44). It's worth noting that, in this case, a low level of protection corresponds to a very high level of vulnerability.
The last part of the matrix is directly referred to urban fabrics, although parameters for assessing physical vulnerability of urban fabrics to volcanic phenomena and specifically to lahars were not specified in the general framework set up in the WP4. As mentioned above, vulnerability of urban fabrics depends on the vulnerability of the buildings included in each fabric but also on some features of the fabric itself.
Thus, the features which mostly contribute to make an urban fabric vulnerable to lahars have been defined. In detail, the following parameters have been taken into account:

- built-up surface/surface of urban fabric;
- artificial surface/surface of open spaces;
- surface of residential building placed at road level/built-up surface of the urban fabric;
- surface of basement (basement or semi-basement)/built-up surface of the urban fabric.

The last parameter requires in-depth direct surveys, being very difficult to derive this information from indirect sources. Therefore, due to the lack of information for all the buildings included in the area of investigation, this parameter has been neglected.
Then, the mentioned parameters have been calculated for each of the 9 fabrics identified in the area of investigation, as shown in the table 4.4.

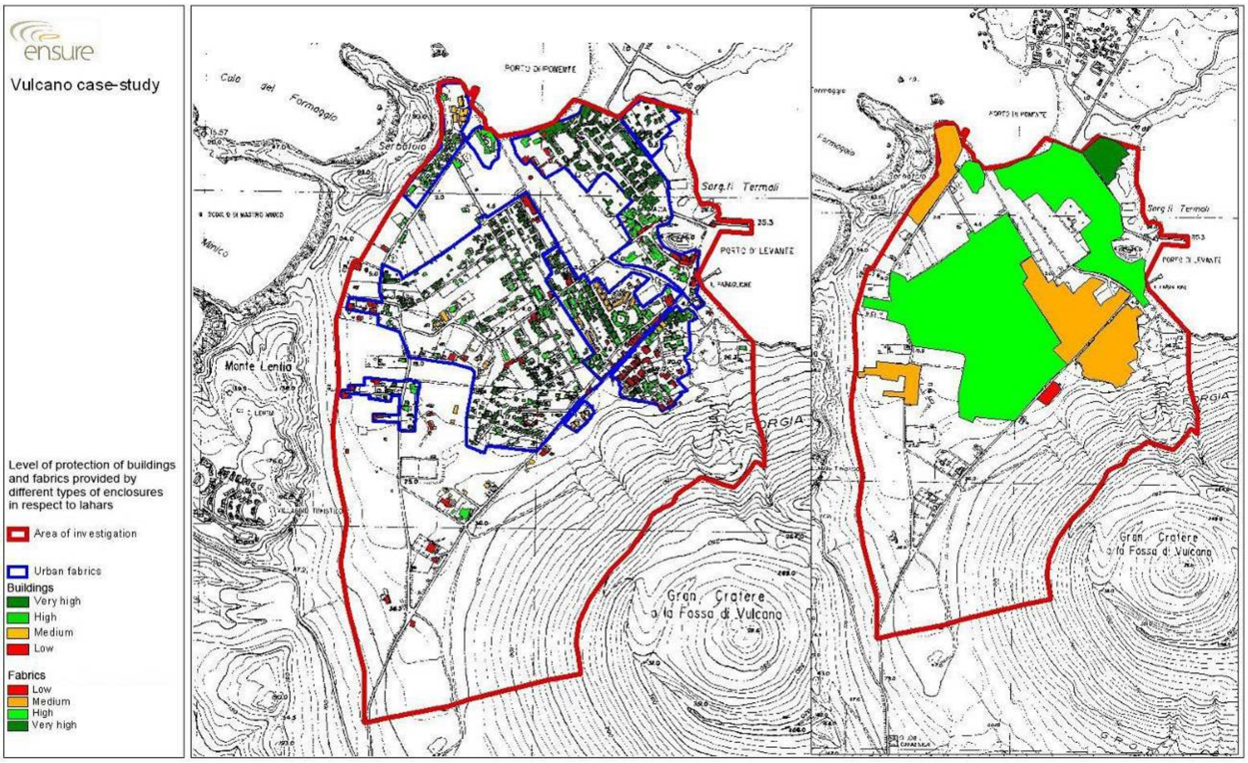

Figure 4.36 – Level of protection of buildings and fabrics provided by the different types of enclosures in respect to lahars

Based on these results, the key-element "Factors related to the urban fabrics morphology" has been calculated for each fabric, through the average of the scores assigned to each parameter (fig. 4.45, 4.46, 4.47).

Then, the final value of physical vulnerability for each fabric has been obtained through the average of the obtained scores for the two key-elements of the vulnerability matrix and, then, ranking again the final scores into four classes (fig. 4.48).
It is worth emphasizing that the final scores of key elements, key topics, aspects and system have been obtained through the calculation of the average (respectively of parameters, key elements and so on), the ranking of the values in respect to the 9 fabrics and finally, the "translation" of the numerical scores into four qualitative classes through the natural breaks procedure in ArcGis.

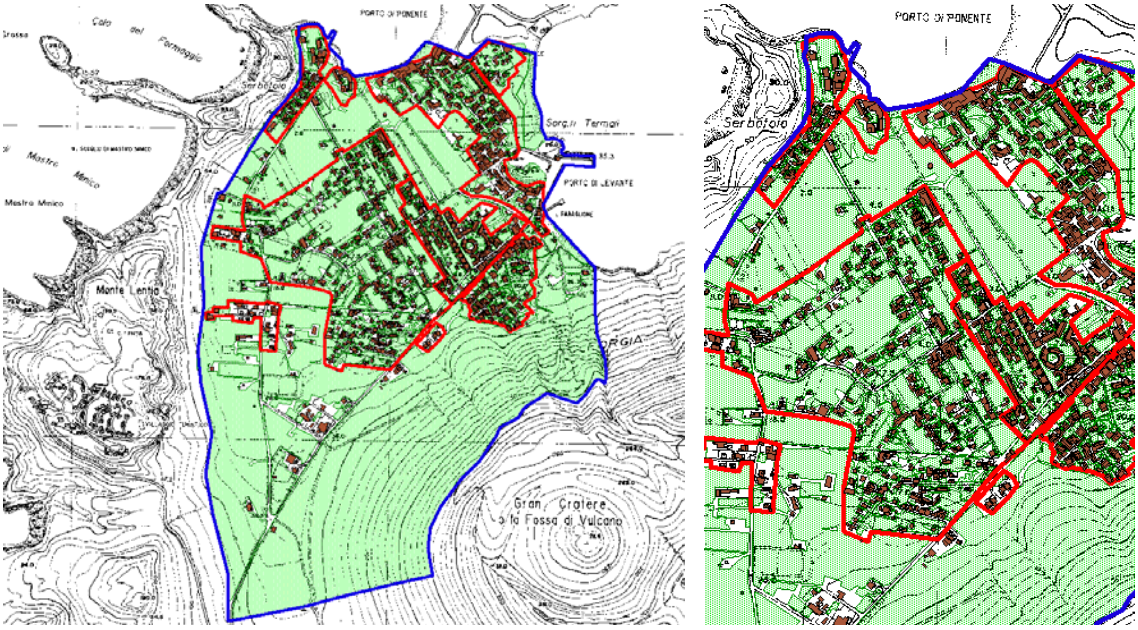

Figure 4.45 – Natural surfaces (green) and urban fabrics (red boundary)

Id	Surface (sqm)	UF Class	Built-up surface/ Total fabric surface (%)	Artificial surface /surface of open spaces (%)	Surface of residential building at road level/ built-up surface of urban fabric	Surface of basement/ Built-up surface of the urban fabric
1	44.146	A1	26,08	44,41	76,11	
2	65.331	B1	30,19	53,46	72,68	
3	284.901	B2	11,44	35,51	78,43	
4	110.727	B2	28,38	59,07	60,93	
5	16.884	B3	13,80	34,42	65,72	
6	25.188	A1	19,94	39,80	86,42	
7	7.648	B2	24,29	44,46	36,60	
8	4.005	A2	13,68	75,10	88,87	
9	15.779	B2	14,42	81,20	88,09	

Table 4.4 – Vulnerability parameters for the identified fabrics in the area of investigation

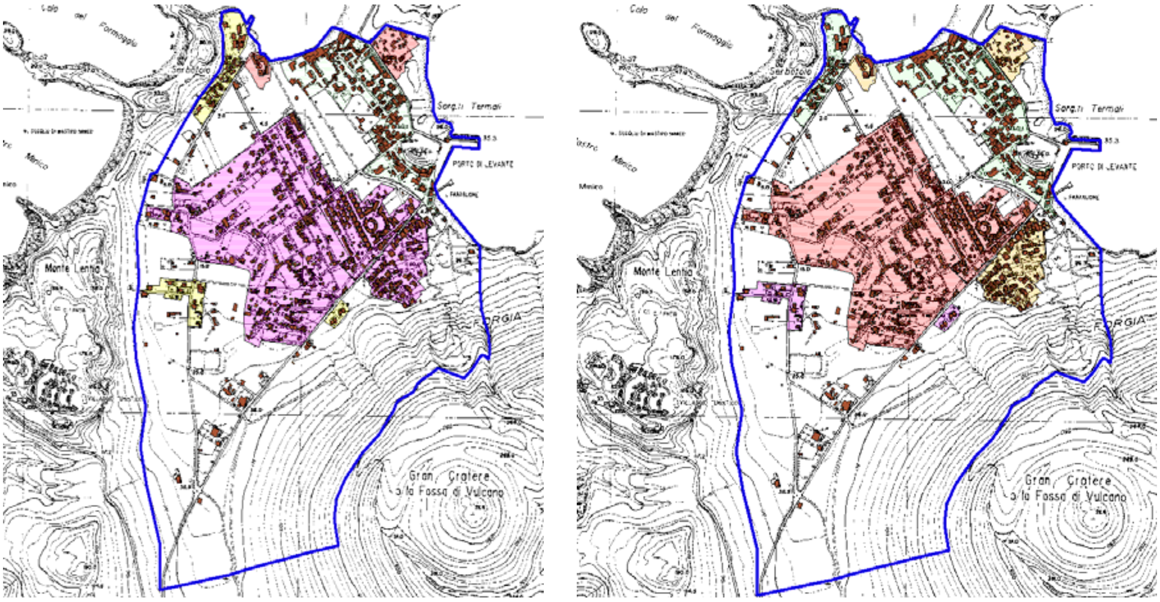

Figure 4.46 – Physical vulnerability assessment of urban fabrics: on the left the classification of urban fabrics in respect to the parameter "built-up surface/total fabric surface"; on the right, the classification in respect to "artificial surface of open spaces". In both cases, fabrics have been ranked according to four vulnerability classes: low (green), medium (yellow), high (red), very high (violet).

Figure 4.47 – Physical vulnerability assessment of urban fabrics: on the left the classification of fabrics in respect to " residential buildings at road level surface/built-up surface of fabric"; on the right the ranking of the urban fabrics related to the key-element "factors related to the urban fabric morphology". In both cases, fabrics have been ranked according to four vulnerability classes: low (green), medium (yellow), high (red), very high (violet).

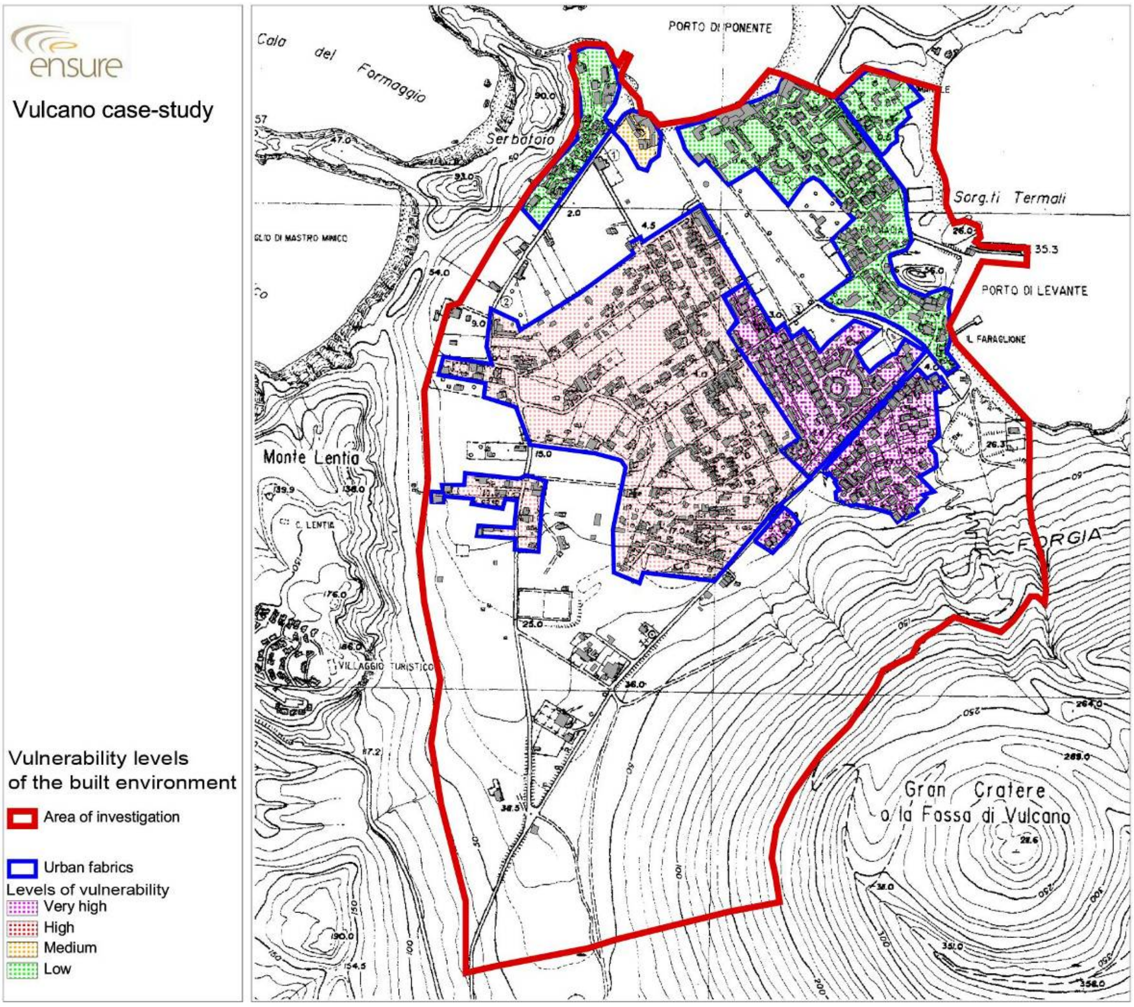

Figure 4.48 – Physical vulnerability assessment of the built environment: final ranking of urban fabrics

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	*Exposure and vulnerability of* ***Urban Fabric n. 1***	**1**	What are the factors that make the urban fabric vulnerable to the stress?	**1**	Factors related to the features of buildings and public facilities of urban fabric	**1**	roof	connection to structure		good/poor				**0,8 = VERY HIGH**	**0,77 = VERY HIGH**	**0,77 = VERY HIGH**	**0,77 = VERY HIGH**
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	**High**	The assessment has been developed grounding on in-situ surveys and photos	**0,75**				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	**High**	The assessment has been developed grounding on in-situ surveys and photos	**0,5**				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	**Very high**	The assessment has been developed grounding on carthography and lahars run out analysis	**1**				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**Very high**	The assessment has been developed grounding on carthography and lahars run out analysis	**1**				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**Medium**	The assessment has been developed grounding on carthography	**0,75**				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics features	**1**	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**Very high**	The assessment has been developed grounding on carthography	**1**	**0,75 = HIGH**			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	**Medium**	The assessment has been developed grounding on carthography and orthophoto	**0,5**				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	**High**	The assessment has been developed grounding on in-situ surveys and carthography	**0,75**				
								surface of basement/built-up surface of the urban fabric	not available								

