A semantic approach for modeling vulnerability of communities

Sofia Kostakonti
Dpt. of Informatics and Telecommunications
National and Kapodistrian University of Athens
sofkost@di.uoa.gr

Ramona Velea
Institute of International Sociology Gorizia
velea@isig.it

Vassilis Papataxiarhis
Dpt. of Informatics and Telecommunications
National and Kapodistrian University of Athens
vpap@di.uoa.gr

Daniele Del Bianco
Institute of International Sociology Gorizia
delbianco@isig.it

Uberto Delprato
IES Solutions
u.delprato@i4es.it

Stathes Hadjiefthymiades
Dpt. of Informatics and Telecommunications
National and Kapodistrian University of Athens
shadj@di.uoa.gr

ABSTRACT

In this paper, we propose the use of semantic technologies for the representation of concepts and relationships required for the modeling of vulnerability data for local communities. First, we discuss the theoretical concepts of vulnerability and resilience and we try to identify the relationship between the two. We provide background knowledge and we present basic characteristics of the two concepts. Next, we discuss the motivation behind the use of semantic technologies, and we show how the proposed framework can address existing challenges in terms of vulnerability assessment. The core part of this paper focuses on the semantic representation of community vulnerability aspects. We give an overview of the layered semantic framework consisting of interconnected ontological models and we provide a set of use-cases where the use of semantic-based modeling and query answering can prove beneficial in terms of assessing vulnerability.

Keywords

Community vulnerability, semantic modeling, community resilience, knowledge representation and reasoning.

INTRODUCTION

Vulnerability may be understood as both a concept and a phenomenon. Its high degree of complexity makes it so that currently there is no universally accepted definition of the term. Vulnerability gained an increased interest over the past decades in disaster studies and related disciplines, both in terms of academic research and policy-driven studies (Cutter, 2008). Across disciplines and research frameworks, vulnerability is often linked with related concepts such as risk, hazard, exposure and resilience (Fuchs et al., 2018). In literature vulnerability entails elements referring to exposure, sensitivity and adaptive capacity/coping mechanisms (Fuchs & Thaler, 2018). A further degree of complexity to the definition of vulnerability is given by the potential interactions and relations between its inherent elements, such as the spatial scale of vulnerability (national, regional, local, individual), the temporal scale (before, during or after a disaster) and the sectors of interest (physical, economic, institutional, or social system) (Fuchs & Thaler, 2018).

One ordering element when analyzing vulnerability appears to be the so-called subject of concern, who is vulnerable, or better yet, what is the unit to which the vulnerability analysis applies. Stemming from the literature, vulnerability may be analyzed in terms of place, systems, and social groups. A stream of influential studies has addressed the vulnerability in terms of place (a trend set by Cutter et al., 2000; 2008), meaning by this the vulnerability of a locality. The term place emphasizes in this perspective the geographical notion as well as the physical characteristics. Another perspective in analyzing vulnerability is that of considering the sensitivity of individual and social groups, by focusing on existing societal structures and processes that may determine that different socially defined groups may suffer disproportionally as a result of a hazard (Birkmann 2013).

In this paper, the subject of concern, thus the unit of analysis, will be the community and we assume that the concept of *vulnerability* can be generally defined as "The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards"[1] (UNDRR).

This multitude of perspectives and definitions of the concept led to many attempts of establishing methodological frameworks for its analysis. Assessments and measurements of vulnerability have been done in various ways, from vulnerability curves to vulnerability matrixes, to Geographic Information Systems (GIS) maps. Among all the assessment approaches, the most widespread method for assessing vulnerability has been using indicators. These indicators include (explicitly or implicitly) goals that should be reached in reducing vulnerability (or increasing resilience) to natural hazards (Fuchs et al., 2018). Both quantitative and qualitative methods have been used to elaborate measurements of vulnerability, as well as a mixture of both. What is clear is that there is no agreement upon the right method to measure such a complex phenomenon (Fekete & Montz, 2018).

