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“PRELIMINARY RISK ASSESSMENT AT USTICA BASED ON INDICATORS OF NATURAL AND HUMAN PROCESSES”

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ABSTRACT

Geomorphological phenomena have significant repercussions on environmental evolution, triggering changes in natural processes that might have a severe socio-economic impact. To date, vulnerability estimations have been primarily based on natural processes, and secondarily by combining the exposure resulting from socio-economic variables, which can assist in identifying areas under risk. The present investigation proposes a methodology to examine the risk from natural hazards by introducing social indicators as exposure factors. The methodology is based on a combination of socio-economic and natural indicators. In this work the different indicators form indices that are used to make holistic risk estimation for both inland areas and coastal areas. This approach includes four sub-indices that contribute to the overall risk estimation. The sub-indices refer to the geomorphological characteristics, together with natural forcing, coastal erosion for the estimation of the vulnerability and socio-economic indicators for the estimation of exposure. All variables are ranked on a 1-5 scale, with rank 5 indicating the highest, and are estimated in a GIS model. The main difficulty in making these estimations lies in assessing and ranking the socio-economic indicators, and especially cultural heritage sites since their importance cannot be measured. The risk is estimated by using the vulnerability of the area and the socio-economic sub-index that function as the exposure variable in the estimations. This work is an initial approach as part of the Brains2Islands project funded by Fondazione con il Sud and aims to develop a best practice guide for cultural heritage resilience to natural hazards, that will be tested and validated through field studies, using as a case study the island of Ustica, an area of high cultural and economic value, with ancient monuments.

1. INTRODUCTION

Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social factors, as well as from the absence of the capacity to adapt [Adger, 2006], while on the basis of natural hazards and risk assessment the term refers to the potential impact of a specific event [Marzocchi et al., 2009]. In general vulnerability must take account of economic, social, geographic, demographic, cultural, institutional, governance and environmental factors [UNISDR, 2009; IPCC, 2012], while risk quantifies and classifies potential consequences of hazardous events, combining hazard, exposure and vulnerability [IPCC, 2012]. Spatial analysis and spatial data integration are important tools for natural and climate-change hazard vulnerability and risk assessments. The United Nations Environment Programme (UNEP) considers measuring and mapping vulnerability as a top priority for supporting decision-making in planning and protection [PROVIA, 2013]. Spatial vulnerability and risk assessment methods differ according to the study topic and the scope, but in general they are applied in order to identify areas at potentially high risk for natural hazards and climate impacts [UNISDR, 2009].

Natural hazards (e.g. earthquakes, landslides, volcanic activity, soil and coastal erosion, floods), may pose danger to various natural and social entities. A natural hazard has been defined as the elements in the physical environment harmful to humans and nature [Burton and Kates, 1964; White, 1973; UNDRO, 1982; Alexander, 1993]. Thus, prevention strategies for natural hazards need to take into account the particular characteristics of the threatened area or entity, including both the natural and human environment.

Natural hazards are strongly related to geomorphology [Scheidegger, 1994]. In this sense, geomorphological hazards can be categorized as endogenous like volcanism and neotectonics, exogenous like floods, rock falls or landslides, erosion, sedimentation etc., and those induced by climate and land-use change like desertification, degradation, soil erosion, and floods [Slaymaker, 1996]. The dual character of natural disasters has to be addressed by considering not only their natural characteristics, but also the social and economic setting [Alexander, 1993]. With the use of different methods, geomorphology has contributed to the estimation of natural hazard vulnerability. In volcanic and seismic hazard evaluations, geomorphology has been used as the base for zonation of volcanic hazard [Verstappen, 1988, 1992] and risk [Pareschi et al., 2000], for volcanic crisis management [Gómez-Fernández, 2000], and for promoting natural disaster reduction [Elsinga and Verstappen, 1988]. Furthermore, the analysis of tectonic activity has been used as a key element in seismic hazard assessment [Galadini and Galli, 2000]. With respect to the geomorphological dimensions of natural disasters, Rosenfeld [1994] examined the contributions of different geomorphological projects to interdisciplinary research, including rainfall-induced landsliding, flooding, etc. All geomorphological processes influence the conservation of the archaeological sites [Canuti et al., 2000] that constitute one of the most important datasets for the evolution of human settlements and palaeoenvironmental processes in Mediterranean territories [Mercuri and Sadori, 2014].

Sea-level changes over geological time have brought about major changes in the position of the coast, especially in lowland areas [Muhs et al., 2004]. The position of the coastline may vary greatly, over a few months or up to several decades, because of the different time scales of the combined factors that control this process [Morton et al., 1994; Honeycutt et al., 2001; Zhang et al., 2002]. Still, interactions between sediments in the coastal zone and lithology, and the way in which they are linked, affect the evolution of the coastal morphology [Riggs et al., 1995; Honeycutt et al., 2003]. Geological data show that global climate and sea level have been relatively stable during the past 10,000 years [Zalasiewicz et al., 2008]. The expected accelerated sea-level rise and the potential physical changes to the coastline may endanger coastal ecosystems, populations and infrastructure [McLean et. al., 2001]. The sensitivity of the coastal zone to sea level rise, combined with its social, economic, and ecological value [e.g., Costanza et al., 1997; Agardy et al., 2005, Alexandrakis et al., 2015), has led to the proposal of a significant number of vulnerability indices developed for specific coastal areas [Gornitz et al., 1993; Hoozemans et al., 1993; Leggett and Jones, 1996; O'Riain, 1996; Cambers, 1998; Thieler and Hammar-klose, 1999; Mimura, 2000; Vafiadis et al., 2008, Alexandrakis and Poulos, 2014]. The main objective of most of the existing indices is the classification of the coastline into areas with similar attributes or characteristics; the majority use multidisciplinary data related to natural processes. The need for the inclusion of socio-economic variables has also been noted by Gornitz et al. [1993], who stated that the omission of socio-economic variables from their coastal vulnerability index could potentially limit the evaluation of vulnerable areas. Likewise, indices reviewed by Cooper and McLaughlin [1998] reveal a general need to include socio-economic variables in the classification procedure [McLaughlin et al., 2002]. This has led to criticism of vulnerability studies, and to separation of the physical from the socio-economic aspects in vulnerability studies [e.g., Blaikie et al., 1994; Gough et al., 1998; IPCC, 2001; Nicholls and Small, 2002]. In the past socio-economic variables were excluded due to the difficulty of obtaining and ranking the data. Besides, socio-economic data can change over time (e.g. building of new houses and roads etc.) and perceptions of threat and of appropriate response may also change with time [Carter, 1993]. Nowadays those procedures are easier and they can be updated in the future. Also, the fact that socio-economic indicators are time-constrained makes their use more difficult [McLaughlin et. al., 2002], while it may also be more difficult to rank them, since it is not easy to assign an economic value to an attribute. The indicator-based approach proposed by Kaiser [2006] has been accepted as one of the most appropriate approaches for intangible elements that have no physical form, such as cultural heritage sites, in ranking this kind of data. Despite these difficulties, the inclusion of socio-economic variables is of great importance in the development of valid vulnerability indices in order to mitigate risks, and adapt to environmental and climate change [Birkmann, 2006; O'Brien et al., 2006]. However, the evaluation of vulnerability involves various practical challenges, the complexity of the problem, and our poor understanding of related issues, notwithstanding the importance of the results [Patt et al., 2009]. Some vulnerability studies have attempted a more integrative assessment approach by combining both physical and socio-economic vulnerability with an overall vulnerability index system [Wu et al., 2002; Cutter et al., 2003; Boruff et al., 2005; Preston et al., 2008].

The main objective of most indices is vulnerability's quantification in units that exhibit similar attributes or characteristics. These classifications can then assist in the implementation of preventative management strategies in sensitive areas.

The present investigation proposes a methodology for examination of vulnerability and risk in the island of Ustica, with the introduction of socio-economic indicators into a GIS-based Socio-economic Vulnerability Index not only for the coastal area, but taking into consideration all of the Island. All variables are ranked on a 1-5 scale, with 5 indicating higher vulnerability. The four sub-indices that are used were analysed spatially in order to identify the areas in which each index contributes more to the final risk estimation, especially for the areas with important cultural heritage. The same approach employed for the coastal area and the coastal vulnerability index were used, in order to identify the importance of each sub-index in each area.

This paper is an initial approach as part of the Brains2Islands project funded by Fondazione con il Sud, and aims to develop a best-practice guide for cultural heritage resilience to natural hazards, that will be tested and validated through field studies, using as a case study the island of Ustica, an area of high cultural and economic value, with ancient monuments.

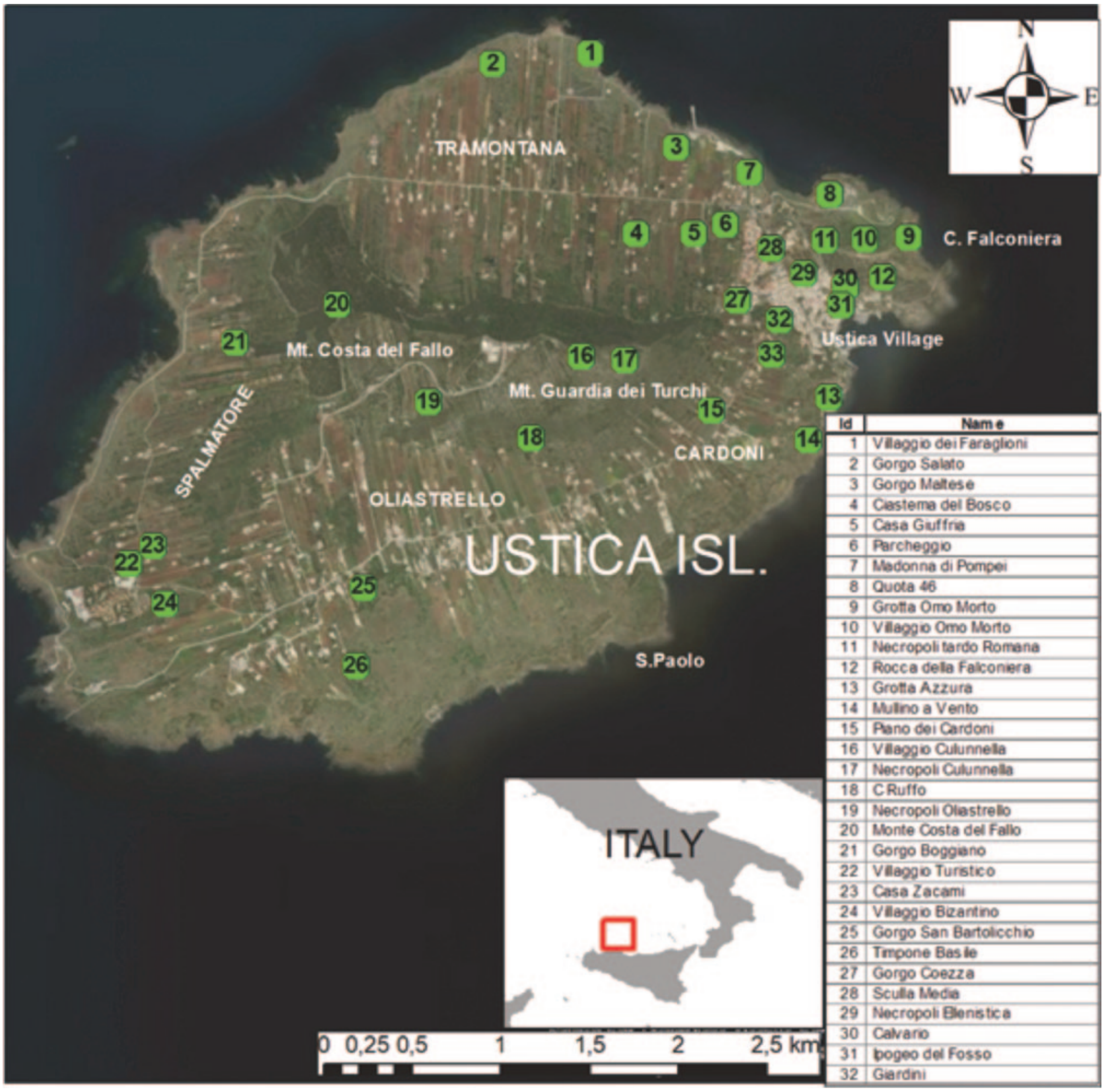
2. STUDY AREA

The island of Ustica is located in the Tyrrhenian Sea, north of Sicily. Ustica is a volcanic island, which occupies an area of approximately 8.65 km^2; it has a perimeter of 12 km and measures 3.5 km in length and 2.5 km in width (Figure 1).