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	*Exposure and vulnerability of **Urban Fabric n. 2***	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,75 = VERY HIGH	0,79 = VERY HIGH	0,79 = VERY HIGH	0,79 = VERY HIGH
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	Very high	The assessment has been developed grounding on in-situ surveys and photos	1				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	High	The assessment has been developed grounding on in-situ surveys and photos	0,5				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	High	The assessment has been developed grounding on carthography and lahars run out analysis	0,75				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	High	The assessment has been developed grounding on carthography and lahars run out analysis	0,75				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography	0,75				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics features	1	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Very high	The assessment has been developed grounding on carthography	1	0,83 = VERY HIGH			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	High	The assessment has been developed grounding on carthography and orthophoto	0,75				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	High	The assessment has been developed grounding on in-situ surveys and carthography	0,75				
								surface of basement/built-up surface of the urban fabric	not available								

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	*Exposure and vulnerability of **Urban Fabric n. 3***	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,6 = HIGH	0,67 = HIGH	0,67 = HIGH	0,67 = HIGH
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	High	The assessment has been developed grounding on in-situ surveys and photos	0,75				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	Medium	The assessment has been developed grounding on in-situ surveys and photos	0,75				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	Medium	The assessment has been developed grounding on carthography and lahars run out analysis	0,5				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography and lahars run out analysis	0,5				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	High	The assessment has been developed grounding on carthography	0,5				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics morphology	1	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Very high	The assessment has been developed grounding on carthography	1	0,75 = HIGH			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	High	The assessment has been developed grounding on carthography and orthophoto	0,75				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on in-situ surveys and carthography	0,5				
								surface of basement/built-up surface of the urban fabric	not available								

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	*Exposure and vulnerability of* ***Urban Fabric n. 4***	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,5 = MEDIUM	0,46 = LOW	0,46 = LOW	0,46 = LOW
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	**Medium**	The assessment has been developed grounding on in-situ surveys and photos	**0,5**				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	**Medium**	The assessment has been developed grounding on in-situ surveys and photos	**0,75**				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	**Low**	The assessment has been developed grounding on carthography and lahars run out analysis	**0,25**				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**Medium**	The assessment has been developed grounding on carthography and lahars run out analysis	**0,5**				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**High**	The assessment has been developed grounding on carthography	**0,5**				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics morphology	1	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**Low**	The assessment has been developed grounding on carthography	**0,25**	0,42 = LOW			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	**Low**	The assessment has been developed grounding on carthography and orthophoto	**0,25**				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	**High**	The assessment has been developed grounding on in-situ surveys and carthography	**0,75**				
								surface of basement/built-up surface of the urban fabric	not available								

Built environment	*Exposure and vulnerability of* ***Urban Fabric n. 5***	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,35 = LOW	0,42 = LOW	0,42 = LOW	0,42 = LOW
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	**Medium**	The assessment has been developed grounding on in-situ surveys and photos	**0,5**				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	**High**	The assessment has been developed grounding on in-situ surveys and photos	**0,5**				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	**Low**	The assessment has been developed grounding on carthography and lahars run out analysis	**0,25**				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**Low**	The assessment has been developed grounding on carthography and lahars run out analysis	**0,25**				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**Very high**	The assessment has been developed grounding on carthography	**0,25**				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics morphology	1	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	**High**	The assessment has been developed grounding on carthography	**0,75**	0,5 = MEDIUM			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	**Medium**	The assessment has been developed grounding on carthography and orthophoto	**0,5**				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	**Low**	The assessment has been developed grounding on in-situ surveys and carthography	**0,25**				
								surface of basement/built-up surface of the urban fabric	not available								

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	Exposure and vulnerability of *Urban Fabric n. 6*	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,5 = MEDIUM	0,46 = LOW	0,46 = LOW	0,46 = LOW
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	Low	The assessment has been developed grounding on in-situ surveys and photos	0,25				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	Low	The assessment has been developed grounding on in-situ surveys and photos	1				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	Low	The assessment has been developed grounding on carthography and lahars run out analysis	0,25				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Low	The assessment has been developed grounding on carthography and lahars run out analysis	0,25				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography	0,75				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics morphology	1	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography	0,5	0,42 = LOW			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Low	The assessment has been developed grounding on carthography and orthophoto	0,25				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on in-situ surveys and carthography	0,5				
								surface of basement/built-up surface of the urban fabric	not available								

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	Exposure and vulnerability of *Urban Fabric n. 7*	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,45 = MEDIUM	0,6 = MEDIUM	0,6 = MEDIUM	0,6 = MEDIUM
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	Very high	The assessment has been developed grounding on in-situ surveys and photos	1				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	Very high	The assessment has been developed grounding on in-situ surveys and photos	0,25				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	Low	The assessment has been developed grounding on carthography and lahars run out analysis	0,25				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Low	The assessment has been developed grounding on carthography and lahars run out analysis	0,25				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	High	The assessment has been developed grounding on carthography	0,5				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics morphology	1	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	High	The assessment has been developed grounding on carthography	0,75	0,75 = HIGH			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography and orthophoto	0,5				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Very high	The assessment has been developed grounding on in-situ surveys and carthography	1				
								surface of basement/built-up surface of the urban fabric	not available								

Summing up, the assessment of physical vulnerability of urban fabrics highlights remarkable differences among the 9 urban fabrics singled out in the area of investigation, allowing the identification of the priority areas on which to intervene for reducing vulnerability and guiding us towards the definition of appropriate mitigation measures.

Moreover, it is worth noting that the investigation carried out in respect to the built environment provides numerous and heterogeneous data; among them: building and fabric typologies that, as mentioned above, may be very helpful for extending vulnerability assessment to a wider context; specific data useful for assessing building or fabric vulnerability in respect to lahars.

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	Exposure and vulnerability of *Urban Fabric n. 8*	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,7 = VERY HIGH	0,76 = VERY HIGH	0,76 = VERY HIGH	0,76 = VERY HIGH
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	Low	The assessment has been developed grounding on in-situ surveys and photos	0,25				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	High	The assessment has been developed grounding on in-situ surveys and photos	0,5				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	High	The assessment has been developed grounding on carthography and lahars run out analysis	0,75				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Very high	The assessment has been developed grounding on carthography and lahars run out analysis	1				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Low	The assessment has been developed grounding on carthography	1				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics morphology	1	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography	0,5	0,83 = VERY HIGH			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	Very high	The assessment has been developed grounding on carthography and orthophoto	1				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	Very high	The assessment has been developed grounding on in-situ surveys and carthography	1				
								surface of basement/built-up surface of the urban fabric	not available								

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Built environment	Exposure and vulnerability of *Urban Fabric n. 9*	1	What are the factors that make the urban fabric vulnerable to the stress?	1	Factors related to the features of buildings and public facilities of urban fabric	1	roof	connection to structure		good/poor				0,55 = HIGH	0,69 = HIGH	0,69 = HIGH	0,69 = HIGH
								weight		heavy/light							
								shape		large inclination/plane							
							structure	material	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (iron-wood and mixed, masonry, reinforced concrete)	High	The assessment has been developed grounding on in-situ surveys and photos	0,75				
								homogeneity		large/largely disomogenous							
								type of connection among parts	not available	good/poor							
								floors rigidity		rigid/non rigid							
							foundation	depth and type	not available	non-existent, deep, superficial							
							spans between resistant elements	distance in m.		> 3 mt; < 3 mt (for masonry mainly)							
							shape	openings	not available	number and dimension of windows/doors							
								quality of openings		may be easily sealed/not							
								basement	not available	existant/non existant							
								inflammable objects	not available	existant/non existant							
								sources of radiation or toxic chemicals		existant/non existant							
							maintenance	building conditions	Low	Four classes obtained through the ranking of the index with the natural breaks procedure (poor/medium/ good/very good)	High	The assessment has been developed grounding on in-situ surveys and photos	0,5				
							position	soil on which the building is built (crest, alluvial deposits, etc.)		amplification soils yes/no							
								with respect to dangerous channels	High	Four classes obtained through the ranking of the index with the natural breaks procedure (out of the channel/lateral zone/middle zone/central zone)	Medium	The assessment has been developed grounding on carthography and lahars run out analysis	0,5				
								distance from dangerous areas	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Low	The assessment has been developed grounding on carthography and lahars run out analysis	0,25				
							protection	protection provided by enclosures (type and position)	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography	0,75				
							vulnerability assessment of public facilities	internal machinery sensitive to the volcanic hazards	not available	yes/no; type of machinery							
					Factors related to the urban fabrics morphology	1	rainproof level of the settlement	built-up surface/total surface of urban fabric	High	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high, very high)	Medium	The assessment has been developed grounding on carthography	0,5	0,83 = VERY HIGH			
								artificial surface /surface of open spaces	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	Very high	The assessment has been developed grounding on carthography and orthophoto	1				
							activities at ground floor	surface of residential building placed at road level/buit-up surface of the urban fabric	Medium	Four classes obtained through the ranking of the index with the natural breaks procedure (low, medium, high,	Very high	The assessment has been developed grounding on in-situ surveys and carthography	1				
								surface of basement/built-up surface of the urban fabric	not available								

Figure 4.49 – The matrixes for physical vulnerability assessment of the 9 urban fabrics in the area of investigation

Hence, according to the available data, different paths for analyzing vulnerability can be followed. The procedure we have chosen in order to assess physical vulnerability of built environment in face of lahars represents one of the possible paths for applying the general framework developed in WP4, although different paths for interpreting and applying the provided indicators could be singled out, according to the type of hazard (e.g. localized or widespread phenomena), to the peculiarities of the context at stake (in terms of features, of assessment scale which, in turn, depends on the scale of the phenomenon) and of the objectives of the assessment itself (Figure 4.49).

Critical Infrastructures

The third part of the assessment matrix refers to critical infrastructures and production sites. Nevertheless, in respect to the Vulcano case study, parameters related to the vulnerability of production sites have been neglected, since no important productive activity is located on the Vulcano island.

According to the matrix developed in WP4, physical vulnerability of critical infrastructures to lahars depends on numerous factors, mainly related to the typological features of the infrastructures and to their position in respect to the lahars flows. In order to assess physical vulnerability of critical infrastructures, the latter have been firstly singled out in the area of investigation (fig. 4.50).

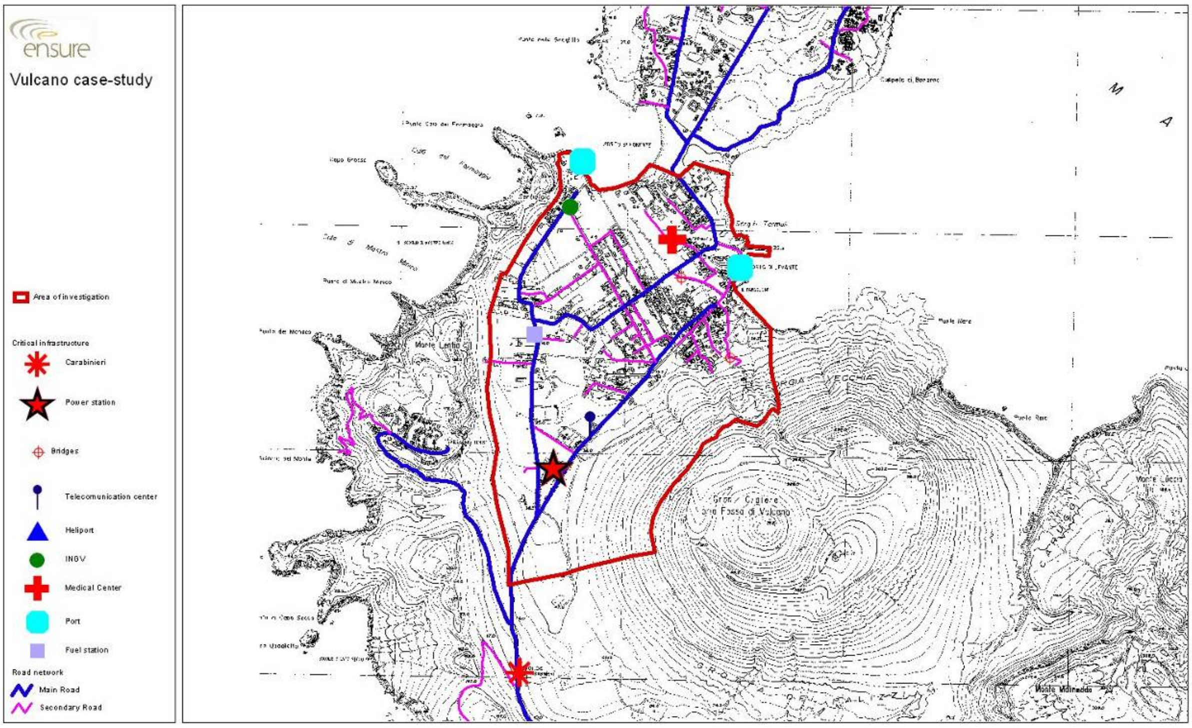

Figure 4.50 – Critical infrastructures in the area of investigation

Physical vulnerability assessment has been referred to the two main groups of critical infrastructures at stake: networks and punctual infrastructures.
Physical vulnerability assessment of the main networks should require in-depth analyses referred to numerous vulnerability parameters. Due to the lack of available data and information (specific features of the road network, features and position of other networks such as electricity, gas pipelines, etc.), only the position of the primary road network in respect to lahars flows, identified through the run out analysis, has been taken into account.
Three main roads cross the investigation area: all of them are characterized by a strategic role, since they represent the main accesses to the ports (Porto Levante e Porto Ponente) and connect the investigation area with Vulcanello and Piano.
These roads have a total length approximately of 10.200 m. The percentage of primary roads located in the lahars run out area is about 55%: hence, applying the qualitative/numerical correspondence scale adopted also for natural and built environment vulnerability assessment, such a value corresponds to a high level of vulnerability.
In respect to the punctual infrastructures six elements, which can be considered as critical at least on a local scale, are located in the area of investigation: the medical center, the INGV building, the two ports (Porto Ponente and Porto Levante), the power plant, the telecommunication center. For each element, the assessment has been carried out taking into account its position in respect to lahars and some parameters related to the physical vulnerability of the buildings in which they are allocated. With reference to the first parameter, related to the position, the assessment has been developed taking into account the position of each infrastructure in respect to lahars run out channels and its distance from the hazard source.

As the position in respect to run out channels is concerned, the assessment has been carried out according to simplified criteria in respect to those already applied in case of built environment. In detail, a binary scale (internal/external) has been applied for assessing the position of each infrastructure in respect to lahars channels.
As the distance from the hazard source is concerned, three different distances have been considered, in order to graduate the level of vulnerability:

- in case of infrastructures placed along the crater slopes or in the plain area, at a distance of 100 meters from the crater slope, vulnerability level has been considered very high;
- in case of infrastructures placed in the plain area, at a distance included between 100 and 150 meters from the crater slope, vulnerability level has been considered medium;
- in case of infrastructures located in the plain area, at a distance greater than 150 meters from the crater slope, vulnerability level has been considered low.

It has to be highlighted that the telecommunication center and the Porto Levante are the only critical infrastructures which are not placed along the run out channels, although included in the area potentially inundated: the final values assigned to these infrastructures (Medium for the Telecommunication center and low for the Porto Ponente) represent an average between a low value of vulnerability due to their position in respect to lahars run out channels (being these infrastructures external to the run out channels) and the values obtained in respect to the distance from the hazard source (which is very high for the Telecommunication center and low for the Porto Ponente).