Various critiques have been voiced at the methodologies of measurement, and these focus mainly on the challenges of using indexes, on problems associated with spatial and context differences and assessment of data at various scales of analysis (Barnett et al., 2008; Fekete & Montz, 2018). Comparisons have been warned against, on the argument that vulnerability is a context-specific rather than a generic condition (Barnett et al., 2008). Also, another critique is focused on the dynamic nature of the vulnerability phenomena, which is in a continuous state of flux (Adger, 2006), which brings limitations to the use of socioeconomic indicators measured at certain points in time to actually predict the vulnerability of assessed communities. Such an approach to the analysis may revel essential elements for quantification of the damage produced by exposure, however, it may result limiting for what concerns the adequate assessment of adaptive capacity elements, such as skills and resources, which may be deployed differently in different contexts.[2]

Usually, most studies derived from the widely-used methodologies devised by Cutter (e.g. Cutter et al., 2003, 2010; Guillard-Gonçalves et al., 2015), provide a spatial assessment and an empirical ranking. So, in brief, a vulnerability score (a numerical value which aggregates all the operations performed through collecting values for indicators, aggregating them, etc), cannot be in itself high or low, but it can be high or low only by reference (distance) to a mean value, therefore, only by reference to other units of analysis, which compose this mean. It is challenging to identify thresholds or benchmarks in vulnerability assessments (Fekete, 2019). Vulnerability, as well as resilience, are relative (Cutter, 2016; Fekete, 2019).

If assessment of vulnerability (or of resilience frameworks) is considered in the perspective of strategy design and setting it is desirable to adopt a participatory approach, in which communities themselves are included in building the indicators and finding the proxies for data collection, as well as in defining their weight and vector. By doing so, the assessment becomes a bottom-up one, and thus becomes meaningful for the end-users, instead of being a top-down approach, with metrics elaborated independently.

Relativity, thus, appears an essential element in the assessment of proxies and indicators (and thus for building

[1] https://www.undrr.org/terminology/vulnerability

[2] Taking the example of a community, flood prone, in which the number of senior citizens (i.e. above 65 years old) is significatively high. Looking at this variable from a merely quantitative approach would be associated with a negative connotation, implying that an ageing population represents an element of vulnerability (Cutter, 2003). However, incorporating qualitative elements that contextualise the implications of the variable at local level could challenge such hypothesis. Senior residents in the community, for instance, may be considered as a resource in terms of adaptive capacity, as they retain knowledge on the territory and the impact of floods, that may guide the community both in preparing to face the hazardous event, as well as in the recovery phase (ISIG, ECOSTRESS, 2015).

indexes) of both vulnerability and resilience. Previous studies focused on relativity mainly within continuous geographical area within which different units of analysis face a similar hazard (Cutter, 2003; ISIG/ECOSTRESS, 2015). This paper proposes, however, a different approach in the assessment of vulnerability and of resilience that maintains the relativity perspective in the sense that, by applying clustering parameters, different profiles of similar communities can be identified. Such clusters or community profiles allow for the application of the relativity perspective, beyond the limits of location, thus allowing communities from different and distant contexts across Europe to assess their vulnerability (and later resilience) against similar communities. The approach to relativity is tested within the Community Vulnerability Analysis, within the limits of the data availability.

The contribution of this paper is twofold: First, we provide a common language (i.e., the semantic framework) that can be used by different communities to represent vulnerability data; this approach minimizes the required human intervention to integrate heterogeneous metrics, concepts and attributes regarding vulnerability. Secondly, we describe a specific use-case where the adoption of semantics proves necessary in order to cluster communities based on vulnerability data and, when data is missing or vulnerability cannot be calculated, identify relative communities that might provide useful and reproducible practices. Providing a methodology to define and assess the vulnerability of a community, will help the local experts identify issues within the area and with the policies in place, and take further action to strengthen the community resilience and lower its vulnerability in face of an emergency. In addition, by using this framework, they have access to all the other areas that have provided information and can compare their vulnerability. The aim of this feature is not to create competition between the various communities, but to promote the value of peer-to-peer cooperative learning process among them.

In the rest of this paper, we describe a semantic modeling approach for representing vulnerability data. We first provide a literature review of vulnerability and we identify the connections between the concepts of vulnerability and resilience. We give the motivation of the work by identifying the challenges that need to be met. Next, we propose a semantic modeling framework for community vulnerability data. Finally, we specify the next steps of this work by focusing on the relative assessment of vulnerability between communities and a couple of use-cases we plan to support.