Numerous caves are present along the island's high, steep coasts. The climate is characterised by very low precipitation, with an average annual total of approximately 500 mm, on average distributed in 68 days of rain.

The human settlements in the island date from the Neolithic period, about 7000 BP [Spatafora, 2009]. During the Middle Bronze Age, (3400-3200 BP) it was intensely and permanently inhabited [Mannino, 1979]. In the eastern part of the island, at the foot of Falconiera Hill, Punta dell'Omo Morto and at Case Vecchie (near Ustica town), there are traces of small Middle Bronze Age dwellings. Other settlement evidence can be found near the Spalmatore tourist village, in the western part of the island and at Piano dei Cardoni and at San Paolo, in the southern part of the island. Smaller settlements were located on some hilltops (e.g. Culunnella Village) along the eastern slope of Monte Guardia dei Turchi [Spatafora and Mannino, 2008]. Archaeological remains are also found underwater, due to the numerous shipwrecks that have occurred over time [Purpura, 2010]. The most important archaeological site is the village of Faraglioni, which is located in the northern part of the island, close to the modern town. The village dates to the Bronze Age (about 3500 BP), when settlements were scattered over the eastern and central part of the island [Mannino and Ailara, 2016]. A number of archaeological excavations, carried out discontinuously since the 1970s by Mannino [1979, 1982], Holloway and Lukesh [1995, 2001] and Spatafora [2009] highlighted a settlement that has been described as one of the best-preserved Middle Bronze Age towns of the Mediterranean region [Martin, 2014]. The village of Rocca Falconiera dates to the third century BC; its remains, together with those of a late 18th century fort, are located at the top of the Falconiera Hill. In the 20th century the island became a popular tourist destination – mainly for scuba diving, due to the rich marine environment – and is listed as a protected marine area.

The island is entirely of volcanic origin and was created from multiple eruptions that occurred over an interval of >700 ka from Middle to Late Pleistocene. Its morphology has been altered by marine terracing, which has erased most of the original volcanic landforms and shaped its post-emersion geomorphology. In addition, geometric changes in the shallow magmatic feeding system have altered the position of volcanic vents over time [de Vita, 1993; de Vita et al., 1995; 1998; de Vita and Foresta Martin, 2017]. The interaction



Id	Name
1	Villaggio dei Faraglioni
2	Gorgo Salato
3	Gorgo Maltese
4	Ciastema del Bosco
5	Casa Giuffria
6	Parcheggio
7	Madonna di Pompei
8	Quota 46
9	Grotta Omo Morto
10	Villaggio Omo Morto
11	Necropoli tardo Romana
12	Rocca della Falconiera
13	Grotta Azzura
14	Mulino a Vento
15	Piano dei Cardoni
16	Villaggio Culunnella
17	Necropoli Culunnella
18	C Ruffo
19	Necropoli Oliastrello
20	Monte Costa del Fallo
21	Gorgo Boggiano
22	Villaggio Turistico
23	Casa Zacami
24	Villaggio Bizantino
25	Gorgo San Bartolicchio
26	Timpone Basile
27	Gorgo Coezza
28	Sculla Media
29	Necropoli Ellenistica
30	Calvario
31	Ipogeo del Fosso
32	Giardini

FIGURE 1. Ustica Island and areas of interest under investigation.

of these varied geological processes and eruption locations within a relatively small area has produced a complex geological setting. Volcanism at Ustica started with the activation of a series of submarine vents along ENE-WSW trending, deep transtensional faults that allowed magmas to quickly reach the surface, directly from their mantle source, feeding effusive eruptions [Barberi et al., 1969; Barberi and Innocenti, 1980; de Vita, 1993]. Following this, the activity concentrated into a main seamount, whose products reached the surface in the Middle Pleistocene, making Ustica the only volcano of anorogenic origin that has emerged in the Southern Tyrrhenian Sea. The emergence of the island coincided with the birth of the Mt Guardia dei Turchi subaerial basaltic stratovolcano at about 520 ka [de Vita et al., 1998]. A series of eruptions occurred, forming the Mt. Costa del Fallo basaltic tuff-cone, and later a small caldera in the northern sector of the island [de Vita, 1993; de Vita et al., 1995; 1998]. Volcanic activity on the island ceased at around 130 ka, with the explosive Falconiera phreatomagmatic eruption and the formation of an asymmetric tuff cone, which is the most easily recognizable volcanic edifice present on the island [de Vita and Foresta Martin, 2017]. Throughout Ustica's volcanic history there have been several overlapping cycles of marine transgression and regression, resulting from Middle-Upper Pleistocene glacioeustatic movements. The sea-level stands related to these oscillations generated typical sedimentary terraces, which were later raised by tectonics to variable heights above their original positions. Five orders of marine terraces have been identified at heights ranging from about 100 m for the oldest and highest terrace, to 5 m for the most recent and lowest one [de Vita and Orsi, 1994; de Vita et. al., 1998]. The occurrence of marine terraces of various ages – at decreasing elevation from the oldest to the youngest – helps to define the total amount of uplift undergone by the island (less than 120 m), at least since the formation of the oldest level surface at 350 ka [de Vita and Foresta Martin, 2017].

3. METHODOLOGY

For the estimation of the island's vulnerability four different indices were used. The Geomorphological Characteristics index (GC) is related to the resistance of the island to erosion, the Natural Forcing index (NF) quantifies the forcing variables, the Coastal Vulnerability Index (CVI) concerns coastal erosion phenomena, and the Socio-Economic index (SE) quantifies the vulnerability of existing societal activities and infrastructure. Each sub-index is calculated using the geometric mean and contributes equally to the final index score.

The Geomorphological Characteristics sub-index (GC), which is related to the type of Landforms (Lf), Lithology (Li), Slope gradient (Sg), Slope Aspect (AS), and Drainage System density (DS), is calculated by means of Equation 1.

$$GC = \sqrt{\frac{Lf \cdot Li \cdot Sg \cdot DS \cdot AS}{5}} \tag{1}$$

The Natural factors Forcing sub-index, which includes the indicators of Structural stability of the geological formations (Ss), Vegetation coverage (Vg), Soil Erosivity (SER), Soil Thickness (ST), Landslide Type (LT), Land cover (LC) and Volcanic Hazard (VH), is given by Equation 2.

$$NF = \sqrt{\frac{Ss \cdot Vg \cdot SER \cdot ST \cdot LT \cdot LC \cdot VH}{7}} \tag{2}$$

For the estimation of the vulnerability of the coastal zone, the Coastal Vulnerability Index of Thieler and Hammar-Klose [1999] was used, which includes six physical indicators that are related in a quantifiable manner. These are the Coastal Landforms (CLf), Coastal Slope (CS), Relative Sea-Level Rise rate (RSLR), Shoreline Changes rate (SC); mean Tidal range (T) and mean wave Height (Hs), and are combined in Equation 3.

$$CVI = \sqrt{\frac{CLf \cdot CS \cdot RSLR \cdot SC \cdot T \cdot Hs}{6}} \tag{3}$$

The Socio-Economic sub-index includes the socio-economic indicators of the presence and size of Settlements (SET), Cultural Heritage sites (CH), the Transport Network (TN), Land Use (LU) and Economic activities (E), and is estimated by Equation 4.

$$SE = \sqrt{\frac{SET \cdot CH \cdot TN \cdot LU \cdot E}{5}} \tag{4}$$

The final index for the inland part of the island is estimated by Equation 5.

$$SVI = \frac{GC + NF + SE}{3} \tag{5}$$

The resulting scores were normalised by converting them to a range defined by the maximum and minimum scores. The ArcView GIS system (ESRI) was used to calculate the index and map the results. Variables were selected and ranked on a 1-5 scale according to their perceived vulnerability to wave-induced erosion, with 5 being the most vulnerable and 1 the least vulnerable.

3.1 RANKING VARIABLES

Inland landforms (Lf) were ranked based on their potential for soil erosion and creation of landsliding phenomena. Thus beaches and deltaic areas were ranked as very low vulnerability, terraces and alluvial plains as low vulnerability, while low cliffs were ranked at medium vulnerability. Medium cliffs are considered highly vulnerable, while the high cliffs and areas of past landslides are placed in the very high category. The data used for this index were obtained from the SITR – Sistema Informativo Territoriale Regionale, Geoportale Regione Siciliana geomorphological maps.

Slope gradient (Sg) is considered the most important factor influencing gravitational movements down slopes because the sliding of loose material is directly related to it [Dai et al., 2002; Liu JG et al., 2004; van Westen et al., 2008; Catani et al., 2013; Di Traglia et al., 2017]. Slope gradient at local scales affects the presence of soil moisture as well as the level of pore pressure and can lead to slope instability. Areas with slope gradient less than 10° are considered of very low vulnerability while those with a gradient of more than 45° are considered to be of very high vulnerability [Ayalew and Yamagishi, 2005]. Aspect of the slopes (AS) is considered in the estimations, since wind loading can also play an important role in wind erosion mapping as slopes are exposed to various wind speeds and directions, while some areas can be more protected than others. Thus, with respect to the dominant high-velocity wind direction, a 15° aspect is considered as very low vulnerability while a 90° aspect is considered as very high vulnerability [Meléndez-Pastor et al., 2017]. Data used for the slope and aspect indicators were derived from topographic data available at Istituto Nazionale di Geofisica e Vulcanologia-Osservatorio Vesuviano, provided in a DTM 2x2m resolution.