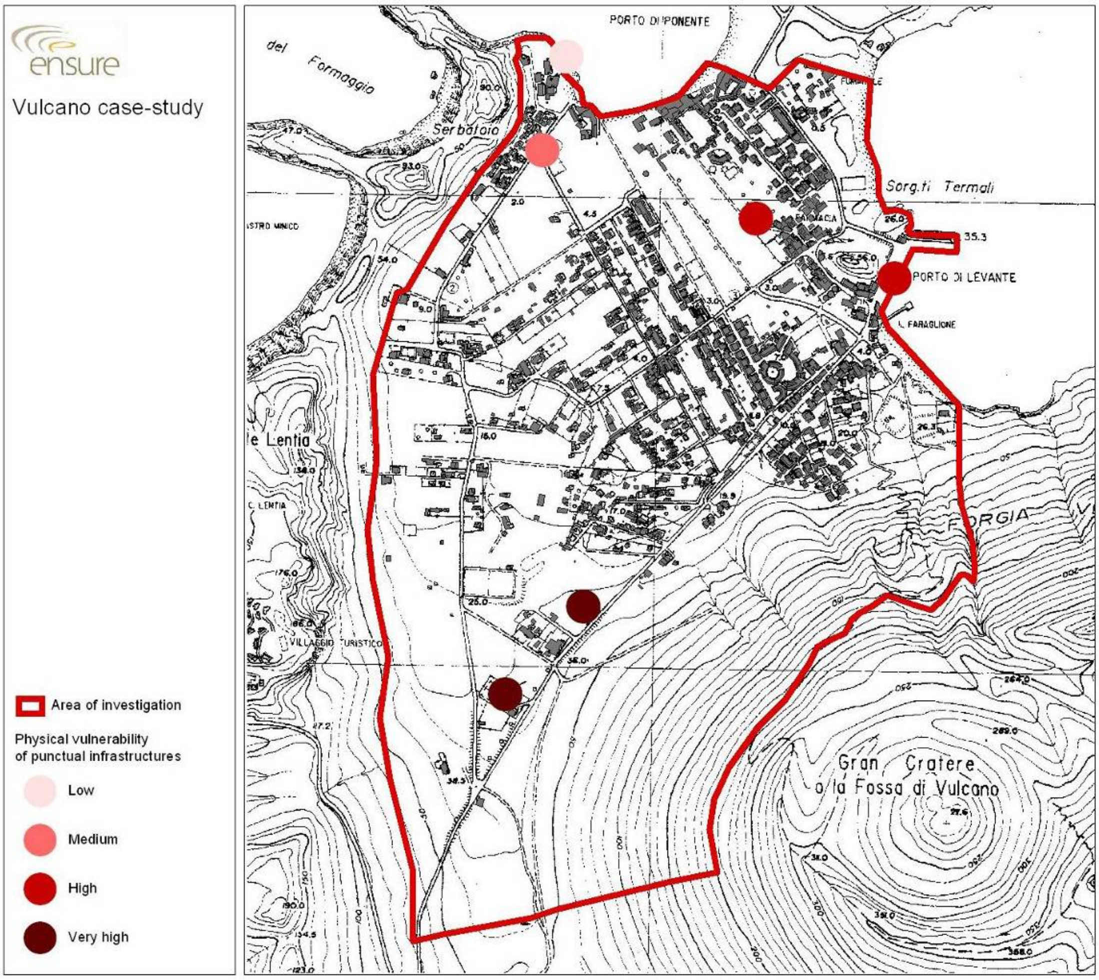

Figure 4.51 – Physical vulnerability of punctual infrastructures

In respect to the physical vulnerability of the buildings in which critical infrastructures are located, according to the available information, only parameters related to the construction materials and typologies have been taken into account, even though more detailed data would have been required.
The assessment is based on qualitative judgments related to the maintenance level of buildings and to the building classification described in the previous paragraph and mainly related to the construction techniques (masonry, reinforced concrete, mixed).

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Infrastructure and production sites	*Critical infrastructures*	1	What are the factors that make critical infrastructures vulnerable?	1	Network infrastructures	1	electricity and communication	lines		aerial lines/underground				0,75 = High	0,62 = High	0,62 = High	0,62 = High
								position		inside/outside potentially affected areas (scenario dependent)							
							gas	position of gas conducts		across hazardous zones							
								connection to buildings		vulnerable buildings/not vulnerable							
							water and sewerage	position of water pipes		across hazardous zones							
								pipes condition		obsolete/new							
							main road network	position of roads	High	type of roads inside/outside potentially affected areas (scenario dependent)	High	The assessment has been developed grounding on carthograpy and lahars run out analysis	0,75				
								specific roads vulnerability assessment		see buildings assessment							
					Punctual infrastructures	1	Power plant	position	High	inside/outside potentially affected areas and distance from hazard source (scenario dependent)	Very high	The assessment has been developed grounding on carthograpy and lahars run out analysis	1	0,5 = Very high			
								type of materials, typology, specific vulnerability assessment	Low	Construction materials, level of maintenance	Low	Qualitative judgement based on available data	0,25				
							INGV	position	High	inside/outside potentially affected areas and distance from hazard source (scenario dependent)	Low	The assessment has been developed grounding on carthograpy and lahars run out analysis	0,25				
								type of materials, typology, specific vulnerability assessment	Low	Construction materials, level of maintenance	Medium	Qualitative judgement based on available data	0,5				
							Medical center	position	High	inside/outside potentially affected areas and distance from hazard source (scenario dependent)	Medium	The assessment has been developed grounding on carthograpy and lahars run out analysis	0,5				
								type of materials, typology, specific vulnerability assessment	Low	Construction materials, level of maintenance	Medium	Qualitative judgement based on available data	0,5				
							Port of Ponente	position	High	inside/outside potentially affected areas and distance from hazard source (scenario dependent)	Low	The assessment has been developed grounding on carthograpy and lahars run out analysis	0,25				
								type of materials, typology, specific vulnerability assessment									
							Communication center	position	High	inside/outside potentially affected areas and distance from hazard source (scenario dependent)	Medium	The assessment has been developed grounding on carthograpy and lahars run out analysis	0,5				
								type of materials, typology, specific vulnerability assessment	Low	Construction materials, level of maintenance	High	Qualitative judgement based on available data	0,75				
							Port of Levante	position	High	inside/outside potentially affected areas and distance from hazard source (scenario dependent)	Medium	The assessment has been developed grounding on carthograpy and lahars run out analysis	0,5				
								type of materials, typology, specific vulnerability assessment									
	Production sites		What are the factors that make production				presence of flammable materials	binary; amount		yes/no; quantities							

Figure 5.52 – Physical vulnerability matrix related to critical infrastructures

Then, based on the obtained qualitative values, a quantitative score (varying between 0 and 1) has been assigned to each parameter. The scoring of the key-elements has been obtained through the average of the scores assigned to the related parameters.
The obtained numerical scores related to each element have been associated to the points representing each infrastructure within the GIS (fig. 4.51).
Then, these values have been ranked into four classes through the natural breaks procedure, in order to compare the levels of vulnerability of the critical infrastructures. Finally, the values of the key-topic, aspect and system have been obtained through the average of the related scores (fig. 5.52).

Social System

As already mentioned, data and information for assessing physical vulnerability in face of hazards have to be collected and elaborated in respect to defined spatial elements or units, which vary in respect to the scale of the analysis but also to the system which has to be investigated.
Thus, the assessment of physical vulnerability to lahars of social system has been carried out in respect to the census units, the smallest partition of a Municipal area to which the Italian Institute for Statistical Surveys (ISTAT) provides data related to population.
The Vulcano island is divided into 9 census units; in the area of investigation only 2 units, which cover almost completely the built up area, are included (fig. 5.53).
Based on the ISTAT data (2001), the Vulcano island has 715 inhabitants; almost the 50% of the population (361) is placed in the area of investigation. It is worth noting that, being tourism the main economic activity on the Vulcano island, population significantly grows during summer. According to information provided by local Authorities, indeed, during summer (and mainly in July and August), tourists are about 5-10.000 and they are mainly

gathered in the areas of Porto, corresponding to the area of interest, and Vulcanello. The matrix for assessing physical vulnerability of the social system is mainly addressed to evaluate preparedness and susceptibility of individuals and community to suffer damage, focusing on the main factors that make them vulnerable to stress.

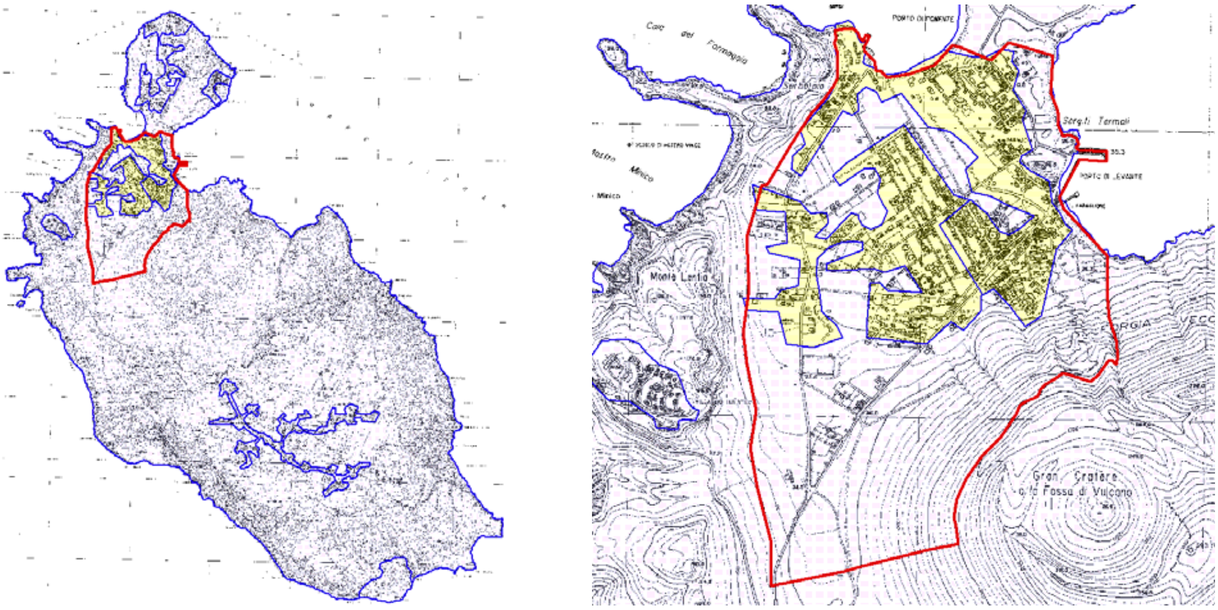

Figure 5.53 – The census units (blue border) of the Vulcano island (on the right); the census units (yellow) in the area of investigation (red border).

Two main groups of factors have been taken into account:

- a first one is focused on preparedness activities (such as training activities, evacuation drills, etc) and availability of self protection means (which seems to be not so important for lahars);
- a second one is related to features and distribution of population.

As preparedness activities are concerned, it has to be underlined that no emergency plan is currently available and the only evacuation drill in face of volcanic event was carried out in November 1991.
Therefore, the qualitative value assigned to the parameter is Absent, which corresponds to a numerical score equal to 1, in that it corresponds to the highest level of vulnerability.
In the second group, factors related to the age of population and to its concentration in hazardous areas have been taken into account.
In respect to the age, which should affect the capacity of people to escape in case of hazardous event, the relationship between the amount of population over 65 and under 15 on the total population of each census unit per 100 inhabitants has been taken into account. In order to obtain a comparative value for each census unit, the parameter has been calculated for all the census units of the island and the obtained values have been classified in four classes, applying the natural breaks method. To each class, a numerical score between 0 and 1 has been assigned. Summing up, the population characterized by a reduced capacity to escape in case of event on the Volcano island amounts to 202 people, corresponding to the 28% of the total population and the two census units in the investigation area are included in the class High (fig. 5.54).

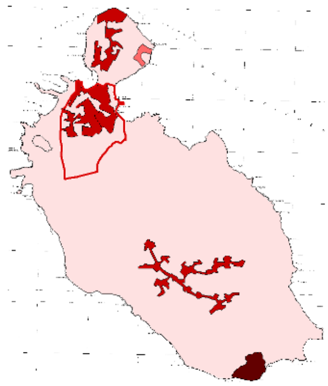

Figure 5.54 – Classification of census units in respect to population age

In respect to the concentration of population in dangerous areas, it has to be underlined that the two census units included in the area of investigation can be both considered as dangerous areas in respect to lahars.

Due to the relevant change of population during seasons, two different scenarios have been considered: a winter scenario in which only resident population has been taken into account; a summer one in which the amount of population includes tourists.

As above mentioned, data collected from local Authorities highlight that during summer tourists are about 5-10.000, mainly gathered in the areas of Porto, which corresponds to the area of interest, and of Vulcanello.

According to this information, we have considered that during summer (July and August), about 9.000 tourists can be contemporarily on the island: they will be mainly gathered in the area of Porto (the area of investigation) (60%), whereas the remaining 40% can be divided as follows: 25% in the area of Vulcanello; 5% in the area of Lentia; 10% in the area of Piano. Therefore, 5400 tourists have been considered in the area of investigation. This value has been further divided between the two census units, in respect to the number of unoccupied dwellings (189 in the southern unit and 504 in the northern one) and to the number of accommodation facilities.

Hence, the total amount of tourists has been considered equal to 1.400 in the southern unit and to 4000 in the northern one.

The considered parameter is population density: such parameter has been calculated in respect to the first (only residents) and the second scenario (residents and tourists). It is worth noting that, in order to provide a reliable classification of the census units, the parameter has been calculated for all the units of the island; the obtained values have been articulated into four classes through the natural breaks (fig. 5.55) and to each class a numerical score varying between 0 and 1 has been assigned.

In respect to the first scenario, the two census units in the area of investigation are classified according to the following values: very high the southern unit and high the northern one. These values are reversed in respect to the scenario 2. The final score for each census unit has been obtained as an average between the two scenarios. The two considered units are both classified as Very High (fig. 5.56).

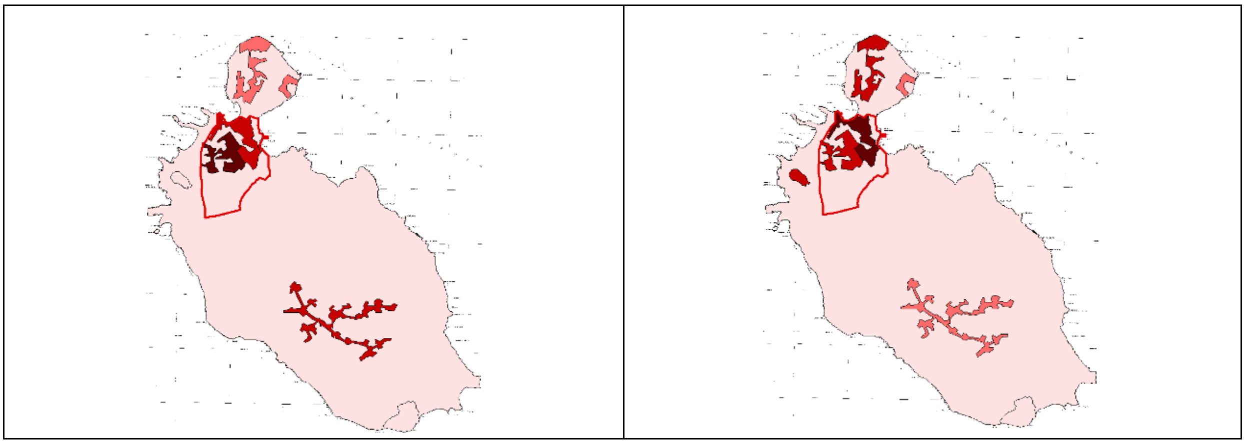

Figure 5.55 – Population density (inhabitants/hectares) in respect to the first scenario (only residents) on the left and to the second one (residents and tourists) on the right.