RELATION BETWEEN VULNERABILITY AND RESILIENCE

Resilience is defined by the United Nations (United Nations) as "the ability to resist, absorb and accommodate to the effects of a hazard, in a timely and efficient manner". Thus, resilient communities are those in which their citizens, environment, businesses, and infrastructures have the capacity to withstand, adapt, and recover in a timely manner from any kind of disaster they face, for which they may be either prepared or not. In recent years efforts have been spent to understand and increase resilience and there is, still, a long way forward in defining an EU valid and sound approach to this issue.

In the literature, vulnerability and resilience are related yet "*remain different approaches to understanding the response provided by systems and actors to natural hazards*" (Fekete & Montz, 2018, p.3). As concepts they are similarly multifarious, and they belong to several paradigms, amenable to multiple definitions, depending on the field and focus of study, also to multiple ways of measuring. "*Resilience refers to the capacities of people, places, and infrastructure to, not only cope with hazards, but also the longer-term adjustment and learning processes to adapt to future threats*" (Fuchs & Thaler, 2018, p.3). Literature also suggests that the factors which determine vulnerability may also contribute, to different extents, to the building of resilience (ECLAC 2011).

For what concerns academic research across different disciplines, the relation between vulnerability and resilience can be broadly divided in two main streams:

- One that sees the concepts in an inverse relation (i.e., vulnerability as the flipside of resilience).
- Another that acknowledges the correlation but it does not envisage it as a simple linear inverse proportionality (Fuchs & Thaler, 2018).

From early on, the disaster research community adopted divergent paths in the study of vulnerability and resilience (Cutter, 2018; Cutter et al., 2008). As vulnerability, put forward especially by the social sciences, examined the susceptibility for harm, especially to people and things they valued, resilience, by contrast, was furthered by the ecological sciences in order to understand "*disturbances in systems and the ability of such systems to absorb "shocks," recover from them, and return back to some steady-state condition*" (Cutter, 2018).

In the context of this paper, both vulnerability and, at a later stage, resilience are analysed from a systemic view that implies that vulnerability and resilience are highly dependent on the context, thus requiring to be analysed within their multidimensional system of references (i.e. ecological, social, economic, political) (Manca et al, 2017). Here, we propose a community perspective, which analyses vulnerability and explores resilience-related considerations within a multidimensional system – i.e. the community.

ANALYSIS OF COMMUNITY VULNERABILITY: THE RESILOC APPROACH

The project Resilient Europe and Societies by Innovating Local Communities (RESILOC) aims to increase the understanding of resilience in local communities and to generate strategic tools empowering local actors to assess concepts such as the vulnerability and the resilience of their communities and identify actions to improve them. In that context, the RESILOC Community Vulnerability Analysis is premised on the fact that understanding the vulnerability of a community is key for designing resilience-enhancing recommendations and strategies in a sustainable manner, both locally and at a global level. Furthermore, given the complexity of the concept, as well as the absence of standard assessment benchmarks and thresholds, the most adequate way to approach vulnerability analysis, and consequently its assessment, is in relative (i.e., comparative) terms.

Understanding vulnerability as a relative concept should consider vulnerability in context, vulnerability in comparison with other similar units of analysis, that is to say neighbouring communities exposed to similar hazards. Within this perspective a community is defined as a 'group of interacting people living in a common location'[3]. In operational terms the community has been defined as a functional one, described by means of 5 interacting dimensions that shape a community (i.e. social, economic, institutional, environmental and human capital) as well as in terms of hazard-related interacting factors (i.e. hazard elements and hazard governance)[4]. For each of the 5 dimensions defining a community, vulnerability indicators and related proxies have been identified (i.e., by means of a literature review) so to allow for depicting the overall vulnerability frameworks of the communities under analysis.

RECVI – RESILOC Community Vulnerability Indexes

In this paper, the analysis of vulnerability is performed as a calculation of vulnerability relative indexes. The participatory design and implementation of the data collection process for the purpose of building those indexes were conducted in five phases and targeted 5 communities in 4 countries[5]. First, vulnerability indicators (27) and proxies (158) were identified through the literature review. For each of the 5 communities, contextualisation interviews and focus groups were organised (with expert respondents from the partnership) in which the list of indicators and proxies was assessed against two variables: relevance for the context at focus and availability of data. This supported the elaboration of community-specific sets of indicators and proxies. Lastly, the statistical data was collected by the local partners according to the determined list of proxies and the RESILOC Community Vulnerability Indexes (RECVI) indexes were built for each community.