Lithology (Li) influences the occurrence of landslides, because different parent materials have different degrees of weathering which may control the scale of landsliding [Carrara et al., 1991; Wati et al., 2010; Catani et al., 2013; Di Traglia et al., 2017]. For example, hard and massive rocks are resistant to weathering whereas sandstones are more vulnerable to weathering and thus more susceptible to slippage [Wati et al., 2010]. Formations such as limestones, plutonics, lava and welded tuff, and high-medium grade metamorphics are assigned to the very low vulnerability category. The low vulnerability category contains formations like sandstones, tuffs, low grade metamorphics, and conglomerate, and the medium category clays, low-cohesion sedimentary rocks and soft tuffs. The classification is based on bibliographical research [Reid et al., 2001; Apuani, et al., 2005a,b; del Potro et al., 2008; Reid et al., 2010; Nolesini et al., 2013;, Di Traglia et al., 2018]. Non-cohesive materials, coarse and poorly sorted unconsolidated sediments and loose pyroclastics are ranked in the high vulnerability category. Debris, weathered material, fine unconsolidated sediments and volcanic ash are placed in the very high category. The data used were post-processed from the geological map of Ustica [de Vita, 1993].

Drainage density (Ds) Drainage density is the ratio of the total length of a stream to the area of the drainage basin measured in km/km^2 [Yalcin, 2008]. As drainage density increases, so does the surface movement due to a decrease in infiltration capacity, and this may encourage landslide occurrence [Pachauri et al., 1998; Nagarajan et al., 2000; Cevik and Topal, 2003; Yalcin, 2005]. Areas with a density of less than 1km/km^2 are ranked as being of very low vulnerability, while those with density greater than 2.51 km/km^2 are placed in the very high category. The data used for this indicator were derived from the SITR – Sistema Informativo Territoriale Regionale, Geoportale Regione Siciliana.

Structural stability (Ss) is evaluated on the basis of discontinuities in rock formations, which are major elements of rock mass classification. Geological discontinuities are those breaks or visible planes of weakness in the rock mass that separate it into discrete units. They include structural features such as joints and faults, and depositional features such as bedding planes. Fractures include all breaks in a rock body or core sample, regardless of origin. Fractures may be of geological origin or they may be man-made. A joint is a fracture or parting surface in a rock along which there has been no visible movement parallel to the joint surface. Joints may range from perpendicular to parallel in orientation with respect to bedding, and are considered as low vulnerability. A bedding plane is a planar, or nearly planar surface that visibly separates each layer of stratified rock (of the same or different lithology) from the preceding or following layer. Cross-bedding, as in many sandstone formations, may give an erroneous impression of post-deposition tilting, especially in core samples. These are considered as medium vulnerability features. A fault is a major fracture along which there has been appreciable displacement and is ranked in the high category. Open cracks are open fissures in the subsurface rock that are generally due to the removal of rock materials and are considered as very highly vulnerable. The classification also recognizes that the effect of structural elements differs according to the scale of investigation [Apuani et al., 2015a,b and Catani et al., 2013]. Therefore, at the mesoscale small-scale structural elements are classified as part of the rock masses and are included in the low category of classification, since the analysis focuses on larger scales. These data were processed using the geological map of Ustica [de Vita, 1993] and the published structural analysis data [de Vita et al., 1995].

Vegetation (Vg) along with land cover contributes positively to land stability [van Westen et al., 2008]. According to Zhou et al. [2008], which showed that different vegetation covers have different effects on the risk of soil loss, for this work five different vegetation cover percentages are used, from 40% for high risk, to 70% for low risk. Data used for this indicator were derived from the SITR – Sistema Informativo Territoriale Regionale, Geoportale Regione Siciliana and Copernicus database from the High Resolution Layers (imperviousness, Forest, Natural Grassland, and Grassland).

Soil Erosivity (SER) assessment is based on the soil erodibility factor (K-factor) after Stewart et al. [1975]. This is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot. The factor reflects the fact that different soils erode at different rates when the other factors that affect erosion (e.g., infiltration rate, permeability, total water capacity, dispersion, rain splash, and abrasion) are the same. Texture is the principal factor affecting Kfact, although structure, organic matter, and permeability also contribute. The soil erodibility factor ranges in value from 0.02 to 0.69 [Goldman et al., 1986; Mitchell and Bubenzer, 1980].

Soil thickness (ST) represents the depth of the soil present and is one of the important factors for assessing the stability of the soil and landslide susceptibility of the land. With increased soil depth, the tendency of the soil to absorb moisture increases, resulting in reduced runoff rate. Hence, thin soil is considered to be more unstable and prone to landsliding than thick soil [Sharma et al., 2012]. Based on this, ranking criteria were adopted for the varying soil thicknesses found in the study area, as shown in Table 1 [Catani et al., 2010; Segoni et al., 2012; Del Soldato et al., 2018]. Data used for this indicator were derived from the SITR [Sistema Informativo Territoriale Regionale, Geoportale Regione Siciliana, Panagos, 2015; Tóth and Hermann, 2015].

Landslide type (LT) is defined by the scale of landslide events, which were initially categorized on the basis of Varnes' [1978] classification. Moreover, for the validation of the ranking, information from del Potro and Hürlimann [2008], Nolesini et al. [2013], Catani et al. [2013] and Di Traglia et al. [2018] were used. In the first category areas with no events are ranked. In the second category, are considered events like rock falls when abrupt movements of masses of geological material, such as rocks and boulders, become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water. In the third category there are toppling failures, which are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the action of gravity and forces exerted by adjacent units or by fluids in cracks. In the fourth category is debris flow, which involves rapid mass movements of loose soil, rock, organic matter, air, and water. In the fifth category there are the large earth flows that have a characteristic "hourglass" shape. The slope material liquefies and runs out, forming a bowl or depression at the head. Creeping events are also included in this category. The data used for this indicator were derived from the SITR –geomorphological risk data sets.

Land cover (LC), according to van Westen et al. [2008], is one of the main factors in soil erosion and slope stability analysis. Land cover, as a landslide factor, is also the most influenced by human activities, since it is easy to manage and change [Akgun and Türk, 2010; Di Traglia et al., 2017]. Land cover type can also function as a measure for surface roughness when not relative measurements exist, although roughness can be more detailed [Korzeniowska et al., 2018; Di Traglia et al., 2018]. In future works this indicator be supplemented by roughness measurement with the use of topographic (DEMs) and SAR data if available [Catani et al., 2013]. Data used for this indicator were derived from the CORINE Land Cover data from the Copernicus database.

Volcanic hazards (VH) were ranked based on the size of the impact area. Thus in the first category there are areas that are not affected, in the second one there are areas affected by vent openings and phreatic explosions. In the third one there are those effected by lava flows, while in the fourth and fifth categories there are areas impacted by pyroclastic fallout and pyroclastic currents respectively. Similar approaches can be found in Bartolini et al. [2013] and Di Traglia et al. ([2017].

3.2 COASTAL INDICATORS

The ranking of coastal indicators is based on the database developed by Gronitz [1990], which includes both quantitative and qualitative information. Thus, numerical variables are assigned to a risk ranking based on data value ranges, while the non-numerical coastal landforms indicator is ranked according to the relative resistance of a given landform to erosion. Coastal slopes (CS) are considered to be very low risk at values >12%; very high risk consists of regional slopes <3%. Relative sea-level rise (RSLR) is ranked using the modern rate of eustatic rise (1.8 mm/a) as very low risk. Since this is a global or "background" rate common to all shorelines, the sea-level rise ranking reflects primarily regional to local isostatic or tectonic effects. Shoreline changes (SC) are based on erosion/accretion rates. A rate between -1.0 and +1.0 m/a, is ranked as moderate. Increasingly higher erosion or accretion rates are ranked as correspondingly higher or lower risk. Tidal range (T) is ranked such that microtidal coasts are high risk and macrotidal coasts are low risk. In previous and related studies [Gornitz, 1990; Shaw et al., 1998], large tidal range (macrotidal; tide range > 4m) coastlines were assigned a high-risk classification, and microtidal coasts (tide range <2.0 m) received a low risk rating. This decision was based on the concept that large tide range is associated with strong tidal currents that influence coastal behaviour. We have chosen to invert this ranking, so that a macrotidal coastline is at a low risk. This reasoning is based primarily on the potential influence of storms on coastal evolution, and their impact relative to the tide range. For example, on a tidal coastline there is only a 50 percent chance of a storm occurring at high tide. Thus, for a region with a 4 m tide range, a storm having a 3 m wave height is still up to 1 m below the elevation of high tide for half a tidal cycle. A microtidal coastline, on the other hand, is essentially always ”near” high tide and therefore always at the greatest risk of inundation from storms. Mean wave height (Hs) rankings range from very low (<0.55 m) m to very high (>1.25 m). The data used for this indicator were derived from the Copernicus database and EUROSION 2004.

The choice of socio-economic variables as indicators was guided by the criteria that these must be easily obtainable, and include, if possible, most of the characteristics related to the island’s economic growth and social development. In this work the following social indicators were used: the presence and size in respect of area coverage and people present of Settlements (SET), Cultural Heritage sites (CH), the Transport Network (TN), Land Use (LU) and Economic activities (E). Of these variables, information on the transport network and cultural heritage is easily obtained, while settlements, land use and economic activities are time dependent, and must therefore be reassessed after a certain period. This approach requires the insertion of a current estimation, which can be easily updated in the future. The variables were ranked on a 1-5 scale, according to their perceived vulnerability (with 5 being the most vulnerable and 1 the least vulnerable).

Settlement size (SET) is used as a proxy for the estimation of the population in the study area and area coverage. Population is not a commonly used variable in published vulnerability indices, but it is acknowledged that an area with a larger population would have a greater economic value [Hughes and Brundrit, 1992]. Settlement size can be considered as an economic variable because in larger settlements more people would be affected and act to protect their properties from hazards [Dilley and Rasid, 1990; Rivas and Cendrero, 1994]. Settlement data are time dependent, since the size of settlements may change with time and need to be re-evaluated periodically. Settlement size is ranked on a 1-5 basis, with the assumption that larger settlements are affected more by erosion, since more people are affected; they are therefore directly correlated with increased vulnerability. Data used for this indicator were derived from the European Settlement Map 2016 [EU-GHSL, 2016] from the Copernicus database because it can provide also the special destitutions of the data, while other authors have used statistical data [Biass et al., 2016].

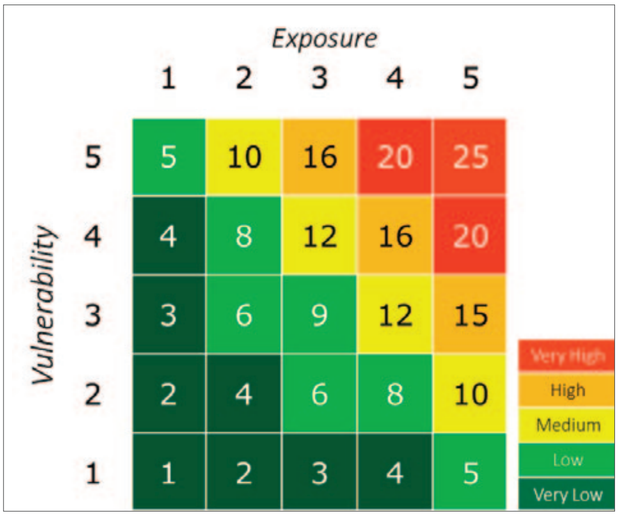
Cultural heritage sites (CH) such as archaeological and historical monuments, as part of cultural resources and universal material and immaterial heritage, are irreplaceable [Magnaghi, 2005]. This makes them important not only in economic terms, but also in social, cultural, historical and palaeoenvironmental terms. Thus, although hazards are unavoidable in some areas, protection measures are necessary for cultural heritage sites [Castorina et al., 2017]. Even though it is unproblematic to identify a cultural heritage site, it is difficult to assign a priority value to a cultural heritage resource. Even if one site is better preserved than another, this does not mean that it is more important. Therefore any method of ranking this variable is subjective. To address this problem, the sites in the present study were ranked in terms of their global importance in world history and the evidence they provide. Hence sites of global interest are considered to have an increased exposure, while less important sites are assigned a lower exposure value.