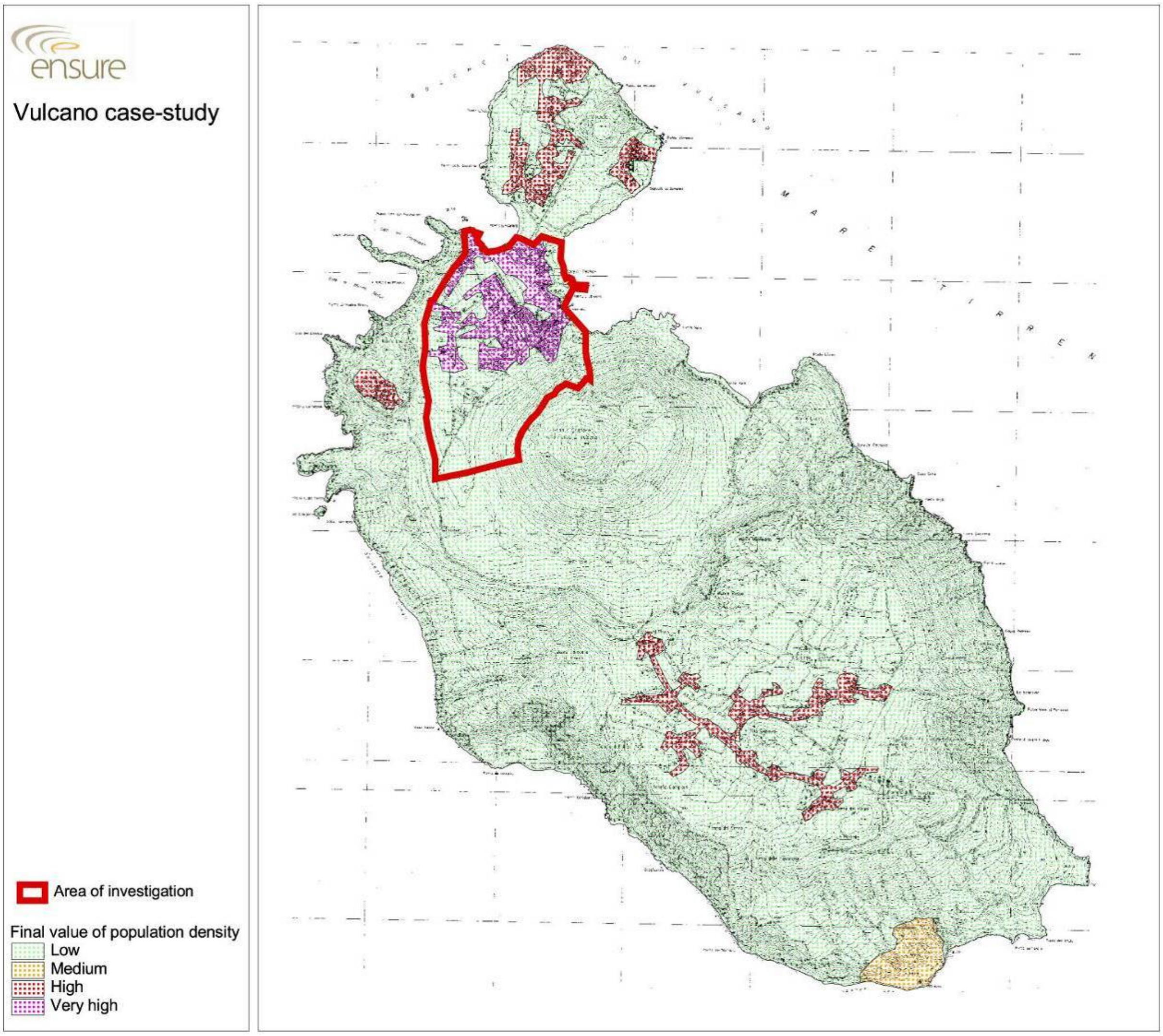

Figure 5.56 – Classification of census units in respect to the final value of the population density

According to the obtained values, the matrix related to the physical vulnerability of the social system has been filled in for the two census units included in the area of investigation: both of them show a Very high vulnerability (fig. 5.57).

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Social system (agents)	*Vulnerability and prepardness of people and community of* ***census unit 1***	1	What are the factors that make people/community vulnerable to stress?	1	Factors related to prepardness	1	preparedness	prior training and exercises; information about what do do	High	yes/no; frequency of training	**No**	The only evacuation drill on the island related to volcanic event was done in November 1991. No emergency plan is currently available.	**1**	**1 = Absent**	**0,93 = Very high**	**0,93 = Very high**	**0,93 = Very high**
							sensistivity to health effects of volcanic hazards	means of self protection		yes/no;							
					Factors related to people features and concentration	1	age of resident population	difficulties to comply with evacuation orders; difficulties in escaping	High	percentage of people younger than 15 and over 65 years in respect to total population	**High**	The assessment has been developed grounding on 2001 ISTAT database	**0,75**	**0,87 = Very High**			
							concentration	resident population and tourists in dangerous areas with respect to winter and summer seasons	Low	inside/outside potentially affected areas (scenario dependent); number of tourist and residents in different times	**Very high**	The assessment has been developed grounding on 2001 Istat database and on-site surveys	**1**				

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Notes on the Vulcano case-study	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Social system (agents)	*Vulnerability and prepardness of people and community of* ***census unit 2***	1	What are the factors that make people/individuals vulnerable to stress?	1	Factors related to the prepardness	1	preparedness	prior training and exercises; information about what do do	High	yes/no; frequency of training	**No**	The only evacuation drill on the island related to volcanic event was done in November 1991. No emergency plan is currently available.	**1**	**1 = Absent**	**0,93 = Very high**	**0,93 = Very high**	**0,93 = Very high**
							sensistivity to health effects of volcanic hazards	means of self protection		yes/no;							
					Factors related to the people features and concentration	1	age of resident population	difficulties to comply with evacuation orders; difficulties in escaping	High	percentage of people younger than 15 and over 65 years in respect	**High**	The assessment has been developed grounding on 2001 ISTAT database	**0,75**	**0,87 = Very High**			
							concentration	resident population and tourists in dangerous areas with respect to winter and summer seasons	Low	inside/outside potentially affected areas (scenario dependent); number of tourist and residents in different times	**Very high**	The assessment has been developed grounding on 2001 Istat database and on-site surveys	**1**				

Figure 5.57 – Physical vulnerability to lahars of social system in respect to the census units in the area of investigation.

Systemic vulnerability

The third set of matrixes set up in the WorkPackage 4 is focused on systemic vulnerability and addressed to evaluate the potential reaction of the different systems (natural and built environment, critical infrastructures, social systems) to the first level losses. For example, in respect to built environment and critical facilities, the capacity to keep functioning despite some level of physical damage is evaluated, considering the interdependencies among systems and among components of fundamental systems.

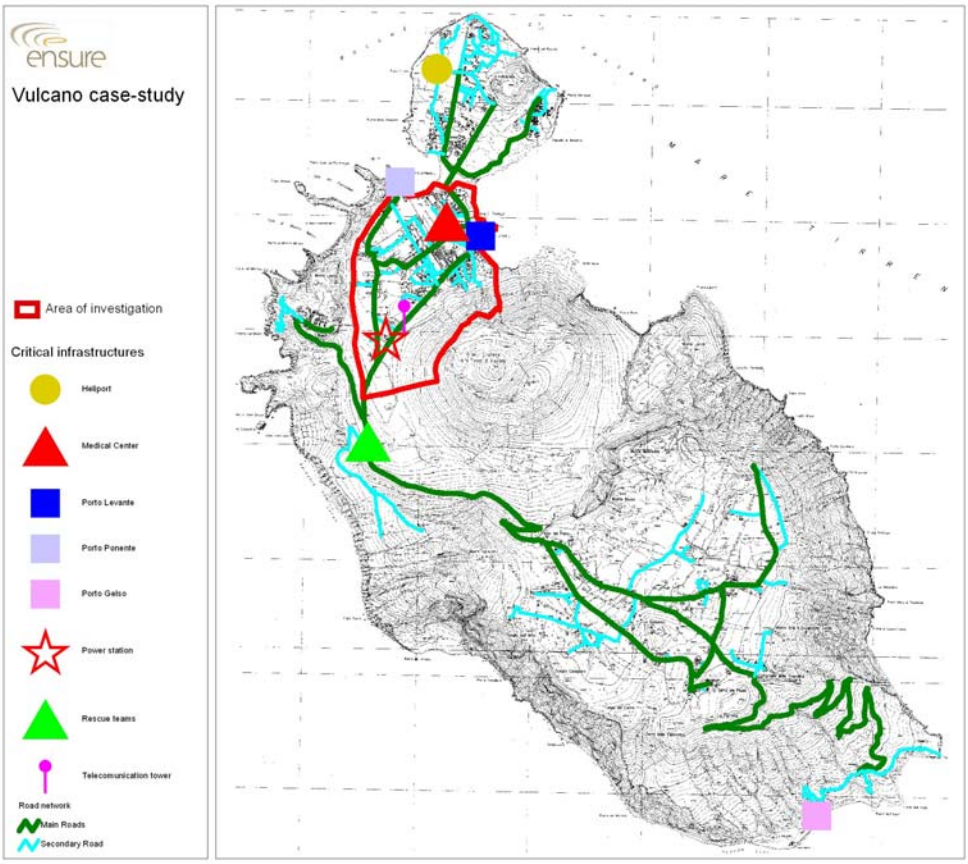

Figure 5.58 – Punctual and network infrastructures

With reference to the general framework set up in WP4, in the Vulcano case studies particular attention has been devoted to the systemic vulnerability of critical infrastructures, being this aspect the most relevant one in respect to the Vulcano case study. In detail, taking into account that most of the critical infrastructures of the island are located in the lahars prone area, and above all the main roads connecting the residential settlement in the investigation area to the three ports of the island and to some crucial equipments during emergency (such as the medical center), the assessment of systemic vulnerability has been mainly addressed to evaluate:

- the potential loss of accessibility to critical equipments from residential settlements placed in the investigation area;
- the degree of interdependency of some punctual infrastructures on the network infrastructures;
- the level of substitutability of some strategic equipments located in the investigation area.

Also in this case, slight changes and integration to the matrixes for systemic vulnerability assessment set up in the WP4 and some changes to the parameters have been required. The matrix has been modified, emphasizing the two groups of critical infrastructures at stake: networks and punctual infrastructures. Nevertheless, it is worth noting that the assessment has been specifically referred to punctual infrastructures playing a strategic role in case of emergency (the ports of Ponente, Levante and Gelso, the Police Station, the Medical center, the Northern heliport, the Telecommunication Center and the Power Plant; Fig. 5.58).
The road network has been taken into account in order to evaluate the accessibility to or from the considered punctual infrastructures and water and gas networks have been considered in order to assess the vulnerability arising from the interdependency among these networks and some critical equipments (such as the medical center).
In the matrix for assessing systemic vulnerability of critical infrastructures to lahars (fig. 5.62), the rows in grey represent parameters which are not very relevant to lahars; the ones in orange refer to parameters which, although relevant, would have required detailed in situ surveys: hence, these parameters have been neglected in respect to the case study.
In the matrix, the accessibility to the strategic infrastructures (ports, medical center, heliport, police station) from or to the residential areas has been assessed: to this aim, a specific procedure has been set up. For power plant and telecommunication center, the accessibility from the ports has been considered. Moreover, for the medical center, a qualitative judgment on the level of dependency from the electricity and communication networks has been considered.
Finally, for the telecommunication center and for power plant, a qualitative judgment on the level of redundancy in supplying has been provided.
The developed procedure has been addressed to evaluate the different levels of accessibility of critical infrastructures in ordinary conditions and in emergency phase, due to the potential effects of lahars on the road network.
First of all, the residential areas have been pointed out with reference to the nine fabrics singled out, in the investigation area, as spatial units of reference for physical vulnerability assessment. A centroid has been associated to the area of each fabric through an Arcgis routine: this point will represent the whole urban fabric in the accessibility assessment (fig. 5.59).

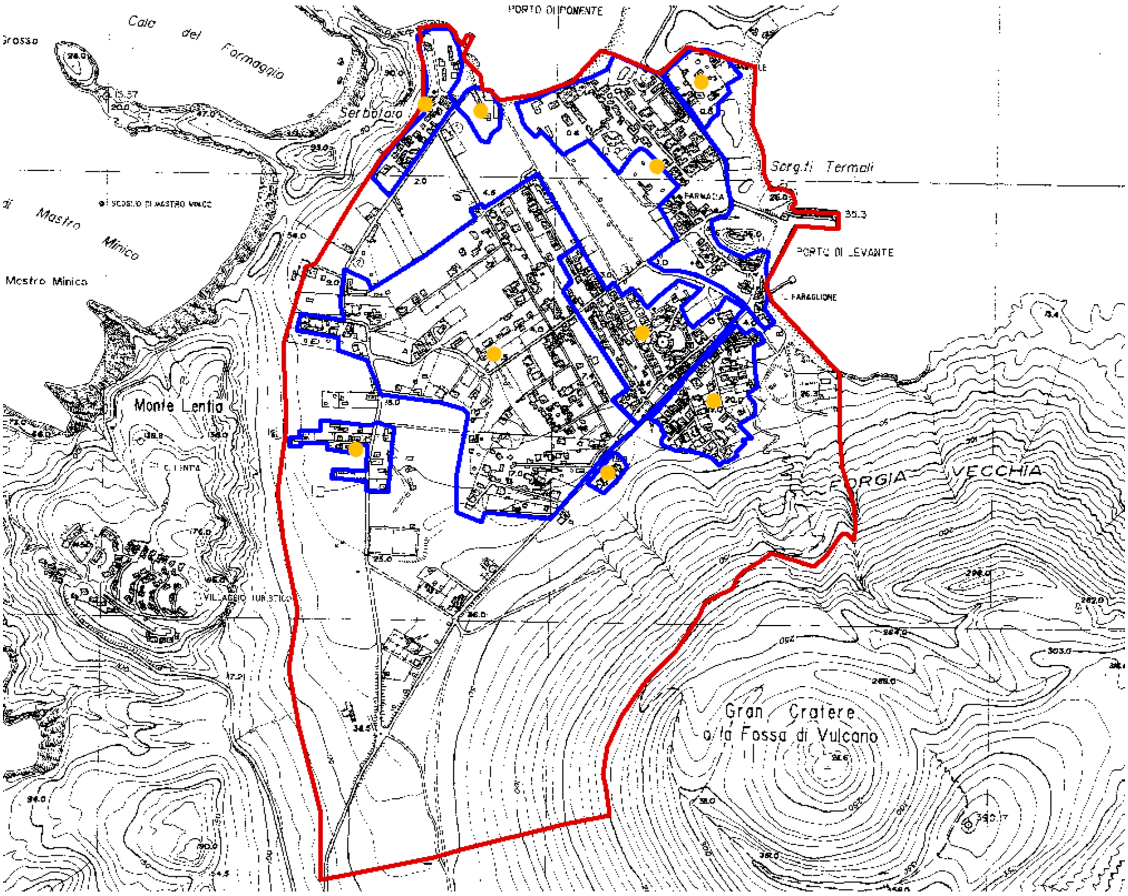

Figure 5.59 – The investigation area (red), the nine urban fabrics (blue) and the centroids (yellow points)

Then, with respect to each considered strategic infrastructure and each urban fabric, the minimum connection path along the main and secondary roads has been defined. It has to be underlined that in case of Power Plant and Telecommunication Center, the minimum path has been calculated with respect to the three ports of the island, since in this case the priority is that these plants have to be accessible for being repaired in case of damages.