By 'indicators' we refer to variables which provide an operational representation of a characteristic of a community (Birkmann 2006). By 'proxy' we refer to an indirect data source contributing to the assessment of an indicator. The RECVIs are built in relative terms (i.e., comparative terms), implying that each unit of analysis (i.e., community) was placed in comparison with its area of reference (i.e., neighbouring territorial/administrative units). Thus, statistical data was collected for both: (i.) pilot areas communities and (ii.) the neighbouring communities. The vulnerability indexes allowed, finally, for depicting a snapshot, a 'static' picture of the communities under analysis, in terms of the 5 dimensions considered as relevant for describing a community and under which the vulnerability indicators and proxies were clustered (i.e., social dimension, economic dimension, human capital dimension, institutional dimension, environmental dimension). Such a snapshot of vulnerability can be upgraded with 'dynamic' elements (e.g. adaptive capacity) as interviews with experts and stakeholders will allow for the upgrading of the Vulnerability Inventory, integrate further local knowledge, ultimately allowing for the identification of resilience enhancing strategies. Hence, the indicators and proxies may be further elaborated with 'dynamic' components by the RESILOC communities. In this sense, the participatory design and of the data collection, under focus, may be considered as a first test towards the further developments envisaged by this work.

Based on the performed analysis, it was shown that data availability represents a limit across EU communities, both in terms of data describing the specific community and of its relative area (i.e., as highlighted by the gap between indicators and proxies considered relevant and actually used ones in the analysis). Although communities in general appreciate the availability of a rich list of indicators and proxies, the availability of open-source data is limited and difficult to collect especially for smaller administrative units. Finally, it was also shown that allowing for flexibility in the selection process of the proxies (i.e. allowing local communities to add proxies under the proposed indicators) has been proven successful.

MOTIVATION

[3] Elaboration from Sharifi (2016) and Project Glossary definition of Community
[4] For facilitating the data collection process, the unit of analysis should ideally correspond to an administrative unit.
[5] Municipalities of Gorizia – IT, Catania – IT, West Achaia – GR, Tetovo – BG, Kamnik – SL

Data availability, especially when talking about small regions and communities, is not always easy to achieve. In that sense, collecting, storing, and making community data available might be problematic. In some cases, even if the data exist, it might be outdated. Sometimes, it might be also conflicting because they are referring to different periods of time. Such limitations make evident the fact that the assessment of vulnerability is not always feasible.

In addition, even if the data is available, vulnerability is difficult to measure and to assess in absolute terms. In the absence of critical benchmarks and thresholds, assessing vulnerability in relative (i.e. comparative) terms appears to be one of the most adequate approaches especially when such analyses are aimed to provide support to policymaking. Previous studies of vulnerability focused mainly on delineating such relative area in a continuous territorial perspective (Cutter & Emrich, 2017; Cutter et al. 2010; Burton et al., 2018). Such continuity, especially when it does not cross over national borders tends to facilitate, first the process of data collection, and even more so, it allows decision makers to relate, most of the times, to familiar contexts (e.g. taking the example of a vulnerability index that puts in relation municipalities across a province of a region). Furthermore, it must be stressed that assessing vulnerability by means of relative indices should not be seen as a contest in between different units administrative-territorial units, but rather it should serve the purpose of stimulating an exchange between peers faced with similar challenges.

The relative character of the indexes implies that there are not absolute thresholds under or above which the vulnerability of a community on a certain dimension is high or low, but that a certain measure gains its degree of significance only in relation to the indexes calculated for similar units of analysis. Operationally, this implied the necessity to perform data collection not only for the units of analysis but also for a certain number of same-level neighbouring cities or municipalities, exposed to the same hazards and of comparable sizes.

The relative area is delineated in previous studies based on territorial continuity. That is to say that the relative area is envisaged as encompassing the unit of analysis, in terms of administrative, territorial and statistical setting (e.g., if the unit of analysis is a municipality, the relative area could be represented by the province or the region within which the municipality is included). Where does the 'interest' perimeter end? In practice, the definition of the relative area is, just like in the case of the unit of analysis, highly dependent on the availability of reliable statistic data.