Transport networks (TN) are easily incorporated into an index, because they have well-defined geometrical characteristics (length and width), which can be measured, and the cost of their protection or replacement can be calculated. Transport networks also show very little variation over time. Here the TN variable is ranked according to road size, with larger roads considered as more vulnerable.

Land Use (LU) type is very significant in determining vulnerability because protection measures for a vulner-

	VARIABLES		Categories				
			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
Geomorphological Characteristics	Landforms	Lf	Beaches, Deltas	Terrace. Alluvial Plains	Low Cliffs	Medium Cliffs	High Cliff, landslides
	Slope (°)	Sg	10	10 – 25	25 - 30	30 - 45	<45
	Aspect	AS	<15	15-30	30-45	45-75	>90
	Lithology	Li	Limestone Plutonic, lava/ welded tuff, High-medium grade metamorphics	Sandstone, Tuff Low grade metamorphics, and conglomerate	Clay, Low-cohesion sedimentary rocks, soft tuff	Non Cohesive, Coarse and unconsolidated sediments and pyroclastics	Debris/weathered materia Fine unconsolidated sediments, volcanic ash
	Drainage density (km/km^2)	Ds	<1	1-1.5	1.5-2	2-2.5	>2.5
	Structural stability	SS	none	Joints	Bedding Planes	Faults	Open cracks
Natural factors	Vegetation coverage (%)	Vg	>70	60-70	50-60	40-50	<40
	Soil Erosivity	SER	0.15	0.15- 0.30	0.30-0.45	0.45- 055	>0.55
	Soil thickness (m)	ST	>10	5-10	1-5	0.5 - 1	<1
	Landslide type	LT	None	Rock falls	Toppling	Debris/earth flow	Debris avalanche
	Land cover	LC	Bare rocks / water bodies	Artificial areas	Forest	Grasslands	Cultivated area
	Volcanic hazards	VH	None	Vent opening/ phreatic explosion	Lava flows	Pyroclastic Fallout	Pyroclastic currents
Coastal erosion	Coastal landforms	CLf	Rocky, Cliff coasts	Medium cliffs, indented coasts	Low cliffs, alluvial plains	Cobble Beaches, Lagoon	Barrier beaches, beaches, deltas
	Shoreline Changes (m/a)	SC	>2.0	from 1.0 to 2.0	from -1.0 to 1.0	from -2.0 to -1.0	<-2.0
	Coastal Slope (%)	CS	12	12 – 9	9 - 6	6 - 3	<3
	Relative Sea-Level Rise(mm/a)	RSLR	<1.8	1.8 - 2.5	2.5 - 3.0	3.0 - 3.4	> 3.4
	Mean Wave Height (m)	Hs	<0.55	0.55 - 0.8	0.85 - 1.05	1.05 - 1.25	>1.25
	Mean Tide Range (m)	T	>6.0	4.0 - 6.0	2.0 - 4.0	1.0 - 2.0	<1.0
Socio-Economic	Settlement	SET	Absent	Village	Small Town	Large Town	City
	Cultural Heritage	CH	Absent	Local	Regional	National	Global
	Transport Network	TN	Absent	Secondary	National road	Ports	Highway
	Land Use	LU	Absent	Forest	Semi-rural	Agricultural	Urban, Industrial
	Economic activities	E	Absent	Industrial	Agricultural	Commercial	Tourism

TABLE 1. Ranking variables.



		Exposure				
		1	2	3	4	5
Vulnerability	5	5	10	16	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5

TABLE 1. Risk estimation matrix.

able area will be considered only if it has sufficient economic, cultural or environmental value to justify protection. Land value can be defined in different ways, such as in financial terms, or replacement cost or in aesthetic or conservation worth. Other indices that incorporate Land Use as a variable include those of McCue and Deakin [1995] and O'Riain [1996]. Ranking of Land Use variables should consider the characteristics of the given area in terms of economic growth [Hughes and Brundrit, 1992]. For the purposes of this study, Land Use types were grouped and then ranked according to EUROSION 2004, with urban and industrial sites assessed as being more vulnerable. The data used for this indicator were derived from the Copernicus database.

Economic activities (E). This variable represents the financial value associated with the land-use type of the areas. In this study the coastal sectors that are used for tourism purposes are considered most vulnerable, since tourism is the main factor that drives local economic growth. Table 1 gives the ranking of all variables.

4. RISK ANALYSIS

Risk assessment was estimated by using the definition of risk proposed by the European Commission [ISO/IEC, 2009], according to which risk is "the probability of harmful consequences, or expected losses (deaths, injuries to property, livelihoods, disruption to economic activities or environment), resulting from interaction between vulnerability and exposure". Vulnerability was thus estimated as risk probability, with the economic impact functioning as the exposure variable. More specifically, risk was estimated by Equation 6:

$$R = V \times E \tag{6}$$

where R is the estimated risk, V is the vulnerability and E the exposure of the system.

Risk, vulnerability and exposure variables are ranked in five categories, corresponding to Very Low, Low, Medium, High and Very High ranking values (Figure 2).

Risk was estimated by using GC and NF as vulnerability, and SE for exposure for the inland part of the island (Equation 7), while for the coastal areas risk was evaluated from a combination of CVI and SE (Equation 8)

$$R = V \times E = (GC + NF) \times SE \tag{7}$$

$$R = V \times E = CVI \times SE \tag{8}$$

5. RESULTS AND DISCUSSION

5.1 RANKING OF INDEX VARIABLES

The variables controlling all sub-indices were determined and assessed on the basis of existing information [e.g. EUROSION, 2004], which was combined and spatially interrelated. With respect to variables related to Ustica geomorphological characteristics, it was found that the Landforms variable is associated with high and very high vulnerability for the 36.65% and 28.73% of the island's area, respectively; 20.90% is of moderate vulnerability, and the remaining area of 13.72% is of very low and low vulnerability. The very high and high vulnerability areas are located mainly in the central part of the island, whereas the coastal part has moderate values. Slope variable for the inland part of the island was found to be of very low (48.47%) and low (15.13%) vulnerability, while there are areas with high and very high vulnerability (8.87% and 23.75% respectively), and the remaining area is of moderate vulnerability (3.78%). Aspect has very low ranking in 56.30% of the island, while the other classes range from 8.83% for the highly vulnerable areas to 15.90% for those of low vulnerability. Lithology is ranked mainly in the very low (35.81%) and high (47.01%) categories. The other lithological formations are ranked as low (5.51%), moderate (0.15%) and very high (11.52%) vulnerability. The drainage density variable is ranked as very low for the whole island due to the complete absence of a drainage network. The spatial distribution of variables is shown in Figure 3, while

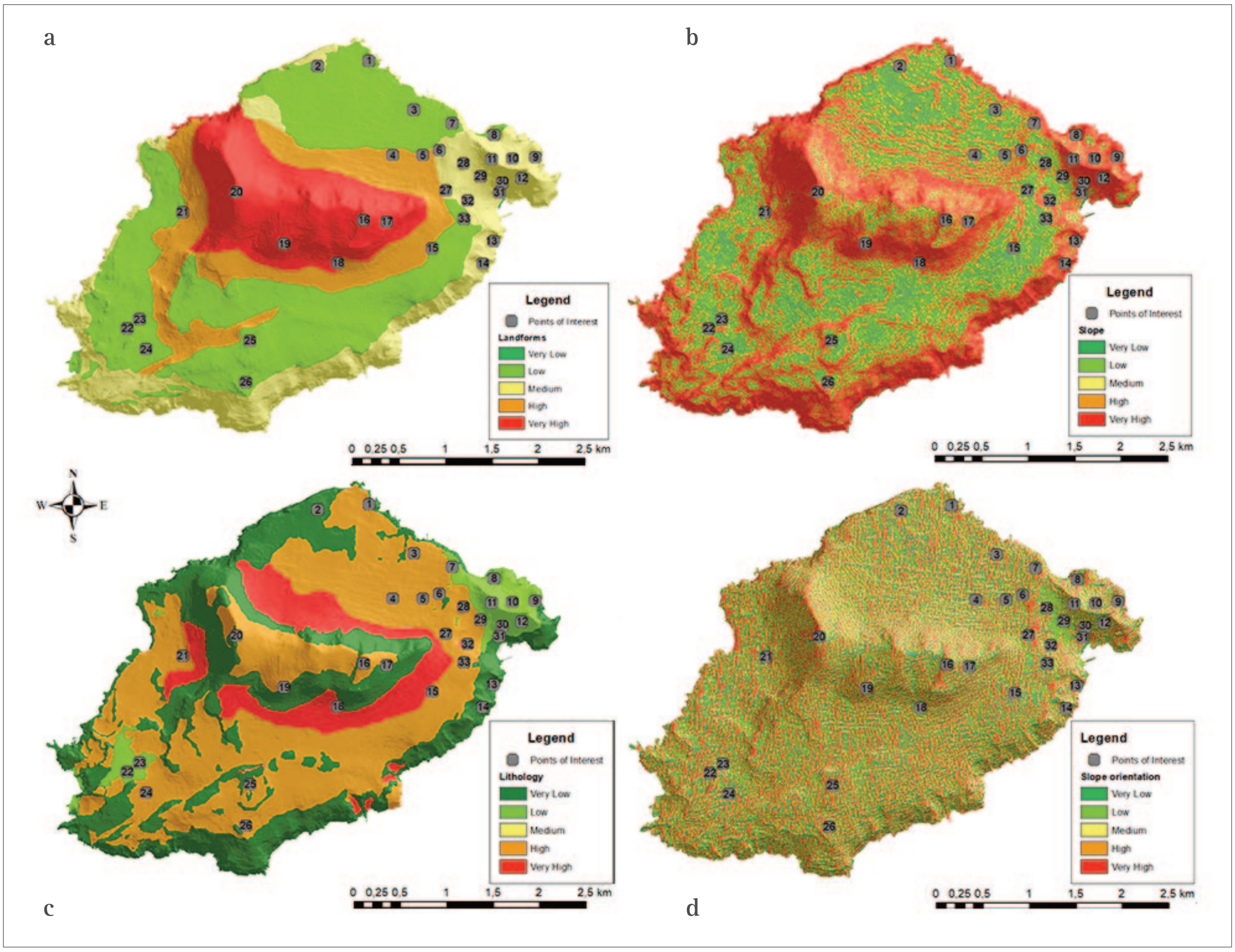


FIGURE 3. Spatial distribution of the Geomorphological Characteristics sub-index variables. a: Landform b: Slope c: Lithology and d: Slope orientation. For names in areas of interest see Figure 1.

the ranking can be seen in detail in Table 2.