For each path, the length along the main road (ML) and the length along the secondary road (SL) have been calculated and a corrected length (CL) has been obtained as follows:

CL = (ML*0.80)+SL

The coefficient 0.80 has been introduced to take into account the differences in terms of practicability and usability between the two types of road. Accessibility has been considered as inversely dependent on this value. Through developed in the assessment of the “position” parameter of the vulnerability of the built environment.

Then, the lahars potential effects on road network have been considered. In detail, for each path, the length of main and secondary roads affected has been calculated, based on the intersection between the road network and the areas potentially affected by lahar flows previously identified (fig. 5.60). In order to simulate the effects of lahars on accessibility, a corrected length has been calculated as follows:

CL* = [(ML*0.80)*a] + (SL*b)

Where for each path:

CL* = Corrected length in the lahars scenario

a = 1 + (main road length affected by lahars/ML)

b = 1 + (secondary road length affected by lahars/SL);

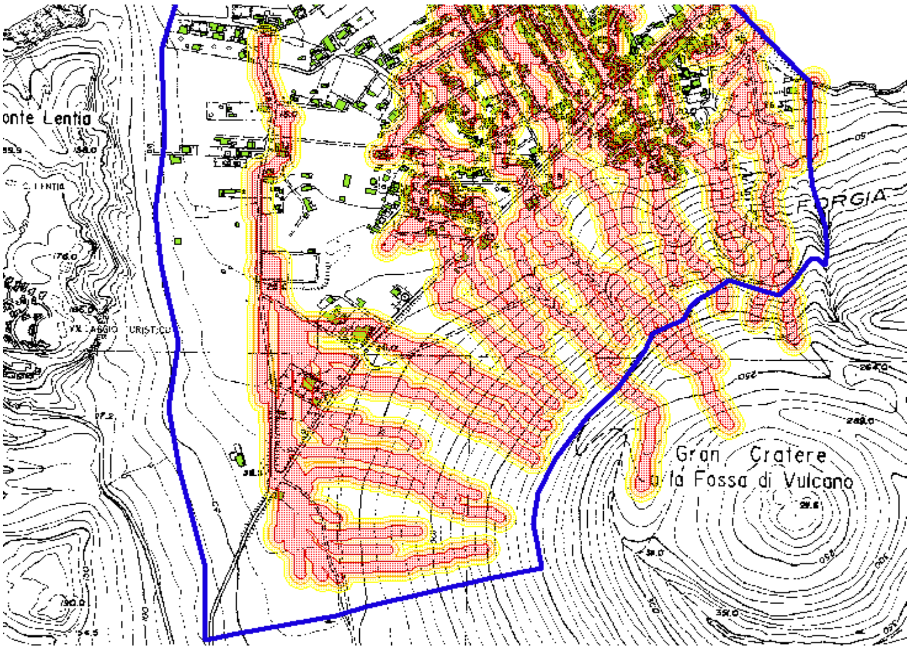

Figure 5.60 – Lahars flows and buffering zones(red 20 meters, orange 10 meters, yellow 10 meters)

Then, accessibility indexes in ordinary condition (Ic) and in lahars scenario (Ic*) have been defined, and for each considered strategic infrastructure the CL and CL* obtained values have been normalized as follows:

Ic = 1-[(CL – minimum value)/(Maximum value-minimum value)]
Ic* = 1-[(CL* – minimum value)/(Maximum value-minimum value)]

Where:
Minimum value represents the minimum of the values of CL and CL*;
Maximum value represents the maximum of the values of CL and CL*.

Furthermore, in order to represent the change in accessibility due to the effects of lahars, the values of the Ic index have been articulated into four qualitative scales through the natural breaks procedure within the GIS environment. Then the Ic* values have been classified, adopting the range of variations developed for the Ic index, which highlight the reduction in accessibility due to effects of lahars. For example, in the Table 4.5, parameters and indexes referred to the Medical Center are shown.

	Ordinary conditions						
	Medical center						
	ID	Total length	Main road length	Secondary road length	Corrected length (CL)	Iac	Qualitative level
Residential areas	1	640	138	502	612	0,85	Very high
	2	478	230	248	432	1,00	Very high
	3	709	551	158	599	0,87	Very high
	4	520	184	336	483	0,96	Very high
	5	564	376	188	489	0,95	Very high
	6	1148	594	554	1029	0,52	High
	7	1219	634	585	1092	0,47	Medium
	8	887	480	407	791	0,71	High
	9	1268	1095	173	1049	0,50	Medium

	Lahars scenario						
	Medical center						
	ID	Total road length affected	Main road length affected	Secondary road length affected	Corrected length (CL*)	Iac*	Qualitative level
Rsidential areas	1	358	138	220	944	0,59	High
	2	303	182	121	699	0,79	Very high
	3	533	505	28	1031	0,52	High
	4	0	0	0	483	0,96	Very high
	5	0	0	0	489	0,95	Very high
	6	469	372	97	1424	0,20	Low
	7	469	372	97	1487	0,15	Low
	8	630	480	150	1325	0,28	Medium
	9	775	755	20	1673	0,00	Low

Table 4.5 – Accessibility of the medical center from residential areas in ordinary conditions and in case of event.

Based on these data, a qualitative assessment of the change in accessibility -which is generally a loss of accessibility-for each considered infrastructure, can be obtained.
This procedure has been developed in respect to all the above mentioned infrastructures, which play a strategic role in case of emergency. Finally, in order to define the Iac and Iac* indexes of each infrastructure, the average of CL and CL* parameters has been considered and, applying the same procedure already described, the Iac and Iac* indexes of each infrastructure and their levels of accessibility in ordinary and emergency conditions have been defined.

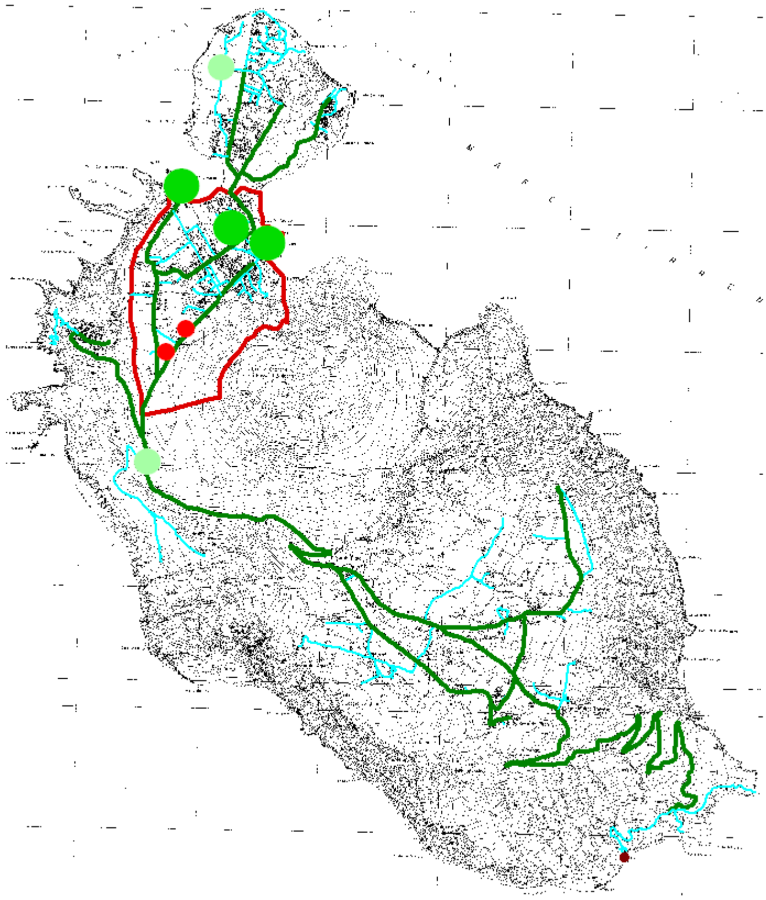

Figure 5.61 – Level of accessibility of strategic infrastructures (very high: green; high: light green; medium: red; low: dark red) and the road network (main road in green; secondary roads in cyan)

The application of the procedure highlighted the very low accessibility both in ordinary and in emergency conditions of the Porto Gelso. However, low accessibility levels are recorded also for the power plant and for the telecommunication center because they are strictly linked to the ports with roads largely exposed to the lahars run-out. Porto Levante and Porto Ponente have the higher level of accessibility from the residential areas (Fig. 5.61).
It is useful to highlight for each strategic infrastructure the difference between the level of accessibility in ordinary conditions and in emergency (Fig. 5.62). This difference is remarkable for the Police Station, the Power Plant and Telecommunication Tower.
In the matrix, based on the developed assessment, a qualitative level of accessibility has been reported and a numeric value, in terms of vulnerability, has been assigned. In detail,

- very high accessibility level = 0.25 (in terms of vulnerability);
- high accessibility level = 0.5;
- medium accessibility = 0.75;
- low accessibility = 1.00.

Finally, the values of the other parameters have been assigned and, by applying the same procedure adopted for physical vulnerability, the values of key-topic, aspect and system have been obtained (Fig. 5.63).

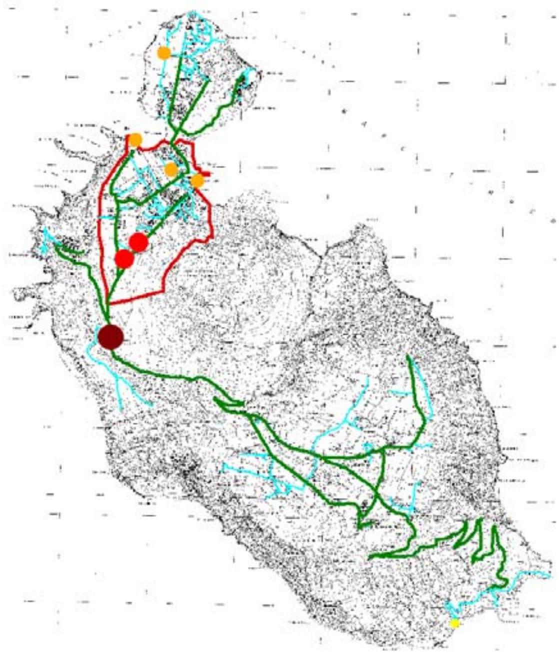

Figure 5.62 – Difference between accessibility indexes in ordinary conditions and in emergency (very high: dark red; high: red; medium: orange; low: yellow) and the road network (main road in green; secondary roads in cyan)

System	Aspect	Aspect weight	Key-topic	Key-topic weight	Key-element	Key-element weight	Parameters	Criteria for assessment	Data Quality	Descriptors	Assessment	Scoring parameter	Scoring key-element	Scoring key-topic	Scoring aspect	Scoring System
Infrastructure and production sites	*Critical infrastructures*	1	What are the factors that make critical infrastructures stop functioning?	1	Network infrastructures	1	gas, water	existence and redundancy		more than 1/ 1/ 0						
								fucntional vulnerability to physical damage (physical vulnerability)		vulnerable components crucial for functioning: yes/no						
								dependency from other systems		dependent/autonomous						
					Punctual infrastructures	1	Medical center	accessibility from settlements	High	The accessibility from the residential areas to the considered strategic infrastructure has been measured through a specific procedure , taking into account the obstruction of the roads due to lahars	Very high	0,5	0,59 = High	0,59 = High	0,59 = High	0,59 = High
								dependency from network infrastructures (elecrticity and telecommunication)	Low	Level of dependency of the medical center from the electricity and telecommunication networks	High					
								gathering zones close								
							Port of Ponente	accessibility from settlements	High	The accessibility from the residential areas to the considered strategic infrastructure has been measured through a specific procedure, taking into account the obstruction of the roads due to lahars	Very high	0,25				
								gathering zones close								
							Port of Levante	accessibility from settlements	High	The accessibility from the residential areas to the considered strategic infrastructure has been measured through a specific procedure, taking into account the obstruction of the roads due to lahars and the existing redundancy	Very high	0,25				
								gathering zones close								
							Port of Gelso	accessibility from settlements	High	The accessibility from the residential areas to the considered strategic infrastructure has been measured through a specific procedure , taking into account the obstruction of the roads due to lahars	Low	1				
								gathering zones close								
							Northern heliport	accessibility from settlements	High	The accessibility from the residential areas to the considered strategic infrastructure has been measured through a specific procedure, taking into account the obstruction of the roads due to lahars	High	0,5				
								gathering zones close								
							Telecommunication tower	accessibility from the ports	High	The accessibility from the ports to the telecommunication tower has been measured through a specific procedure, taking into account the obstruction of the roads due to lahars	Medium	0,875				
								substituatability of the supply node	Low	Possibility to guarantee the supply by substituting the supply node	Low					
							Power plant	accessibility from the ports	High	The accessibility from the ports to the power plant has been measured through a specific procedure, taking into account the obstruction of the roads due to lahars	Medium	0,875				
								substituatability of the supply node	High	Possibility to guarantee the supply by substituting the supply node	Low					
							Police Station	accessibility from the equipment to the residential areas	High	The accessibility from the infrastructure to the residential areas has been measured through a specific procedure taking into account the obstruction of the roads due to lahars	High	0,5				
	Production sites		What are the factors that may lead to halting production?				Degree of dependance of production sites from lifelines	binary; degree of presence of autonomous devices		yes/no; %						
							Accessibility to the plant and to markets	see internal and particulary external accessibility of the area								
							Contingency plan for na-tech	binary		yes/no; considers all potential threats/does not						
							Business continuity plan	binary		yes/no						

Figure 5.63 – Systemic vulnerability of critical infrastructures

4.2.3 Seismic

The major difficulty when passing from the theoretical matrices to an application on a real case is the quantification of the different notions involved in the methodological framework describing the general vulnerability assessment. These notions are organized in different systems, themselves divided into components (also called « aspects » in ENSURE framework terminology) that are similarly split up into parameters or indicators. This quantification necessarily needs the setting up of a scoring and weighting scheme.

We decided to weight between 0 (not significant) and 1 (very significant) the four exposed systems (natural environment, built environment, production sites, social system). This weight represents the significance of one system relatively to the other with regards to the vulnerability to seismic hazard. In the case of the seismic hazard, we consider that the built environment, infrastructure and production sites are in some ways more important than the social agents, and most of all than the natural environment. Subsequently, a similar weight is applied to the aspects and the same rule is applied to the parameters that have to be ranked with respect to all the parameters found within a same aspect. For one specific parameter, multiplying its weight by the weight of the associated aspect and system leads to a general weight that gives insights on the significance of one parameter comparing to another one, no matter what the aspects or systems associated.

As far as the scoring is concerned, the criteria of assessment for one parameter can be binary, quantitative or qualitative. Concerning the parameters whose descriptor is binary, the scoring is, by definition, 0 or 1. It mostly concerns the existence or the availability of a given parameter. Concerning the parameters whose descriptor is quantitative or qualitative, a value (vulnerability score) has to be given to this descriptor, with the same scale for all parameters: in our case ranking from 0 (lowest vulnerability) to 1 (highest vulnerability). However, the quality of the data used to evaluate the parameter is of first importance and has to be taken into consideration. A data quality coefficient is then introduced in order to decrease the score if data are not good, in order to account for uncertainties. This coefficient is, in our assessment, set to 1 (good quality), 1.25 (average quality) or 1.5 (poor quality), and is then multiplied by the initial score to obtain the corrected score.

The final score is obtained for each parameter, multiplying the corrected score by the total weight. This final scoring computation leads to the ranking of all the parameters, allowing an integrated vulnerability assessment. This way of weighting and scoring permits the scoring of aspects and even systems and their ranking according to the associated vulnerability. We expect this ranking within a given exposed system to be useful in highlighting vulnerable aspects that might be ignored otherwise.