As a direct consequence, the necessity for a capability of local communities to learn from the experiences of other 'similar' communities becomes apparent. As a proposal to overcome the above limitations, this paper advances a different view on relativity in the analysis of vulnerability (i.e., as a further theoretical elaboration), that stems from the operational definition of community (i.e., unit of analysis itself). Such an approach envisages the identification of 'clustering' parameters that allow for the establishment of community profiles (i.e., what makes communities similar). Once the clusters have been created, the relative area can be constructed between similar communities beyond geography/territorial limits. In that sense, based only on available data, a local community, whenever this is needed, could infer good practices that worked well for communities with similar characteristics and assess its resilience against similar communities.

For what concerns the parameters for clustering communities, similarity can be treated in various ways considering different types of criteria such as geography (e.g., communities within the same geographical limits are considered similar) or degree of urbanization[6]. For instance, communities can be compared against their neighbouring municipalities, either within their geographical area of reference (e.g., province, region, etc.), or one with the other in order to understand their vulnerability to hazards. In the next sections, we describe how such a clustering approach could be facilitated by a semantic framework that would allow the labelling of proxies/indicators as well as their relationships.

A SEMANTIC ARCHITECTURE FOR MODELING THE VULNERABILITY OF LOCAL COMMUNITIES

Data Modeling Approach

Data related to the vulnerability of local communities may originate from different information sources (e.g., official statistical data from local and regional authorities, internet data, dynamic sensor data, social media), it may be of different types (e.g., social data, physical and digital infrastructure, economic data) and may come in a wide range of formats (e.g., numerical data, qualitative data, unstructured data from social media). Such an increased data complexity calls for a well-defined and, at the same time, agile data architecture that will facilitate data management procedures and will serve data needs of the upper-level services and, finally, users (e.g., civil protection agencies, local administrators, and municipality officers). To cover the wide range of needs stemming

[6] EUROSTAT (2018). Methodological Manual on Territorial Typologies. 2018 Edition

from this data heterogeneity, systems usually need to combine heterogeneous modeling approaches for data representation that considers the use of both relational and non-relational data structures.

On top of the data storage, the use of a semantic model allows for establishing connection links between the different types of databases (Figure 1). Semantics can also support automated classification and correlation of data coming from different communities. Specifically, we envisage a multi-layered semantic framework that can be used to semantically describe, integrate and manage heterogeneous community data that will be collected by the system. The main goals of the semantic layer we propose in this paper are to (i) facilitate information integration for data coming from multiple communities based on different locations and with different characteristics, and (ii) improve system intelligence by allowing for the deduction of new knowledge based on semantic reasoning techniques (e.g., identify or cluster relative communities with similar characteristics).

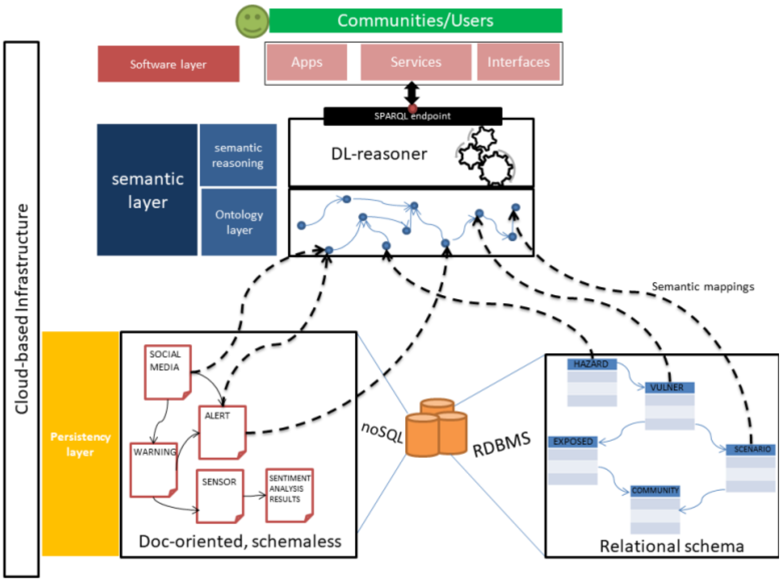


Figure 1. Data storage approach for vulnerability- and resilience-related data

The Semantic Web (SW) is considered as "*a web of data that can be processed directly and indirectly by machines*" (Berners-Lee, Hendler and Lassila, 2001). Practically, it constitutes an extension of the World Wide Web (WWW) in which web resources are supplemented with semantic notations that describe their intended meaning in a formal, machine-understandable way. The Semantic Web (SW) is considered as an integrator across different content, applications and systems connected to the WWW. Ontologies play a key role in SW, providing the machine-interpretable semantic vocabulary and serving as the knowledge representation and exchange vehicle. The Web Ontology Language (OWL) has emerged as the official W3C recommendations for creating and sharing ontologies on the Web (Bechhofer, S., 2009).