Regarding variables that are related to natural factors, Structural stability has 3.04% and 9.25% of high and very high vulnerability and 13.70% of moderate, while the remaining 72.93% has very low and low vulnerability. The vegetation coverage variable for the inland part of the island was found to be of very low (6.12%) and low (0.57%) vulnerability for limited areas, while very high vulnerability corresponds to 92.49%. Soil Erosivity has a very high ranking in 91.76% of the island, while the other classes make up the remaining 8.24%. Soil thickness is ranked mainly in the very low category (60.85%). A very low vulnerability for Landslide type variable was found in 85.3% of the area. Land cover has 10.44% and 56.43% of high and very high vulnerability, 11.81% is moderate; while in 17.24% of the remaining area it is very low and in 4.09% low. The volcanic hazards variable is ranked as very low for the whole island due to the fact that Ustica is an extinct volcano. The distribution of specific variables is shown in Figure 4, while the ranking can be seen in detail in Table 2.

For the Settlement variable, the majority of the area is ranked as very low (94.59%) since there are no settlements there. Of the remaining 5.41% that corresponds to villages and tourist infrastructure areas, 1.19% is ranked as high and 1.77% as very high. For the Cultural Heritage variable, 95.54% of the area is ranked as very low, 6.49% as low, since there are cultural heritage sites of local importance in these areas, and 0.42% as high. Regarding the Transport Network variable, in terms of exposure the 93.26% of the area is ranked in the very low category, since it contains secondary roads, while 0.24% which represent ports and main roads is ranked as high.

For the Land Use variable, 29.04% of the coastline is assigned to the very low category, and 66.86% to the medium category. The remaining 4.09% is ranked as

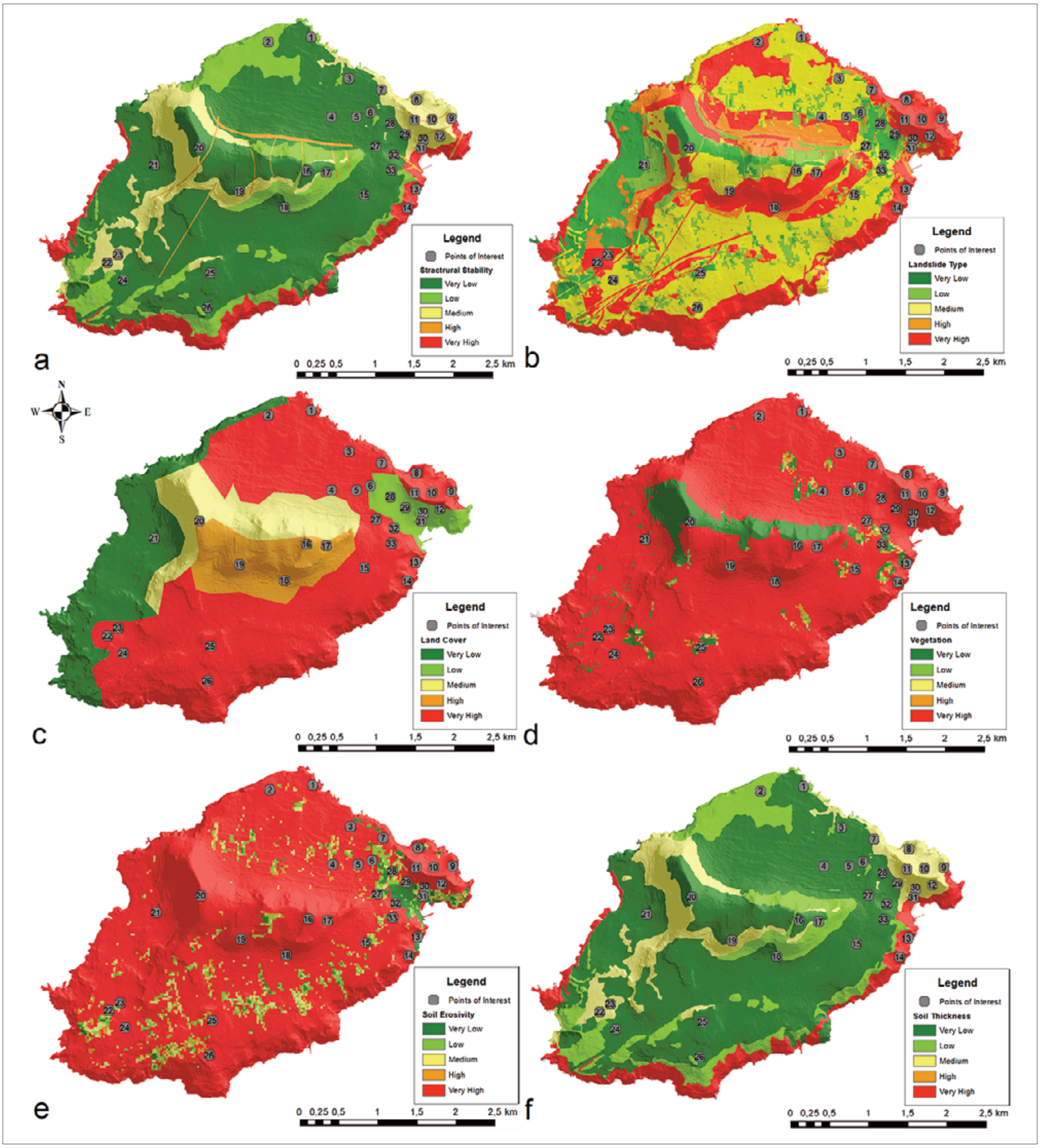


FIGURE 4. Spatial distribution of the Natural Forcing sub-index variables. a: Structural stability, b: Landslide type, c: Land Cover, d: Vegetation, e: Soil Erosivity and f: Soil Thickness. For names in areas of interest see Figure 1.

very highly vulnerable. Lastly, for the Economic Activities variable the majority of the area (59.3%) belongs to the high category, since it contains commercial activities, 27.67% is ranked as medium because it is home to agricultural activities, and only a very small percentage of the area (4.09%) as very high since it is occupied by small-scale tourist activities (Figure 5). All variable rankings as a present of the total area are presented schematically in Figure 6, and in Table 2.

5.2 INDEX CALCULATION

The Geomorphological Characteristics sub-index (GC), which is related to Landforms, Lithology, Slope, Slope aspect and drainage network was found to be of low vulnerability in 34.19% of the area, while 41.62% was ranked as medium vulnerability and 22.33% as high. The very low and very high ranks regard very small percentages, 1.56% and 0.29% respectively.

The Natural factors Forcing sub-index – which in-

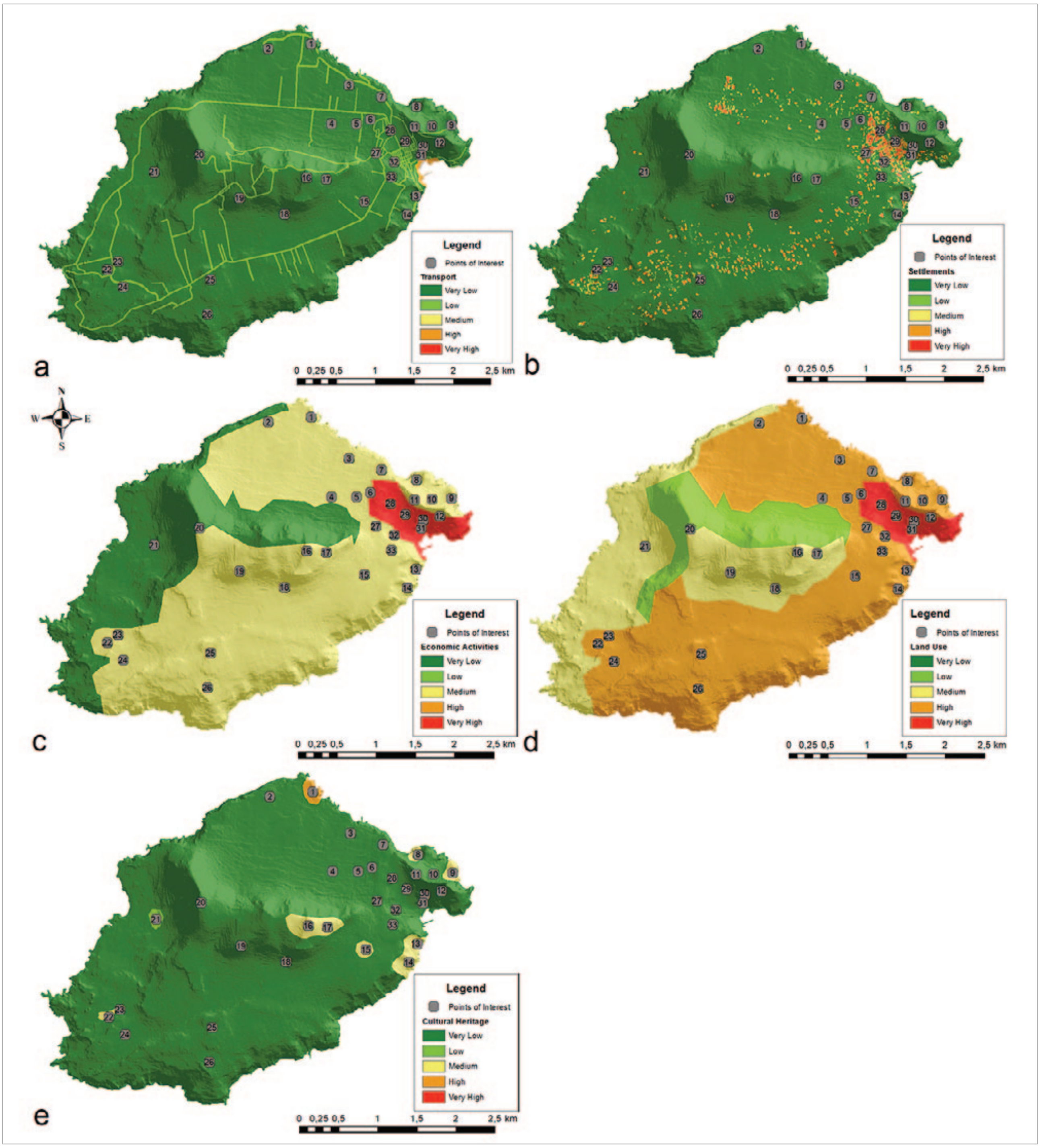


FIGURE 5. Spatial distribution of the socioeconomic sub-index variables. a: Transport Network; b: Settlements, c: Economic activities; d: Land Use and e: Cultural heritage areas. For names in areas of interest see Figure 1.

cludes the indicators of structural stability of the geological formations, vegetation coverage, soil erosivity and thickness, landslide type, land cover and volcanic hazards – gives values of very low (0.55%) and low (69.63%) vulnerability, while there are areas with high and very high vulnerability (8.14% and 3.63% respectively), and the remaining area is of moderate vulnerability (18.06%).

The Socio-Economic sub-index includes the socio-economic indicators of the presence and size of Settlements, Cultural Heritage sites, the Transport Network, Land Use and Economic activities.

It was estimated to have values of very low vulnerability (37.53%) and low vulnerability (59.08%), while the remaining area is ranked as medium (3.10%), high (0.29%) and very high vulnerability (0.01%).

The spatial distribution of the three inland sub-indices is shown in Figure 7.