It is worth mentioning that this rather rough scoring and weighting system is a first approach and was set-up in order to check the applicability of the framework. A more sophisticated approach may need to be developed in further applications.

In the general framework presented in Work-Package 4, the physical and systemic vulnerability are studied separately through two different matrices. In order to be able to compare the indicators belonging to each of them, we merged the two matrices in one and added the time period at which the indicator is relevant. Similarly, as indicators can be evaluated at different space scales and since this information is of first importance, we added columns related to it in the matrix (see Fig. 5.64).

															Time scale		Space scale		
	System	System weight	Aspect	Aspect weight	Parameters	Param weight	Criteria for assessment	Descriptors	Data availa.	Data quality	Descri. score	Param score	Aspect score	System score	Impact	Emergency	Micro	Meso	Macro
Natural environment	*Natural ecosystems*	*0,2*	Are natural ecosystems fragile to the potential effects of hazard?	*1*	extent and location of triggered landslides	*1*	degree and relevance of impacted zones	extended areas / few zones							**1**				
					extent of potentially flooded zones by tsunami	*1*	degree and relevance of impacted zones	extended areas / few zones							**1**				
			Are natural ecosystems fragile to the potential secondary effects of hazard(s)?	*0,75*	areas affected by landslides	*1*	number and extent	few/many; in remote areas/in crucial-central zones								**1**			

Figure 5.64 - Extract of the modified framework for the application to seismic hazards (physical and systemic vulnerability)

NATURAL ENVIRONMENT

The first system to be assessed concerns the natural ecosystem, which is, in comparison to the other systems, not highly vulnerable to seismic hazards. We therefore applied a low weight to this system.

Two aspects have been developed: the fragility of natural ecosystems to the potential effects of seismic hazards (landslides and tsunami) and to their secondary effects; the latter being estimated less critical than the first one. The assessment of these aspects have to be made according to the extent and relevance of the potentially impacted zone, which means that landslide and tsunami hazard maps as well as sensitive ecosystems maps are needed. It was not possible to get all these data for Vulcano and we therefore used the maximum vulnerability index. However, considering the little importance given to natural ecosystem, the total score is relatively low (Fig. 5.65).

	System	System weight	Aspect	Aspect weight	Parameters	Param weight	Criteria for assessment	Descriptors	Data availa.	Data quality	Descri. score	Param score	Aspect score	System score	Time: I	Time: E	Space: Micro	Space: Meso	Space: Macro
Natural environment	*Natural ecosystems*	*0,2*	Are natural ecosystems fragile to the potential effects of hazard?	*1*	extent and location of triggered landslides	*1*	degree and relevance of impacted zones	extended areas / few zones	*N*		*1*	*0,2*	*0,2*	*0,18*	**1**				**1**
					extent of potentially flooded zones by tsunami	*1*	degree and relevance of impacted zones	extended areas / few zones	*N*		*1*	*0,2*			**1**				**1**
			Are natural ecosystems fragile to the potential secondary effects of hazard(s)?	*0,75*	areas affected by landslides	*1*	number and extent	few/many; in remote areas/in crucial-central zones	*N*		*1*	*0,15*	*0,15*			**1**			**1**

Figure 5.65 - Ensure framework applied for seismic hazard to the natural ecosystem

BUILT ENVIRONMENT

The second system is related to the exposure and to the vulnerability of the built environment. The importance of this system is considered high since the potential building damages or collapses occurring during an earthquake are critical parameters.

This system is divided into two different aspects according to the time scale considered: the physical vulnerability or vulnerability to stress (impact time period) and the systemic vulnerability or vulnerability to losses (emergency time period).

Concerning the first aspect, four indicators have to be assessed: the vulnerability index of the residential buildings, the public facilities, the urban fabric and the historical buildings and monuments. Vulnerability assessment for aggregates is not yet fully developed: we then decided to weight this parameter with a low figure. It is worth noticing that these indicators can be seen as global indicators since they are themselves composed of many criteria. The presented framework for assessing physical vulnerability of built environment mentions the global indicators, which are based on a complete and specific study combining more than twenty criteria that make a building vulnerable to seismic hazard. These criteria are gathered in a separate sub-matrix (**Errore. L'origine riferimento non è stata trovata.**5.69).

In the Vulcano case study, the physical vulnerability assessment of buildings was done through a standard statistical vulnerability analysis, the RISK-UE method (Milutinovic & Trendafiloski, 2003). The method, developed within a European project, is well adapted to the Italian context. However, it had to be simplified compared to the usual practice, due to the lack of field data.

The available data did not allow a comprehensive study differentiating residential buildings and important / essential buildings (hotels, schools, medical centers). Furthermore, we used some pictures of buildings on the site, to classify them, observing that their typology is quite similar to current buildings.

In the census data available for Vulcano Island at the municipal scale from the Italian National Institute of Statistics (2001), 895 buildings are registered. The following information has been derived from these data:

- very few buildings are constituted by a reinforced concrete structure (only 2);
- around 50% of the building stock was built between 1972 and 1981 (see **Errore. L'origine riferimento non è stata trovata.**4.6);
- most of the buildings are traditional houses with 1 or 2 floor, only one 3-floor residential building is found on the island.

Figure 5.66 depicts the construction period in the different municipalities of Vulcano.

Before 1919	1919 - 1945	1946 - 1961	1962 - 1971	1972 - 1981	1982 - 1991	After 1991	Total
20	12	66	142	452	197	6	895

Table 4.6 - Age of construction of the Vulcano building stock (after ISTAT, 2001)

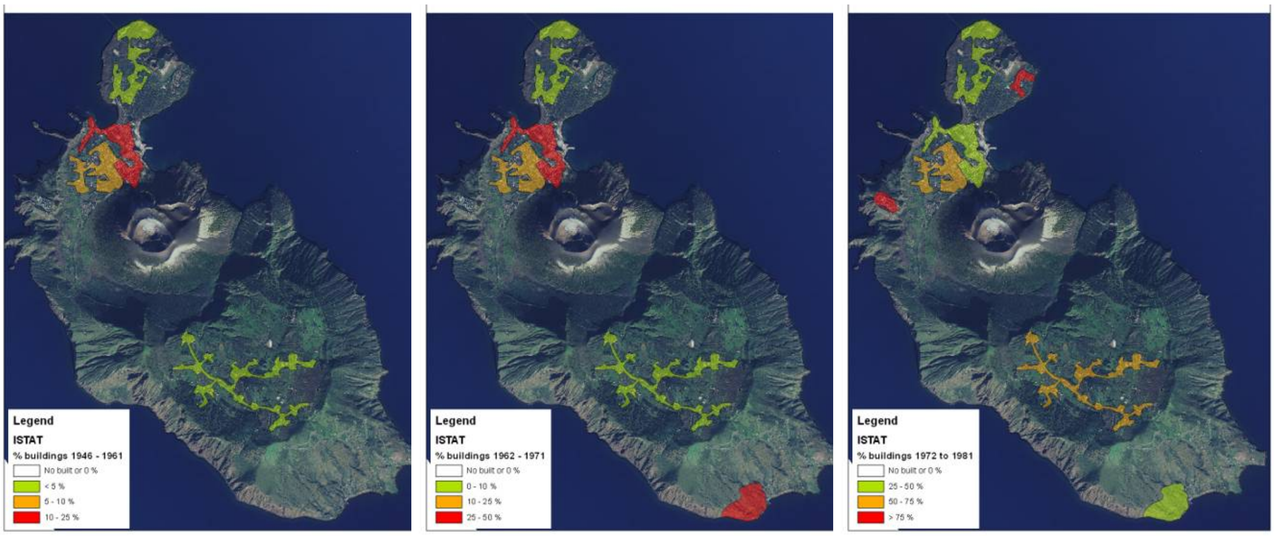

Figure 5.66 - Period of construction of the building stock on Vulcano Island (after ISTAT, 2001)

A field survey dedicated to fill in criteria relevant to volcanic hazard was carried out on 298 buildings over the island. However, it is relatively tricky to identify the structural system only with the pictures available from this survey. We decided to use mainly the ISTAT data and the building vulnerability assessment was then carried out using the census units. In order to convert the ISTAT data into seismic vulnerability types, we then used literature and notably the work of Giovinazzi (2005) that proposed conversion tables for the Ligurian region (see Table4.7).

Following this work, we proposed a simplified table in order to assess the physical vulnerability of buildings (see Table.8). It was analyzed here through a sampling technique, singling out classes of buildings showing the same features, and then extending vulnerability assessment from the sample buildings to the class they belong to.

Combining Table with the ISTAT data, we obtain the vulnerability index Vi for the different municipality areas over the island (see Fig. 5.67).

Masonry Category		Masonry Building Typology							
		M1	M3-w	M3-v	M3-sm	M3-ca	M4	M5-sm	M6
I	M<1919	40	10	15	15	15	5	-	-
II	M=1919 ÷ 1945	15	30	-	40	15	-	-	-
III	M =1945÷ 1971	10	10	-	10	-	-	30	40
IV	M> 1971	-	-	-	10	-	-	10	80

	Building typology
	Unreinforced Masonry
M1	Rubble stone
M2	Adobe (earth bricks)
M3	Simple stone
M4	Massive stone
M5	U Masonry (old bricks)
M6	U Masonry - r.c. floors
	Reinforced /confined masonry
M7	Reinforced /confined masonry

	Masonry Building Horizontal structures typology
M_w	Wooden slabs
M_v	Masonry vaults
M_sm	Composite steel and masonry slabs
M_ca	Reinforced concrete slabs

Table 4.7 - Building typology classification from Giovinazzi (2005)

Type	Period	Class	Medium vulnerability index	EMS-98 class
Traditional housing (rubble stone, wooden slabs). 1-2 floors	Before 1945	M1	0.79	AB
Simple stone walls, RC slabs. 1-2 floors	Between 1945 and 1981	M3_ca	0.66	BC
Unreinforced masonry (bricks) – RC slabs. 1-2 floors	After 1981	M6	0.54	C

Table 4.8 - Table used to assess the physical vulnerability of buildings

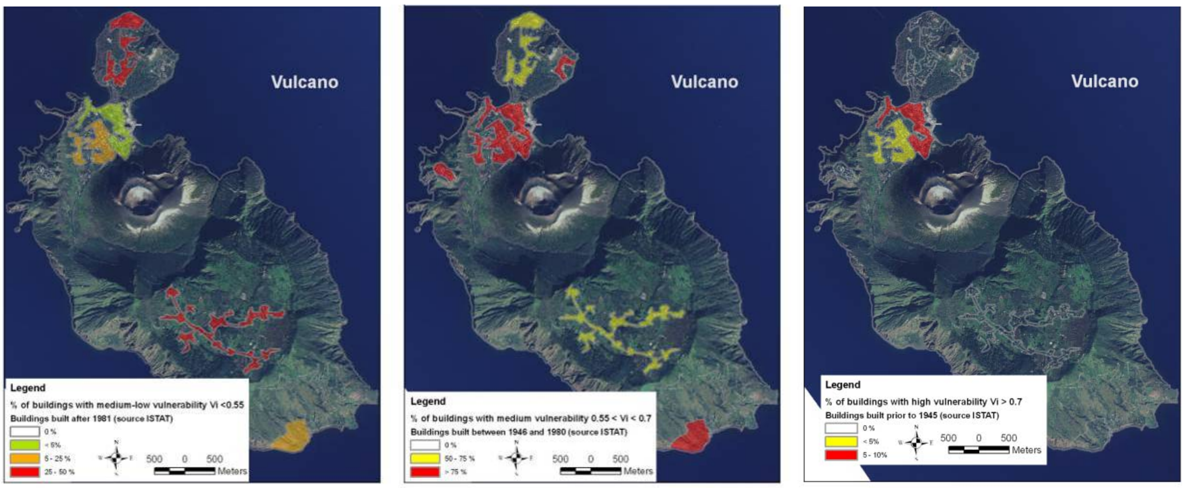

Figure 5.67 - Vulnerability index Vi for the built environment on Vulcano Island

Colored polygons represent the built zones on the island, while the color scale represents the percentage of buildings with low (left image, Vi < 0.55), medium (center image, Vi between 0.55 and 0.7), and high (right image, Vi > 0.7) seismic vulnerability indices. As expected, we see that traditional houses built before 1945 are the most vulnerable to earthquakes (Porto di Levante and Vulcano), while buildings in Vulcano Piano and Vulcanello are less vulnerable.
Because the vulnerability assessment can refer to different spatial units (individual building, urban district, whole area of investigation), the space scale is particularly important when filling in the matrix with the building vulnerability index. In our view, it does not make much sense to average the index obtained at the building scale on the whole island. This means that several matrices are needed for the island, each of them being devoted to an area or to a group of buildings having a similar vulnerability. The information about the space scale for each indicator has also to be given to fully understand the real meaning of that score. For instance,

the matrix given on Figure 5.68 - 25.68 only concerns the group of buildings whose vulnerability index is 0.6. Please note that this index has been decreased to a value of 0.76 since the quality of the available data has been considered as fair. Concerning the urban fabric vulnerability index, we chose the highest vulnerability index (i.e. 1) since not enough data were available to carry out this analysis.

The second aspect that concerns the emergency period has been considered slightly less critical for the built environment than the vulnerability to the stress (impact period). The indicators for this aspect are less demanding than the first one since they do not represent global parameters. However, the lack of data (e.g. means of post seismic assessment) or the poor quality of available ones (e.g. quality and availability of shelters) require special caution regarding the scores obtained. Estimations were indeed done according to the facts that Italy is a developed country, that the population density is rather low in Vulcano and that it is located close to Sicilia, from where help can be brought.

															Time		Space		
	System	System weight	Aspect	Aspect weight	Parameters	Param weight	Criteria for assessment	Descriptors	Data availa.	Data quality	Descri. score	Param score	Aspect score	System score	I	E	Micro	Meso	Macro
Built environment	*Exposure and vulnerability of built environment*	*1*	What are the factors that make buildings, public facilities and the urban fabric vulnerable to the stress?	*1*	Vulnerability assessment of residential buildings (on the basis of available survey forms)	*1*	vulnerability of residential homogeneous urban sectors	vulnerability index (see vulnerability assessment matrix)	*Y*	*1,25*	*0,6*	*0,75*	*0,51*	*0,48*	**1**		**1**		
					Vulnerability assessment of public facilities (on the basis of available survey forms)	*1*	vulnerability of public facilities	vulnerability index (see vulnerability assessment matrix)	*Y*	*1,25*	*0,6*	*0,75*			**1**		**1**		
					Vulnerability assessment of the urban fabric	*0,15*	vulnerability of structural built aggregates	on the basis of: regularity; presence of strong inclination; presence of structural dishomogenity	*N*		*1*	*0,15*			**1**				**1**
					Vulnerability assessment of historical buildings / monuments	*0,4*	vulnerability of historical buildings / monuments	specific vulnerability indicators depending on the type of monument	*N*		*1*	*0,4*			**1**		**1**		
			What are the factors that make buildings, the urban fabric and public facilities vulnerable to losses?	*0,75*	Availability of rapid post seismic buildings usability assessment	*1*	forms pre-prepared and shared among all teams	yes/no	*N*		*1*	*0,75*	*0,44*			**1**			**1**
							information computerized	yes/no	*N*		*1*	*0,75*				**1**			**1**
							existence of trained teams to assess post-earthquake building damage	yes/no	*N*		*1*	*0,75*				**1**			**1**
					Quality of temporary shelters (first emergency)	*0,5*	with heating or conditioning; sanitation; density	good / average / poor quality	*Y*	*1,5*	*0,3*	*0,17*				**1**			**1**
					Quality of more permenent temporary shelters	*0,75*	with heating or conditioning; sanitation; density; dimension; availability of services	good / average / poor quality	*Y*	*1,5*	*0,3*	*0,25*				**1**			**1**
					Accessibility to work sites from temporary shelters	*0,75*	distance; safe paths or roads; frequency of transportation	good / average / poor accessibility	*Y*	*1,5*	*0,3*	*0,25*				**1**			**1**
					Accessibility to public facilities from temporary shelters	*0,5*	distance; safe paths or roads; frequency of transportation	good / average / poor accessibility	*Y*	*1,5*	*0,3*	*0,17*				**1**			**1**

Figure 5.68 - 2Ensure framework applied for seismic hazard to the built environment

Criteria for assessment
identification of homogeneous urban sectors
definition of the building typologies
year of construction
position inside the aggregate
interaction between buildings in aggegates
numbers of floors
roof connection to the building structure
roof weight
structural material
connection between walls (only masonry): tied rods/angle bracket
floors rigidity
foundation depth and type
soil morphology
spans between resistant elements (mainly masonry)
antiseismic joints
soft stories
regularity in plan
regularity in elevation
added parts (balconies, chimneys)
maintenance
retrofitting programs
non structural elements (equipment, furniture)

Figure 5.69 - Submatrix used to estimate the vulnerability index of buildings

INFRASTRUCTURES AND PRODUCTION SITES

Two systems are mentioned in the framework: the critical infrastructures (strategic infrastructures and lifelines) and the production sites. As far as Vulcano Island is concerned, there is no production site.