The W3C OWL 2 Web Ontology Language (OWL) is a knowledge representation language, designed to formulate, exchange and reason with knowledge about a domain of interest. The fundamental notions of how knowledge is represented in OWL 2 are the following:

- *Axioms*: the basic statements that an OWL ontology expresses
- *Entities*: elements used to refer to real-world objects
- *Expressions*: combinations of entities to form complex descriptions from basic ones

An ontology can be considered a collection of statements, *axioms,* which refer to objects of the world and describe them e.g., by putting them into categories (like “Mary is female”) or saying something about their relation (“John and Mary are married”). All atomic constituents of statements be they objects (John, Mary), categories (female) or relations (married) are called *entities*. In OWL 2, objects are denoted as individuals, categories as classes and relations as properties. Properties are further subdivided. Object properties relate objects to objects, while datatype properties assign data values to objects.

Regarding the modelling features of OWL2, the central feature is *classes*, which essentially represent sets of individuals. They are used to group individuals that have something in common in order to refer to them. A hierarchy to classes is also possible by using the axiom “SubClassOf”. Between two classes A and B, a subclass relationship can be specified, if the phrase "every A is a B" makes sense and is correct. Additionally, OWL provides a mechanism by which two classes are considered to be semantically equivalent, if they contain exactly the same individuals.

An ontology is also meant to specify how the individuals relate to other individuals. The entities describing in which way the individuals are related are called *object properties*. The order in which the individuals are written is important and not interchangeable. In addition, it is possible to infer information about individuals from the relation that connects them through the "Domain" and "Range" axioms, that enable class correspondence and order for a property. Since individuals can also be described by data values, OWL provides another kind of properties for that purpose, the *datatype properties*. Domain and range can also be stated for datatype properties as it is done for object properties. In that case, however, the range will be a datatype instead of a class.

In OWL, general information about a topic is almost always gathered into an ontology that is then used by various applications. Instead of requiring the copying of this information, OWL allows the import of the contents of entire ontologies in other ontologies. Several constructs in OWL can be used to state that different names refer to the same class, property, or individual, so, instead of renaming entities, the names used in an ontology can be tied to the names used in an imported ontology using e.g., the "Equivalent" axiom. (OWL 2 Web Ontology Language Primer)

The notions introduced above are essential to understand the development of the considered ontologies and the relation between the entities they describe. The OWL editor used for this purpose is Protégé (Protege) (Musen, M.A.), a free open-source editing framework developed at Stanford University.

The Vulnerability Ontology Network

The semantic architecture is designed as a network of ontologies organized in three layers: the interoperability, the community and the scenario layer (Figure 2). This structure allows the ontologies of lower layers to be used on combination with those of upper layers to provide a more complete image of the available information. A more detailed description of how the model is integrated into each layer will be given in the following section, as it is used in its entirety or partially in all ontologies of the network.

The approach for the model that was decided during the vulnerability analysis describes 10 main concepts: proxy, indicator, index, community, scenario, hazard, action, macro-action and relevancelevel. A proxy can refer to a specific community (proxyRefersToCommunity), have a relevance level (hasRelevanceLevel) and also be related to an indicator (isProxyRelatedToIndicator) for a certain scenario. Since associations between more than 3 entities cannot be represented using a single relation in RDF, the latter is achieved by including the "isProxyRelatedToIndicator" property in the respective scenario ontology. Furthermore, we also include an additional property "isScenarioRelatedToProxy" that signifies the relation between a scenario and a proxy, as well as "scenarioRelatesToCommunity" to state to what community a scenario refers to. A scenario can also be defined by the type of hazard it covers (hasScenarioType). Then, there is the relation between an action and a macro-action (actionPartOfMacroAction), an action and a specific proxy it affects (actionHasEffectOnProxy) and a macro-action which is taken when a certain scenario occurs or is examined (macroActionForScenario). Finally, an indicator is connected to an index (isIndicatorRelatedToIndex) according to the RECVI.