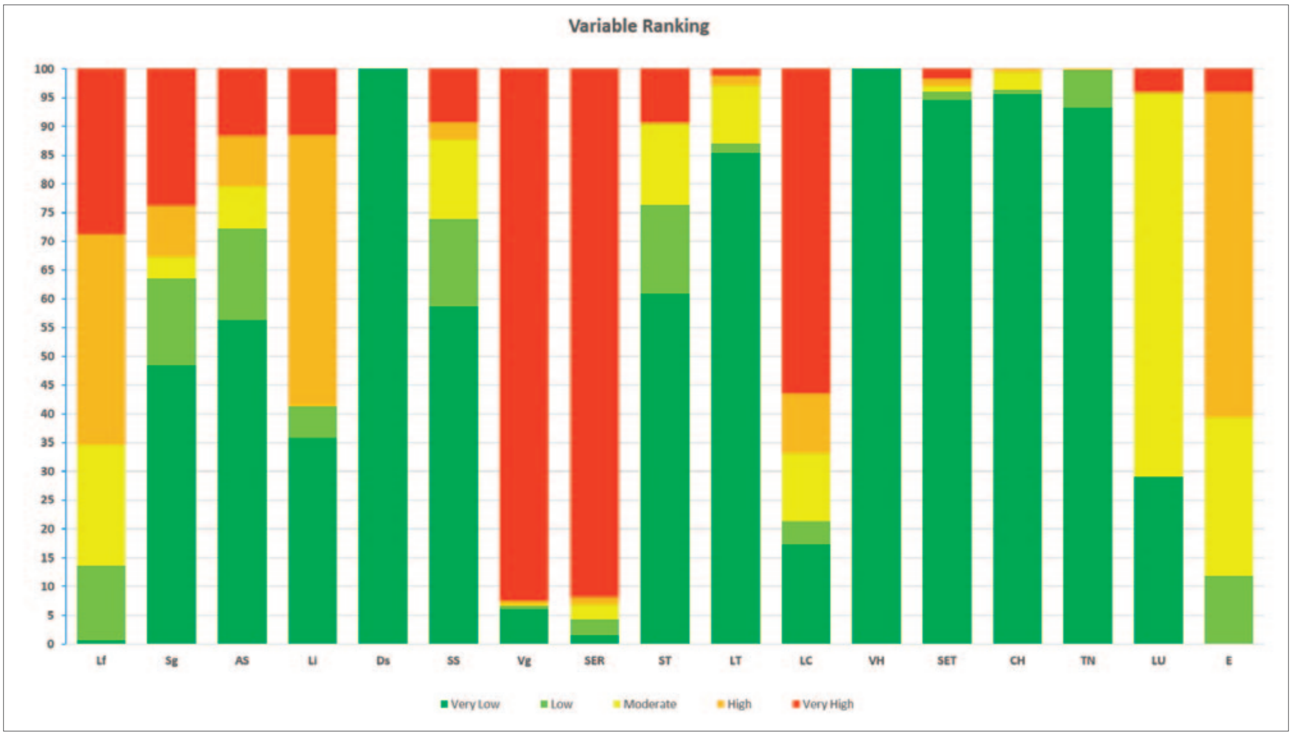


FIGURE 6. Comparison of the variables, as percentages of the total that control the three inland sub-indices.

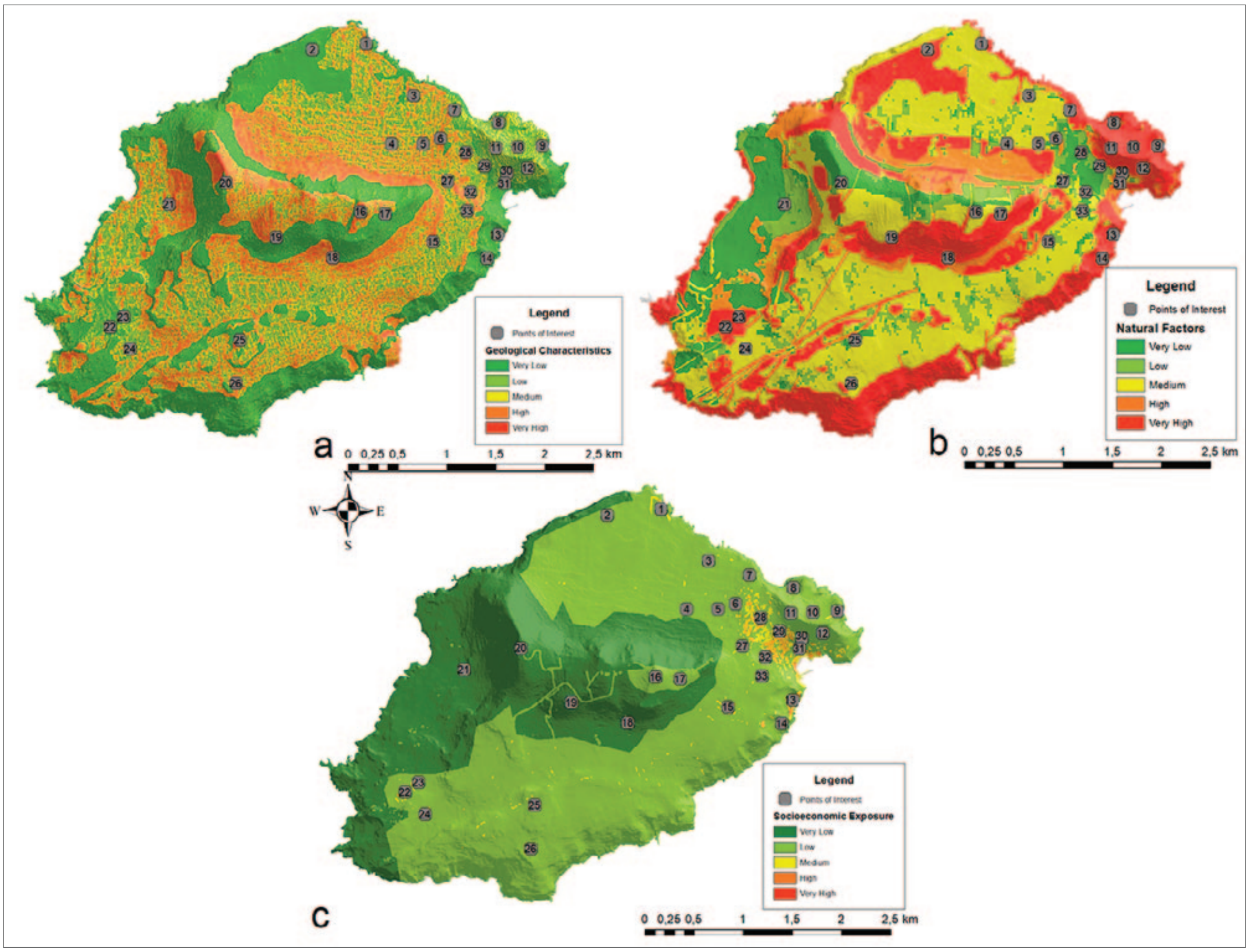


FIGURE 7. Spatial distribution of the three inland sub-indices a: Geological Characteristics b: Natural Factors and c: Socioeconomic exposure. For names in areas of interest see Figure 1.

VARIABLES			Categories				
			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
Geomorphological	Landforms	Lf	0.66	13.06	20.9	36.65	28.73
	Slope (°)	Sg	48.47	15.13	3.78	8.87	23.75
	Aspect	AS	56.3	15.9	7.37	8.83	11.60
	Lithology	Li	35.81	5.51	0.15	47.01	11.52
	Drainage density (km/km^2)	Ds	100.00	0.00	0.00	0.00	0.00
Natural factors	Structural stability	SS	58.70	15.23	13.77	3.04	9.25
	Vegetation coverage (%)	Vg	6.12	0.57	0.26	0.56	92.49
	Soil Erosivity	SER	1.52	2.77	2.59	1.36	91.76
	Soil thickness (m)	ST	60.85	15.57	14.21	0.00	9.37
	Landslide type	LT	85.30	1.71	10.16	1.61	1.21
	Land cover	LC	17.24	4.09	11.81	10.44	56.43
	Volcanic hazards	VH	100.00	0.00	0.00	0.00	0.00
Socio-Economic	Settlement	SET	94.59	1.46	0.99	1.19	1.77
	Cultural Heritage	CH	95.54	0.84	3.20	0.42	0.00
	Transport Network	TN	93.26	6.49	0.00	0.24	0.00
	Land Use	LU	29.04	0.00	66.86	0.00	4.09
	Economic activities	E	0.02	11.8	27.67	56.42	4.09
sub-indices	Geomorphological Characteristics	GC	1.56	34.19	41.62	22.33	0.29
	Natural factors	NF	0.55	69.63	18.06	8.14	3.63
	Socio-economic exposure	SE	37.53	59.08	3.10	0.29	0.01

TABLE 2. Ranking variables for the inland variables and overall sub-indices as percent area coverage.

5.3 COASTAL VULNERABILITY

The coastal landforms are of low vulnerability for 63.71% of the coastline and medium for 18.10%; the remaining vulnerability ranks refer to small percentages (13.86% very low, 3.15% high, and 1.15% very high) of the coastline. For the Shoreline changes variable, 67.36% of coastline is considered of medium vulnerability, and 51.70% as highly vulnerable. The very low, low and very high ranks correspond to very small percentages, 6.61%, 0.00%, and 4.34%, respectively.