As for the previous systems, the critical infrastructure one can be divided in two aspects according to the time period considered: the first one is related to the factors that make the infrastructure vulnerable and the second one, to the factors that can lead to infrastructure disruptions during the emergency period.

The first aspect can be evaluated through the vulnerability index of the strategic infrastructure and lifelines, which are both global indicators coming from a necessary extensive study. As the objective of the case study was not to complete a full analysis of seismic vulnerability, we decided to affect the same vulnerability index for strategic infrastructures as for current buildings. If more information had been available, an assessment especially devoted to each strategic infrastructure (e.g. hospitals, fire and police stations) would have been done. Figure 5.70 depicts the matrix filled in for the case of a strategic infrastructure whose physical vulnerability index has been estimated to 0.6.

Concerning the lifelines, Vulcano has an electricity network, a communication network, a road network and water tanks (no real water supply network). For the first two, no data were available and we then applied the highest vulnerability index (1). Partial information was available for the water tanks that are brought from the continent and that make drinking water system not highly vulnerable to earthquakes. The road network contains no bridge neither tunnel which decreases its vulnerability. But the lack of information on transport lines conditions (age, degree of maintenance) leads finally to a relatively high score. Since the road network is used for water supply on the island, the vulnerability due to physical interaction among lifelines was considered relatively high. In addition, the information was too sparse to estimate the vulnerability due to lifelines connections to vulnerable buildings.

The systemic vulnerability of the critical infrastructures (second aspect), is described through several indicators. First, the redundancy in lifeline systems is considered poor mainly because of the presence of only one road between the northern and southern part of the island, which leads to a high score. As mentioned above, the degree of interdependence among lifelines is rather low since water is transported through the road network (high score). The degree of dependence of critical infrastructures from lifelines has been estimated high. The island being remote, the inhabitants are already used to be autonomous in terms of resources, which means that generators, tanks or other emergency devices are likely to be present (this results in a low score). However, the absence of continuity plan results in a high score.

	System	System weight	Aspect	Aspect weight	Parameters	Param weight	Criteria for assessment	Descriptors	Data availa.	Data quality	Descri. score	Param score	Aspect score	System score	Time I	Time E	Space Mic ro	Space Me so	Space Ma cro
Infrastructure and production sites	Critical infrastructures	1	What are the factors that make critical infrastructures vulnerable?	1	Vulnerability assessment of strategic infrastructures (hospitals, fire & police stations,...)	1	vulnerability of strategic infrastructures	vulnerability index (see vulnerability assessment matrix)	Y	1,25	0,6	0,75	0,70	0,61	1		1		
					Vulnerability assessment of lifelines	0,75	electricity (including nodes like power stations, transformers...)	derived from e.g. network caracteristics (buried/aerial, existence of shut-off valves/circuit-breakers...), conditions (age, degree of maintenance), network redundancy	N		1	0,75			1			1	
							gas network (including nodes like production facilities, tank farms, stations,...)	derived from e.g. network caracteristics (rigid/ductile material, existence of shut-off valves/circuit-breakers...), conditions (age, degree of maintenance), network redundancy											
							water, drinking water and sewerage network (including dams, treatment plants, pumping stations, ...)	derived from e.g. network caracteristics (rigid/ductile material, existence of shut-off valves/circuit-breakers...), conditions (age, degree of maintenance), network redundancy	Y	1,25	0,5	0,47			1			1	
							communication (including nodes like base transceiver station,...)	derived from e.g. network caracteristics (buried/aerial,...), conditions (age, degree of maintenance), network redundancy	N		1	0,75			1			1	
							transport lines: roads, railways for instance (including bridges, tunnels, embankment/slopes...)	derived from e.g. network caracteristics (type of material, ...), conditions (age, degree of maintenance), network redundancy	Y	1,25	0,75	0,70			1			1	
					Vulnerability due to physical interaction among lifelines	0,75	lifelines degree of connection	low/high	Y	1,25	0,75	0,70			1			1	
					Vulnerability due to lifeline connections to vulnerable buildings	0,75	lifelines close and attached to resistant/vulnerable buildings	yes/no	N		1	0,75			1			1	
			What are the factors that make critical infrastructures stop functioning?	0,75	Redundancy in lifelines systems	1	degree	low/high	Y	1,5	1	0,75	0,53			1		1	
					Degree of interdependance among lifelines	0,75	degree	low/medium/high	Y	1,25	0,75	0,53				1		1	
					Availability of emergency devices	1	binary (generators; tanks, etc)	yes/no	Y	1,25	0,25	0,23				1			1
					Continuity plan for lifelines, individually and in a coordinated fashion	0,5	binary and quality	yes/no; considers also induced hazards/ does not	Y	1,25	1	0,38				1			1
					Degree of dependance of critical facilities from lifelines	1	degree	low/medium/high	Y	1,5	0,75	0,75				1		1	
	Production sites	0,75	What are the factors that make production sites vulnerable (including na-tech potential)?	1	Vulnerability assessment of production sites	1	as for public facilities												
					Potential na-tech due to stored materials, types of processes	1	binary, types of processes	yes/no; processes types											
			What are the factors that may lead to halting production?	0,5	Vulnerability due to dependency on lifelines	0,75	dependance on lifelines	low/medium/high (existence of alternative solutions)											
					Degree of dependance of production sites from lifelines	1	degree	low/medium/high											
					Accessibility to the plant and to markets	1	redundancy; quality of roads; usability; expected increase in travel time	redundant/not redundant; open/close roads; t.inc < 30 min/ t.inc > 30 min											
					Contingency plan for na-tech	0,5	binary	yes/no; considers all potential threats/does not											
					Business continuity plan	0,5	binary	yes/no											

Figure 5.70 - Ensure framework applied for seismic hazard to the critical infrastructure and production sites

SOCIAL SYSTEM

This system is divided in two subsystems, namely individuals and institutions, which have to be assessed both at the impact time and emergency periods (two aspects per subsystem). Unlike the built environment or the critical infrastructure parts, most of the indicators used to evaluate the social system are global parameters at the island scale or at an even bigger one.

As far as the individuals are concerned, the factors potentially leading to injuries and fatalities concern the people concentration, the preparedness, and social indicators that can bring about difficulties to comply with evacuations orders (age, impairments,…). The population density is rather low during the winter but it increases significantly during the summer due to touristic activities. However, it should be noted that during the day, people are more outside than inside buildings, which reduces their vulnerability. For these reasons, the vulnerability index has been considered average. Concerning the preparedness, the permanent inhabitants are made aware of natural risks (notably to volcanic risk). However, this might not be the case of the numerous tourists coming on the island during summer, which means that the corresponding score should stay at a rather high level. Finally, the ISTAT data shows a proportion of elderly people situated in the national average, which means that this indicator is not critical.

The second aspect regarding the individuals is made of indicators that may reduce the coping capacity during crisis. First it can be considered that the insular context can lead to difficulties in communication and more generally to the access to useful and understandable information. The trust in information providers is likely to be average, as well as the proportion of impaired groups (as mentioned above).

The system dedicated to community/institutions differentiates the factors that may lead to large number of victims (during the impact) and the ones that may hamper effective crisis management. The score of the first factors has been chosen high since no emergency plan for seismic hazard exists and since resources for search and rescue do not seem to be available at the island scale. Concerning the second type of factors, no contingency plan seems to be existing, which increases the vulnerability on one hand. On the other hand, the overlapping responsibilities among agencies are not critical. However, some data were not available to evaluate more indicators as for instance the existence of established protocols for information sharing or for the use of resources to manage the crisis (fig. 5.71).

	System	System weight	Aspect	Aspect weight	Parameters	Param weight	Criteria for assessment	Descriptors	Data availa.	Data quality	Descri. score	Param score	Aspect score	System score	Time I	Time E	Space Micro	Space Meso	Space Macro
Social system (agents)	*People / Individuals*	*0,75*	What are the factors that may lead to injuries and fatalities?	*1*	People concentration in different zones in the hours of the day	*1*	degree of concentration in vulnerble locations/buildings	low/medium/high	*Y*	*1,5*	*0,6*	*0,68*	*0,55*	*0,46*	**1**				**1**
					Preparedness	*1*	previous training	yes/no	*Y*	*1,5*	*0,75*	*0,75*			**1**				**1**
					Age; mobility impairment, other impairment	*0,5*	difficulties to comply with evacuation orders; difficulties in escaping	yes/no, number of people	*Y*	*1,25*	*0,5*	*0,23*			**1**				**1**
			What are the factors that may reduce coping capacity during crisis?	*1*	Access to understandable information	*0,75*	binary	yes/no; centralized /at each group level (for example in each temporary camp)	*Y*	*1,5*	*0,75*	*0,56*	*0,38*			**1**			**1**
					Trust in information provisers	*0,5*	degree	low/medium/high	*Y*	*1,5*	*0,5*	*0,28*				**1**			**1**
					Preparedness to evacuation	*0,5*	individual plan	yes/no (like going to relatives)	*N*		*1*	*0,38*				**1**			**1**
					Presence of impaired groups (elderly, sick persons, etc.)	*0,75*	binary and quality of caring	yes/no; capacity to provide treatment in temporary camps/or not	*Y*	*1,25*	*0,4*	*0,28*				**1**			**1**
	Community / Institutions	*0,75*	What are the factors that may lead to large number of victims?	*1*	Existence of emergency plan and quality	*0,75*	binary; quality	yes/no; as judged by involved institutions	*Y*	*1*	*1*	*0,56*	*0,38*	*0,42*	**1**				**1**
					Availability of resources for search and rescue (lamps; cranes, special devices)	*0,25*	binary; number with respect to potentially damaged areas	yes/no; imemdiately accessible/remote; sufficient/not sufficient	*Y*	*1,25*	*1*	*0,19*			**1**				**1**
			What are the factors that may hamper effective crisis management?	*1*	Existence of contingency plan fro threats at stake	*0,75*	binary; date of last production or update	yes/no; recent/old	*Y*	*1,25*	*1*	*0,56*	*0,47*			**1**			**1**
					Availability of quick post-event scenarios to be checked and used as a guidance in crisis managment	*0,75*	binary and quality	yes/no; considering also enchained effects and systemic damage/restricted to physical damage	*N*		*1*	*0,56*				**1**			**1**
					Training using the contingency plan	*0,8*	binary; frequency of training	yes/no; every two years/only occasionally	*Y*	*1,25*	*1*	*0,6*				**1**			**1**
					Overlapping responsiblities among agencies	*0,5*	degree	Low/medium/high	*Y*	*1,5*	*0,6*	*0,34*				**1**			**1**
					Established protocols for information sharing	*0,5*	binary	yes/no	*N*		*1*	*0,38*				**1**			**1**
					Established protocols for use of resources to manage the crisis	*0,5*	degree	yes/only partially/high	*N*		*1*	*0,38*				**1**			**1**

Figure 5.71 - Ensure framework applied for seismic hazard to the social system

4.3 Resilience

Natural System

The first part of the matrix refers to the natural environment. Resilience assessment has been referred to the ability of species and ecosystems to recover to damages due to tephra, lahars and seismic hazards. Due to the kind of vegetation placed in the plain area, which mainly consists of Mediterranean shrub, orchards, vineyards and vegetable gardens with the exception of few isolated groups of trees and the vegetation present on the slope of the volcano, the natural environment presents different capacity to react to damages inflicted by those hazards. This system seems not to be perturbated by seismic risk (Figure 5.74), whereas in the areas affected by lahars the capacity of natural environment to react to this kind of stress is low (Figure 5.72). While, the degree of resilience to tephra hazards is medium (Figure 5.73).

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Natural environment	*Natural ecosystems*	Are natural environments hit by the event able to recover from damages to species and ecosystems?	can it be as ofr fires?	binary	yes/no; degree of fire resistance of trees and of bushes		1	1	1	1=LOW
		Are natural environments and ecosystems able to recover from mitigation measures that have a relevant negative impact?	can it be as ofr fires?							

Figure 5.72 - Ensure framework applied for lahars hazard to the natural environment

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Natural environment	*Natural ecosystems*	Are natural environments hit by the event able to recover from damages to species and ecosystems?	can it be as ofr fires?	binary; time to ash removing	yes/no; ash duration; ash composition;		1	3	3	3=Medium
		Are natural environments and ecosystems able to recover from mitigation measures that have a relevant negative impact?	can it be as ofr fires?							

Figure 5.73 - Ensure framework applied for tephra hazard to the natural environment

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Natural environment	*Natural ecosystems*	Are natural environments hit by the event able to recover from damages to species and ecosystems?	can it be as ofr fires?	binary			NOT RELEVANT	NOT RELEVANT	NOT RELEVANT	
		Are natural environments and ecosystems able to recover from mitigation measures that have a relevant negative impact?	can it be as ofr fires?				NOT RELEVANT	NOT RELEVANT	NOT RELEVANT	

Figure 5.74 - Ensure framework applied for seismic hazard to the natural environment

Built Environment

The second system to be assessed concerns the built environment. One aspect has been developed: the ability of urban/fabric environment to recover reducing pre-event vulnerability. The assessment of these aspect have to be made accordingly to the extent and relevance of potentially impacted zone. In addition, the parameters which have been considered are referred to the necessity of transferring relevant facilities, if any reconstruction plan is already addressed in case of a major disaster and the relevance of potentially affected areas. Thus on the base of these parameters the resilience is medium for lahars hazard (Figure 5.75), while for tephra and seismic hazards is low (respectively Figure 5.76 and Figure 5.77) .

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Built environment	Exposure and vulnerability of built environment	Is the urban fabric/built environment able to recover reducing pre-event vulnerability?	Temporary transferability of facilities relevant for the settlement/city community life and economy	binary; type of relocation	yes/no; temporary/permanent	The city hall is already out of the island and most of the strategical facilities are not affected by this hazard.	1	3	3	7=Medium
			Existance of plans for reconstruction in case of severe destruction scenarios	binary	yes/no	no	1	1	1	
			Level of sharing among stakeholders of reconstruction plans	degree	High/low; only formal/substantial		no data available			
			Level of integration of physical reconstruction with community healing processes	degree	High/low; room for interpreting in the new/restored setting the meaning of the destruction		no data available			
			Relevance of potentially affected settlements in geographic/economic terms	level of importance	Central/peripheral	peripherical, but taking into account the yearly touristic flow coming for the presence of the Volcano, the level of importance can be assumed	1	3	3	

Figure 5.75 – Ensure framework applied for lahars hazard to the built environment

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Built environment	Exposure and vulnerability of built environment	Is the urban fabric/built environment able to recover reducing pre-event vulnerability?	Temporary transferability of facilites relevant for the settlement/city community life and economy	binary; type of relocation	yes/no; temporary/permanent	The city hall is already out of the island. Nevertheless, all the economic structures (hotels, souvenir shops, tec.) mainly linked to touristic sector cannot be relocated	1	1	1	5=Low
			Existance of plans for reconstruction in case of severe destruction scenarios	binary	yes/no	no	1	1	1	
			Level of sharing among stakeholders of reconstruction plans	degree	High/low; only formal/substantial		no data available			
			Level of integration of physical reconstruction with community healing processes	degree	High/low; room for interpreting in the new/restored setting the meaning of the destruction		no data available			
			Relevance of potentially affected settlements in geographic/economic terms	level of importance	Central/peripheral	peripherical, but taking into account the yearly touristic flow coming for the presence of the Volcano, the level of importance can be assumed quite high	1	3	3	

Figure 5.76 - Ensure framework applied for tephra hazard to the built environment

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Built environment	Exposure and vulnerability of built environment	Is the urban fabric/built environment able to recover reducing pre-event vulnerability?	Temporary transferability of facilities relevant for the settlement/city community life and economy	binary; type of relocation	yes/no; temporary/permanent	The city hall is already out of the island. Nevertheless, all the economic structures (hotels, souvenir shops, tec.) mainly linked to touristic sector cannot be relocated	1	1	1	5=Low
			Existance of plans for reconstruction in case of severe destruction scenarios	binary	yes/no	no	1	1	1	
			Level of sharing among stakeholders of reconstruction plans	degree	High/low; only formal/substantial		no data available			
			Level of integration of physical reconstruction with community healing processes	degree	High/low; room for interpreting in the new/restored setting the meaning of the destruction		no data available			
			Relevance of potentially affected settlements in geographic/economic terms	level of importance	Central/peripheral	peripherical, but taking into account the yearly touristic flow coming for the presence of the Volcano, the level of importance can be assumed quite high	1	3	3	

Figure 5.77 - Ensure framework applied for seismic hazard to the built environment

Critical Infrastructures

The third part of the matrix refers to critical infrastructures. It is worth noting that the island is extremely dependent from Sicily which provides all the services (such as electricity, water and gas), further the island economy is mainly based on tourism unless for some months when construction activity is in the active phase. The parameters which have been considered are mainly focused: on one hand, on fast availability of material taking into account even if the resource are at relatively low cost and the personnel supply. On the other hand, the availability of a computerized mapping systems of infrastructures. The resilience assessment underlined a low level of ability to recover with reference to both networks and to point-shaped elements belonging to critical infrastructures on the island (Figure 5.78, 5.79,5.80)

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Infrastructure and production sites	Critical infrastructures	Are there tools to recover critical infrastructures rapidly and at low costs?	Computerized mapping systems of infrstructures	binary	yes/no	no	1	1	1	5=LOW
			In site devices for quick survey of damaged parts	binary	yes/no		no data available			
			Availability of spare materials for fast repairs	binary; time needed to bring on site spare materials	yes/no; t < 1 day/ several days	material for fast repairs are not on the island and time needed to bring those material on site depends even from metereological conditions	1	2	2	
			Availability of personnel for repairs	location and number of technicians	on site/in distant areas; number of available technicians with respect to expected need	Companies which are providing these type of services have their own technicians. With reference to Vulcano case study those may not be on the site, nevertheless they are close to the area.	1	2	2	
			Existance of protocols to proceed with repairs requiring inter-lifelines interventions	degree; number of different stakeholders to be coordinated in repair efforts	yes/partial/no; one main stakeholder/several stakeholders		no data available			
	Production sites		Temporary transferability of production in case of need	binary	applicable/not applicable		NOT RELEVANT			
			Existance of funds for fast repairs	binary	yes/no		NOT RELEVANT			
			Existance of inspection and guiding personnel for correct repairs	binary	yes/no/forecasted in the recovery plans		NOT RELEVANT			
			Economic sectors	Diversified or concentrated on few sectors	Few/many different economic sectors in the area		NOT RELEVANT			

Figure 5.78 - Ensure framework applied for seismic hazard to the built environment

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Infrastructure and production sites	Critical infrastructures	Are there tools to recover critical infrastructures rapidly and at low costs?	Computerized mapping systems of infrstructures	binary	yes/no	no	1	1	1	6=Low
			In site devices for quick survey of damaged parts	binary	yes/no		no data available			
			Availability of spare materials for fast repairs	binary; time needed to bring on site spare materials	yes/no; t < 1 day/ several days	material for fast repairs are not on the island and time needed to bring those material on site depends even from metereological conditions	1	2	2	
			Availability of personnel for repairs	location and number of technicians	on site/in distant areas; number of available technicians with respect to expected need	Companies which are providing these type of services have their own technicians. With reference to Vulcano case study those may not be on the site, nevertheless they are close to the area.	1	3	3	
			Existance of protocols to proceed with repairs requiring inter-lifelines interventions	degree; number of different stakeholders to be coordinated in repair efforts	yes/partial/no; one main stakeholder/several stakeholders		no data available			
	Production sites		Temporary transferability of production in case of need	binary	applicable/not applicable		NOT RELEVANT			
			Existance of funds for fast repairs	binary	yes/no		NOT RELEVANT			
			Existance of inspection and guiding personnel for correct repairs	binary	yes/no/forecasted in the recovery plans		NOT RELEVANT			
			Economic sectors	Diversified or concentrated on few sectors	Few/many different economic sectors in the area		NOT RELEVANT			

Figure 5.79 - Ensure framework applied for tephra hazard to the built environment

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Infrastructure and production sites	Critical infrastructures	Are there tools to recover critical infrastructures rapidly and at low costs?	Computerized mapping systems of infrstructures	binary	yes/no	no	0.5	2	1	6=Low
			In site devices for quick survey of damaged parts	binary	yes/no		no data available			
			Availability of spare materials for fast repairs	binary; time needed to bring on site spare materials	yes/no; t < 1 day/ several days	material for fast repairs are not on the island and time needed to bring those material on site depends even from metereological conditions	1	2	2	
			Availability of personnel for repairs	location and number of technicians	on site/in distant areas; number of available technicians with respect to expected need	Companies which are providing these type of services have their own technicians. With reference to Vulcano case study those may not be on the site, nevertheless they are close to the area.	1	3	3	
			Existance of protocols to proceed with repairs requiring inter-lifelines interventions	degree; number of different stakeholders to be coordinated in repair efforts	yes/partial/no; one main stakeholder/several stakeholders		no data available			
	Production sites		Temporary transferability of production in case of need	binary	applicable/not applicable		NOT RELEVANT		NOT RELEVANT	
			Existance of funds for fast repairs	binary	yes/no		NOT RELEVANT		NOT RELEVANT	
			Existance of inspection and guiding personnel for correct repairs	binary	yes/no/forecasted in the recovery plans		NOT RELEVANT		NOT RELEVANT	
			Economic sectors	Diversified or concentrated on few sectors	Few/many different economic sectors in the area		NOT RELEVANT		NOT RELEVANT	

Figure 5.80 - Ensure framework applied for seismic hazard to the built environment

Socio-economic system

The fourth part of the matrix is referred to social system. With reference to this system several different aspects have been considered, such as people, community, institutions and economic stakeholders). The social survey highlighted that the risk perception among citizens is low but they would be trained more, nevertheless for those living the volcano is not viewed as a problem. At community level, social cohesion has a good quality, but some difficulties can be identified within the relationship between citizens and immigrants. While, at the government level, the level of having confidence on institutions is resulted to be medium. Thus, the overall resilience level of the social system has been considered to be medium in respect to all the different hazards, which have been taken into account (Figure 5.81).

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study	Weight (1 high - 0 NOT RELEVANT)	Scoring (5 high - 1 low)	Total Scoring	
Social system (agents)	People/individuals	Are people in the position to be resilient in the face of a catastrophe?	Availability of psychological support for adults and children	binary	yes/no	This kind of support to people is provided by the Italian Civil Protection in case of major disastrous events	1	2	2	23,5=Medium
			risk perception	degree	high/medium/low	low	1	5	5	
			Availability of private resources to resettle/repair	binary; support by public agencies; rapidity of compensation process	yes/no; available/not available; rapid/slow		no data available			
			Access to insurance	binary and coverage	yes/no; percentage of coverage	no	1	1	1	
	Community	Is the affected community resilient to the consequences of a catastrophe?	Age structure	Areas vitality	Aging population; low fertility rates	61% of population living on the island are between 10 and 45 years old.	1	4	4	
			Local condition of aged population	binary	autonomous/not autonomous; relatively healthy/not healthy	People over 65 years is 16.7% of population and they are relativity healty (Relazione Sociale, 2008)	1	2	2	
			Employment rate	degree	high/medium/low	As it is underlined by the Social Science Survey the occupation rate is medium-low	1	3	3	
			Annual population growth rate (over the last five years)	degree	high/medium/low/negative		no data available			
			Immigration index	degree	high/medium/low/negative		no data available			
			Social networking	degree	high/medium/low/negative	high, but relations are worste between residents and immignats	1	2	2	
			Criminality rate	degree	high/medium/low	low	0.5	1		
			Conflict among social/ethnic groups	degree	high/medium/low	the social survey has been underlined that around 54% get along well with migrants and an other 12% is getting fairly well with them.	1	4	4	
	Institutions	Are institutions in charge of reconstruction transparent, reliable and trustable?	Degree of trust in institutions	degree	high/medium/low (from sociological surveys when available)	the social survey has been highlighted that almost 48% of interviewed people do not trust in the local governament	1	2	2	
			Transparency in funds allocation	Existance of public information and independent control mechanisms	yes/no		no data available			
			Long term vision	Existance of strategic development/land use plans	yes/no		no data available			
	Economic stakeholders	Are economic stakeholders capable/wishing to reinvest in affected areas?	Insurance coverage	binary and coverage	Yes/no;percentage		no data available			
			Construction industry	level of development and modernization	high/average/low		no data available			

Figure 5.81 - Ensure framework applied for lahars, tephra and seismic hazards to social system

Weaknesses and strengths of the Ensure framework

Mitigation matrices (UNINA – volcanic, seismic and landslides):

In respect to the weaknesses, it has to be underlined that:

a. the large set of key topics and parameters requires a large amount of data and, mainly, the involvement of different experts from different disciplinary fields; whereas some parameters can be evaluated through data easy to collect and to interpret (availability of hazard map), others are based on expert judgments (quality of monitoring systems or adequacy of hazard maps to support mitigation measures).
b. some of the required data and information are not generally available, but they have to be collected through detailed in situ surveys (e.g. the state of maintenance of buildings) or through questionnaires involving local community or sample of the population or through interviews or questionnaires to local Authorities;
c. data and information are referred not only to different systems but also to different geographical scales; even though the assessment is related, as in the Vulcano case study, to a local scale, national or regional laws or measures have to be taken into account;
d. the procedure for weighting the different elements of the matrixes are not specified;
e. the scoring systems is not clearly defined.

The test on the case study has allowed us to provide ideas and possible solutions for overcoming some of the mentioned weaknesses. With reference to the weighting and scoring system for example, in the Vulcano case study, weights different from 1 have been assigned, in some cases, to key topics and aspects, whose importance in determining the final scores respectively of the related aspects and systems has been considered lower than the others. Nevertheless, it should be useful to weight each parameter too, according to the peculiarities of the case study.

With respect to the scoring system and to the correspondence between numerical scores and qualitative judgment, it has to be noticed that in many cases, numerical scores allow us to better understand small differences among the values obtained by each parameter which can be lost translating them into qualitative classes. Hence, both numerical scores and qualitative classes have been indicated in the matrixes.

With reference to the strengths, it is worth noting that the matrixes allow us to highlight the main deficiencies in the mitigation capacities of a given area and, consequently, to single out the main aspects which have to be strengthened for improving the capacities of preventing, mitigating and coping with hazardous events. In detail, the final aggregate scores, obtained through simple or weighted means among parameters having very high or very low scores, can be very useful in order to compare and prioritize different areas or systems, whereas scores related to individual parameters are crucial to understand the weaknesses and to identify the way to improve mitigation capacities.

Physical and systemic vulnerability (UNINA - lahars):

Summing up, it is worth highlighting the main weakness and the main strengths arising from the application of the Ensure framework to the assessment of physical and systemic vulnerability of the four considered systems.

In respect to the weaknesses, it is worth noting:

a. the lack of specification of parameters related to the physical vulnerability of urban fabrics;
b. the extremely detailed parameters for assessing physical vulnerability of individual

buildings which require, in many cases, in-depth surveys in situ;

c. the missed identification of the spatial units to which the assessment of physical and systemic vulnerability of each considered system (natural and built environments; critical infrastructures and social system) has to be referred to;
d. the lack of techniques for shifting from parameters related to individual buildings toward a final assessment of systems vulnerability.

In respect to the strengths, it is worth emphasizing:

a. the flexibility of the framework to different paths for interpreting and applying the provided parameters, also in relation to different geographical contexts characterized by different features;
b. the possibility of obtaining vulnerability scores at different levels aggregation (from the scores related to each parameters to the final score of the systems) and, consequently, the possibility of comparing physical or systemic vulnerability of different systems or different areas within the same system and also of identifying the main factors contributing to make an element or a system vulnerable, in order to define adequate mitigation measures;
c. the possibility of the matrixes to be applied through automatic procedures within a DSS based on GIS environment.

The application of the Ensure framework to the Vulcano case study has allowed us to provide some ideas for overcoming the identified weaknesses which could represent an useful feedback for a final review of the general framework set up in WP4.

Physical and systemic vulnerability (BRGM - seismic):

Applying the ENSURE framework to Vulcano Island has highlighted the advantages of carrying out such a methodology but also the limiting issues and paths for improvement:

a. First of all, one limiting aspect concerns the scoring and weighting system. The framework is actually highly dependent on this. The scoring issue is particularly essential since the indicators or parameters contained within the matrices are rather different. Despite this variety (e.g. quantitative parameters, qualitative ones), they have to be transformed into a score. Moreover, sometimes one parameter is the combination of several other parameters, which can lead to some difficulties if the system is not well defined or data availability or quality is low. In addition, the scoring and weighting may introduce subjectivity. For all these reasons, the question of the scoring and weighting appears essential, and the setting up of a more accurate description may improve the framework significantly.
b. The framework requires significant amount of data, which can be problematic at a first stage of vulnerability assessment when the information is sparse. However, whatever methodology is used, a deep vulnerability assessment need necessarily lots of data.
c. The framework is divided into systems, aspects and indicators trying to integrate some of the knowledge and information about resilience and vulnerability that have been developed in literature and in previous works. However, the content of the framework might not be totally comprehensive. It then needs to be continuously complemented and adjusted through further theoretical research and applications on other case studies.
d. Another point is relative to the spatial scale at which the framework is applied. Spatial units can indeed vary from a regional or a municipal area, to a partition of a Municipality or to Census units. The indicators are not assessed at the same spatial scale and then special caution should be taken. One solution could be to provide, when filling in the matrices, the scale at which the parameters have to be or have been

evaluated. It is worth noting that the scale of evaluation depends on the parameters but also on the purpose for using the framework (accuracy needed, area considered,…).

e. Finally, the applicability of the proposed methodology by the end-users is a critical point at this stage. The framework being still under development on major points, it may not be yet fully operational. Nevertheless, although improvements are still needed, the methodological framework allows the evaluation of exposed systems (natural environment, built environment, production sites and social system) during the different periods within a crisis cycle, which is a significant outcome. Moreover, as different components of vulnerability (physical, systemic and socio-economic) are integrated, the Ensure methodology allows the comparison between the different systems, aspects or indicators.

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