The coastal slope was estimated by the distance be-

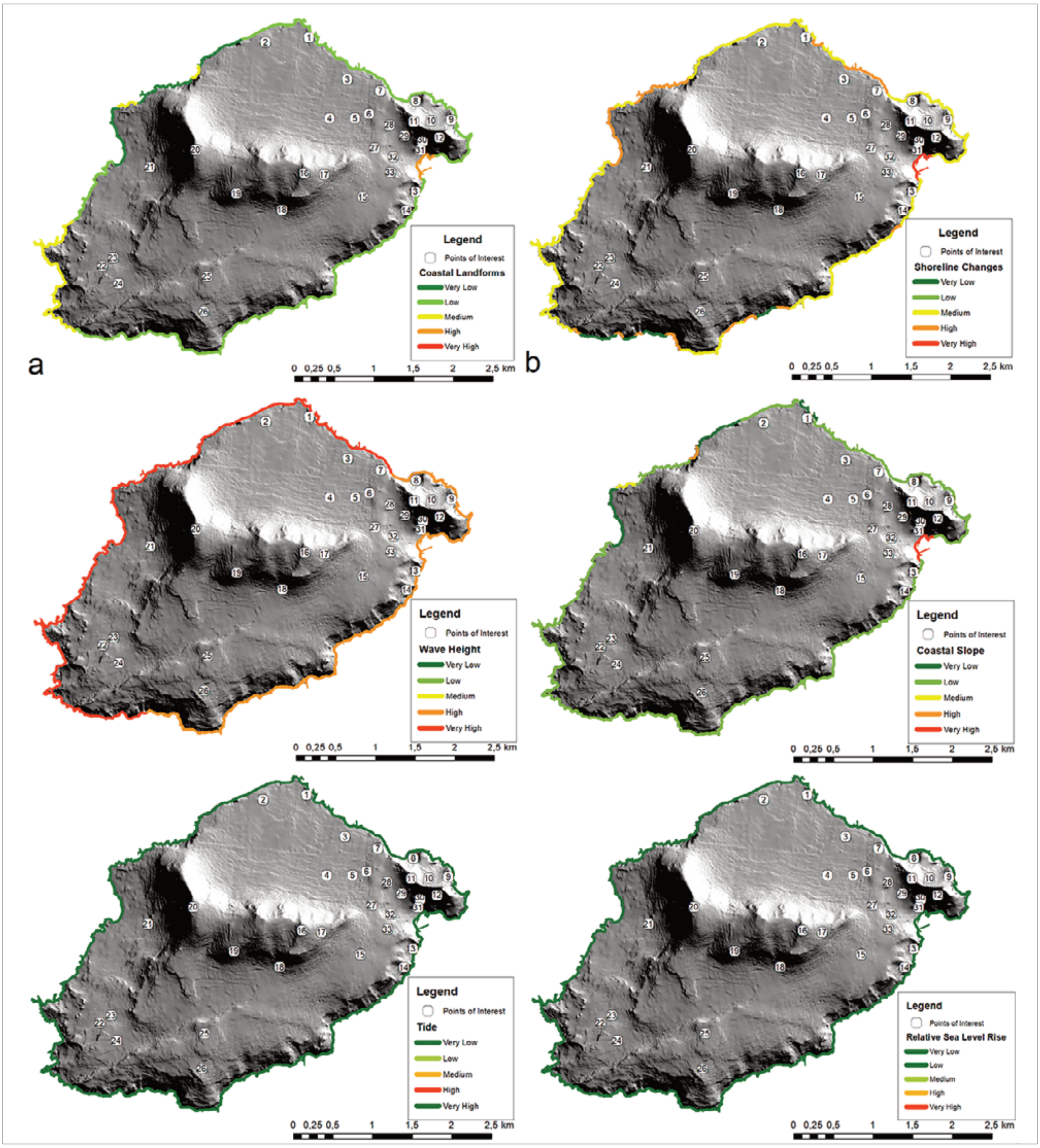


FIGURE 8. Spatial distribution of the coastal vulnerability index where a: Coastal landforms b: Shoreline changes c: Wave Height d: Coastal slope e: Tide and f: Relative sea level rise. For names in areas of interest see Figure 1.

tween 5m isobaths and the 5m elevation contour line, while for its ranking the limits of the five classes indicated in Table 1 were utilised. Thus 83.24% of the coast is considered to be of low vulnerability and 10.16% of very low vulnerability, with the 1.37% medium vulnerability, 0.89% high vulnerability, and 4.34% very high vulnerability rankings representing the coastal cliffs. Relative Sea-Level Change and the Tidal variables are considered to have the same values throughout the whole area; the Relative Sea-Level Change variable in ranked as very low vulnerability and the Tidal range variable as very high vulnerability. The majority of the coastline is ranked as very highly (57.36%) and highly vulnerable (42.77%) with respect to the Mean Wave Height variable.

For the Settlement variable, the majority of the coastline is ranked as very low (88.90%) since there are no settlements in these areas. The remaining 11.10% that

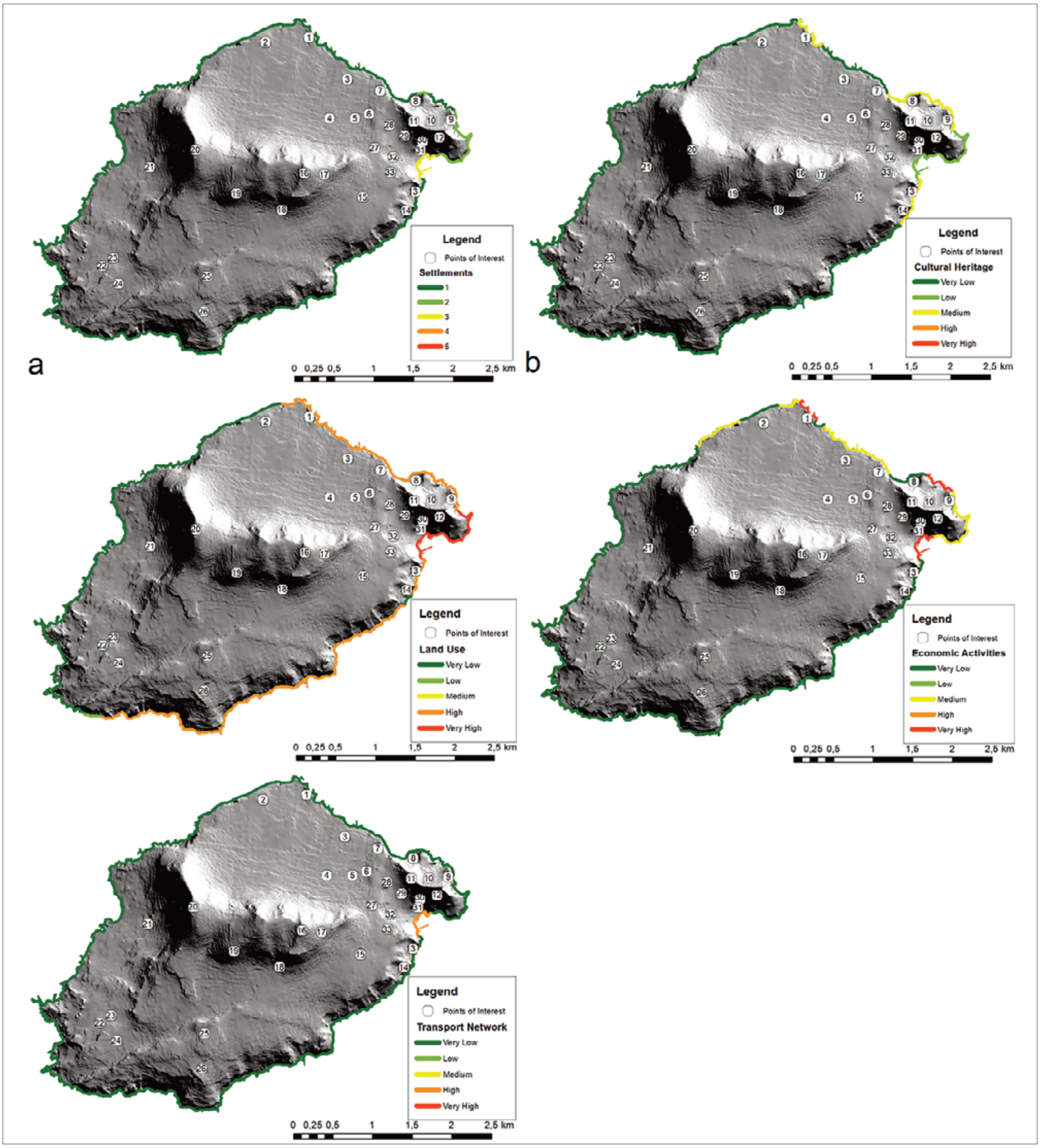


FIGURE 9. Spatial distribution of the Socio-economic Vulnerability Index where a: Settlements; b: Cultural heritage areas, c: Land Use; d: Economic activities and e: Transport Network. For names in areas of interest see Figure 1.

corresponds to coastline in front of villages and tourist infrastructures is ranked as low and medium. For the Cultural Heritage variable, 77.89% of the coastline is ranked as very low and 9.57% as low, since there are no cultural heritage sites or sites of local importance in these areas, and 12.54% as medium. Regarding the Transport Network variable, 95.66% of the coastline is ranked in the very low category, and the remaining 4.34% as highly vulnerable: this represents the docking areas of the two ports. For the Land Use variable, 42.07% of the coastline is ranked as very low, and 47.47% in the high category since it hosts urban structures. Of the remainder, 9.57% lies in front of bare rocks and is ranked as of very high vulnerability, and 0.89% as low. Lastly, for the Economic Activities variable the majority of the coastline (71.91%) was assigned to the very low category, as there are no economic activities there, 19.85% to the medium category as it incorporates agricultural activities, and 8.52% to very high category

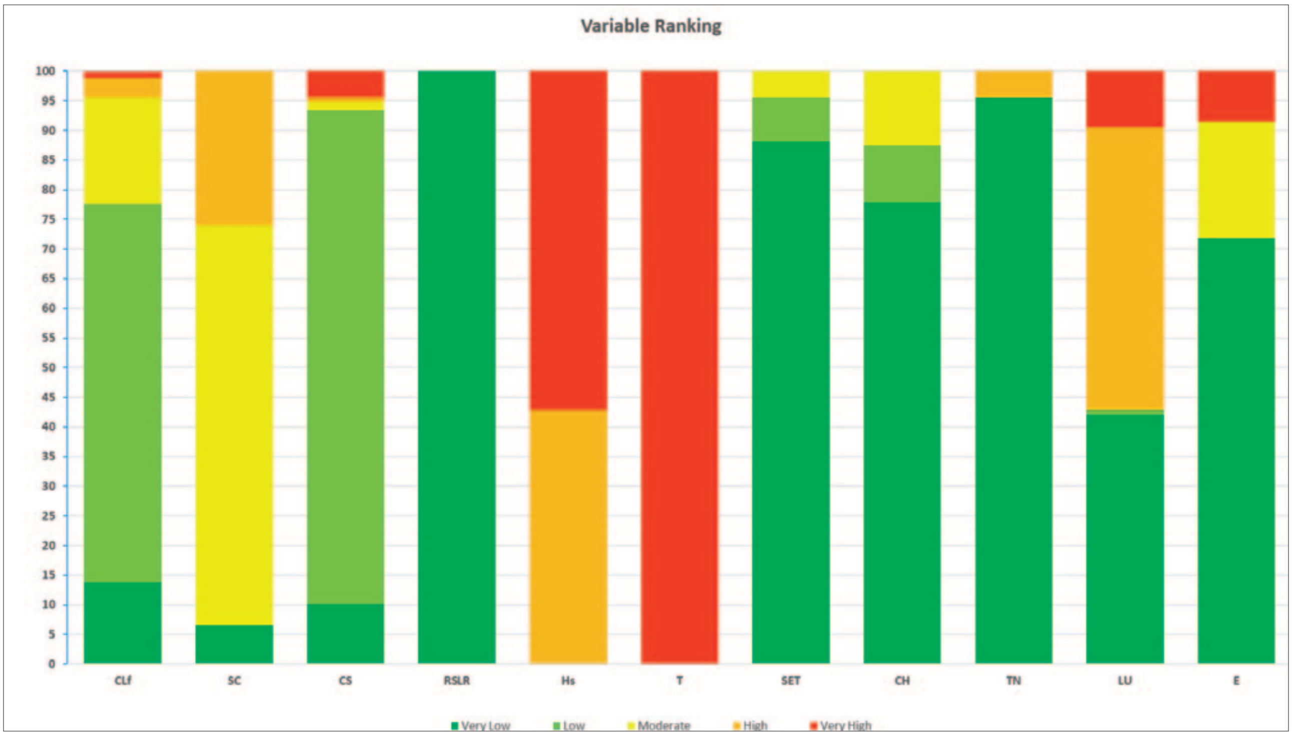


FIGURE 10. Comparison of the variables that control the two coastal sub-indices.

as it contains tourist activities. All variable rankings are presented schematically in Figure 10.

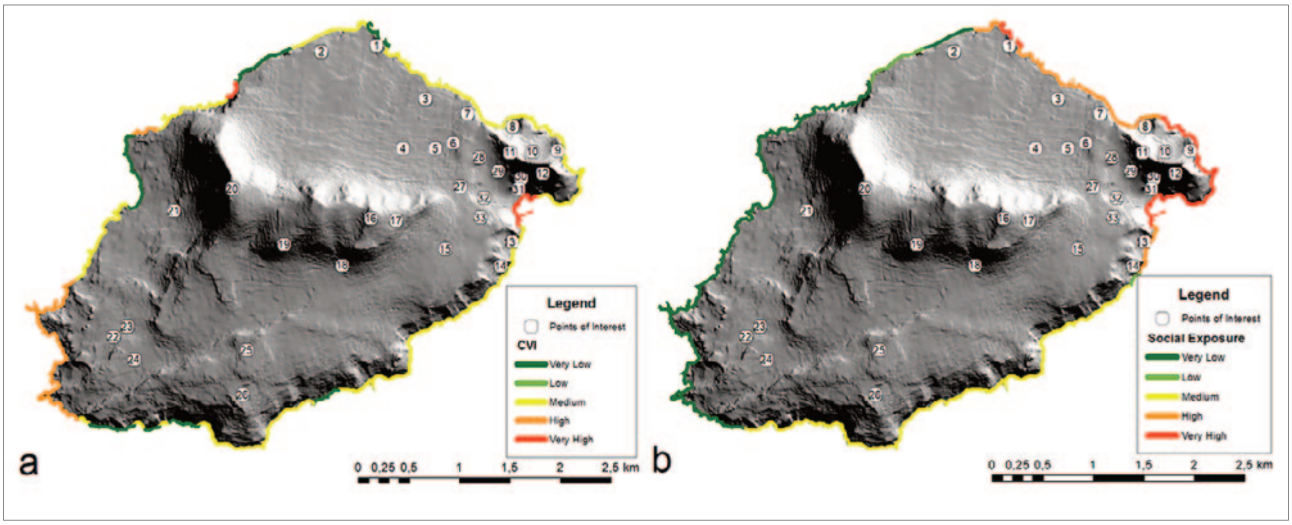


FIGURE 11. Spatial distribution of the CVI (a) and Social exposure (b). For names in areas of interest see Figure 1.

5.4 INDICES

Estimations using CVI show that 16.77% of the coastline is characterized by very low vulnerability areas, mainly rocky coasts, steep slopes, and man-made structures. A percentage of 36.02% is classified as low vulnerability areas, and 19.93% as of medium vulnerability. High and very high vulnerability areas correspond to 6.85 % and 22.44 % of the total coastline length respectively, being mainly beaches and soft-rock coasts. A schematic presentation of the CVI classification is shown in Figure 11. According to the results of the SVI index, there are no areas with very low vulnerability, while 78.51 % of the coastline is characterized as low vulnerability coasts. These consist mainly of areas with steep slopes, hard bedrock and human constructions. For the socio-economic index a small percentage of the coastline (5.5%) is ranked in the low vulnerability category; 15.21% and 15.1% of the coastline are ranked in the high

	VARIABLES		Categories				
			1	2	3	4	5
			Very Low	Low	Medium	High	Very High
Coastal Processes	Coastal landforms	CLf	13.86	63.71	18.10	3.15	1.15
	Shoreline Changes (m/a)	SC	6.61	0.00	67.36	51.70	4.34
	Coastal Slope (%)	CS	10.16	83.24	1.37	0.89	4.34
	Relative Sea-Level Rise (mm/a)	RSLR	100.00	0.00	0.00	0.00	0.00
	Mean Wave Height (m)	Hs	0.00	0.00	0.00	42.77	57.23
	Mean Tide Range (m)	T	0.00	0.00	0.00	0.00	100.00
Socio-Economic	Settlement	SET	88.09	7.58	4.34	0.00	0.00
	Cultural Heritage	CH	77.89	9.57	12.54	0.00	0.00
	Transport Network	TN	95.66	0.00	0.00	4.34	0.00
	Land Use	LU	42.07	0.89	0.00	47.47	9.57
	Economic activities	E	71.91	0.00	19.58	0.00	8.52
Sub-indices	Coastal Vulnerability Index	CVI	16.77	36.02	17.93	6.85	22.44
	Socio-economic Vulnerability Index	SVI	37.46	5.50	26.64	15.21	15.09

TABLE 3. Ranking variables for the coastal variables and coastal indices as percentage of the total coastal length.

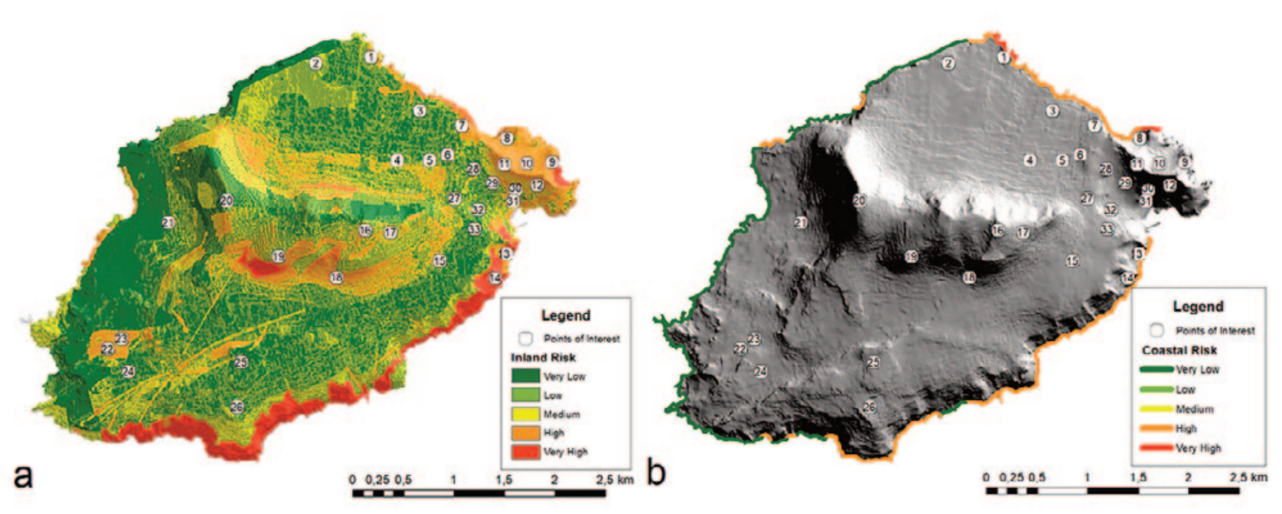


FIGURE 12. Spatial risk distribution for the inland (a) and coastal areas (b). For names in areas of interest see Figure 1.

and very high vulnerability categories, respectively, and 37.46% and 26.64% are assigned to the very low and medium categories.A schematic presentation of the SVI classification is shown in Figure 11 and Table 3.

	Very Low	Low	Medium	High	Very High
Inland RISK	28.56	35.13	22.28	8.63	5.41
Coastal RISK	26.57	37.46	5.57	15.21	15.19

TABLE 4. Risk estimation for the inland and coastal areas.

5.5 RISK

The risk estimated by using GC and NF as vulnerability and SE as exposure for the inland part was found for 28.56% to have very low values, 35.13% low, 22.28% medium, 8.63% high and 5.41% very high vulnerability. For the coastal areas the risk was evaluated to be similar to that of the inland part for the very low and low categories (26.57% and 37.46% respectively), while the medium category has a smaller value (5.57%) and the high and very high increased values (15.21% and 15.19% respectively). The spatial risk distribution for the inland and coastal areas is shown in Figure 11, and the values in Table 4.

Moreover for the inland area a ternary diagram was used in order to present the relative influence of each of the three sub-indices in each area of interest (Figure 13). The diagram shows a general tendency for the natural forcing and geological characteristics sub-indices to dominate the overall influence, with the socio-economic index having the least influence. The diagram also demonstrates that the overall index via its sub-indices does differentiate between areas. If all of the sites were clustered around the centre of the triangle then this would suggest that all areas studied were relatively similar in relation to their geological characteristics, coastal forcing and socio-economic attributes.

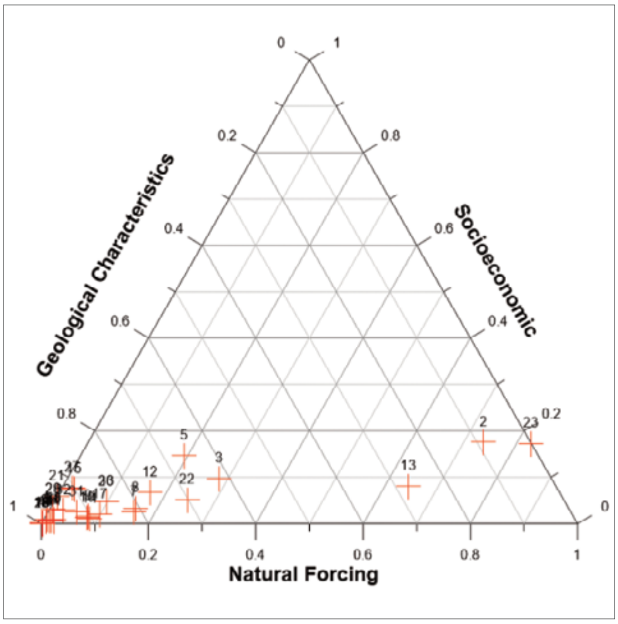


FIGURE 13. Ternary diagram presenting the influence of each sub-index to the overall score for the areas of interest. For locations see Figure 1.

6. CONCLUSIONS

Vulnerability is a human value judgement, so ultimately the perceived estimates for coastal areas will strongly influence management decisions. Consequently the socio-economic component of coastal vulnerability is at the very heart of management practice. The inclusion of socio-economic variables in vulnerability indices is extremely important although not without difficulties. The socio-economic aspect is usually omitted from published indices, probably due to the difficulties in obtaining and ranking the data. The incorporation of a socio-economic sub-index in an overall index to assess vulnerability to wave-induced erosion for Ustica proved to be a useful exercise in examining the problems involved in the compilation of such indices. The indicators that are selected for the vulnerability analysis can strongly influence its final conclusion. The addition of socio-economic variables to coastal vulnerability indices based initially only on natural processes is of great importance, even though the accurate quantification of most of them remains a serious challenge. The inclusion of socio-economic variables in vulnerability assessment studies may prove to be a useful tool for making management decisions more focused on society's actual needs. For Ustica, the eastern part of the island gives higher values, mainly based on socio-economic impact, while the archaeological sites strongly influence the overall risk index score. Slope is a high risk factor for inland processes, but low risk for coastal processes due to the different effect that slope has on the evolution of the inland and coastal parts of the island. The analysis indicated not only that the risk can be determined, but that the main factors influencing the risk in a specific area can also be identified. Although the accurate quantification of most socio-economic variables remains a serious challenge, their addition to existing indices of risk vulnerability, based only on natural processes, is of great importance. Moreover, the inclusion of socio-economic variables in a risk –and-vulnerability estimation can transform it into a decision-making tool with more focus on society's actual needs. An advantage of the proposed approach is that it can include data from field surveys as well as vulnerability modelling results. Future work that involves the check of the obtained results by carrying out specific field surveys, is planned in order to improve the method and apply the same methodology to other locations within the project area (Ischia and Aeolian Islands).

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