In terms of the adopted ontological engineering methodology, we have adopted the NeOn methodology (Suárez-Figueroa et al., 2009) which specifies a Scenario-based process for guiding the ontology engineer to define efficiently the requirements and characteristics of the ontology. It supports the reuse/reengineering of knowledge resources by taking into account the existence of existing ontologies in the ontology networks.

Interoperability Layer

The first layer consists of the core upper-level ontology that serves as a semantic model for the representation of the vulnerability data. It is the heart of the semantic approach where the rest of the models are connected. The core ontology provides semantic descriptions, terminology, and relationships for the different types of vulnerability data considered by the system. It consists of classes representing communities, proxies, hazard types as well as interfaces for data found in the community ontologies (index, indicator, scenario, action, macro-action), that enable the querying over the data uniformly and efficiently. Similarly, the classes are connected through several object and data properties (i.e., proxyRelatedToIndicator, hasValue), some of which act as interfaces for the respective ones in the community models. Those models are connected to the core ontology under the CommunityProxy class. The Proxy Class, which contains most of the information regarding the proxies, has several subclasses describing the hierarchy of the dimensions and indicators. On the first level, there are the dimension classes (e.g., Social, Institutional, Human Capital, Economic, Environmental) (*Figure 3*), and on the second level there are the indicator classes which are interfaces for the community indicator subclasses (*Figure*

4). The third level refers to the community models.

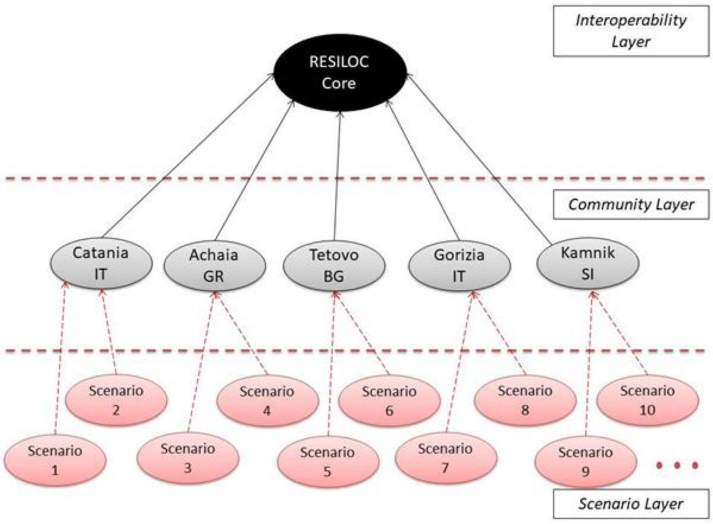


Figure 2. Structure of Vulnerability ontology network

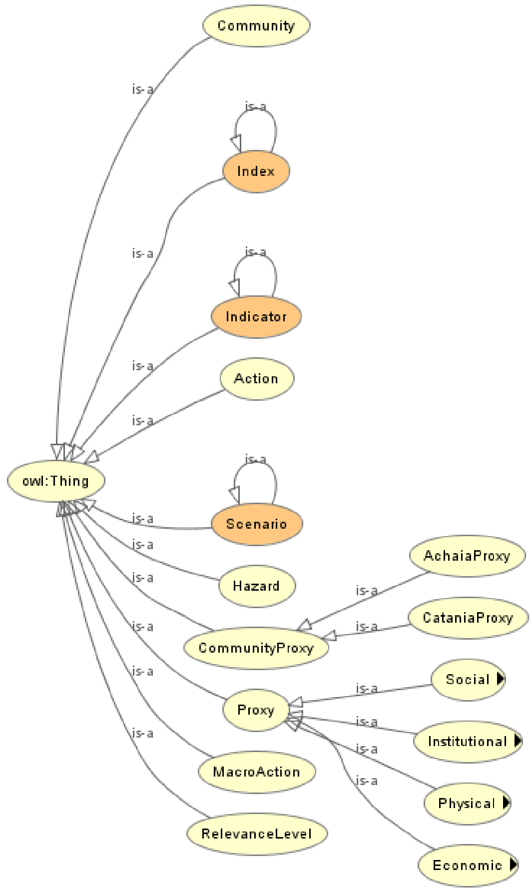


Figure 3. Core Taxonomy

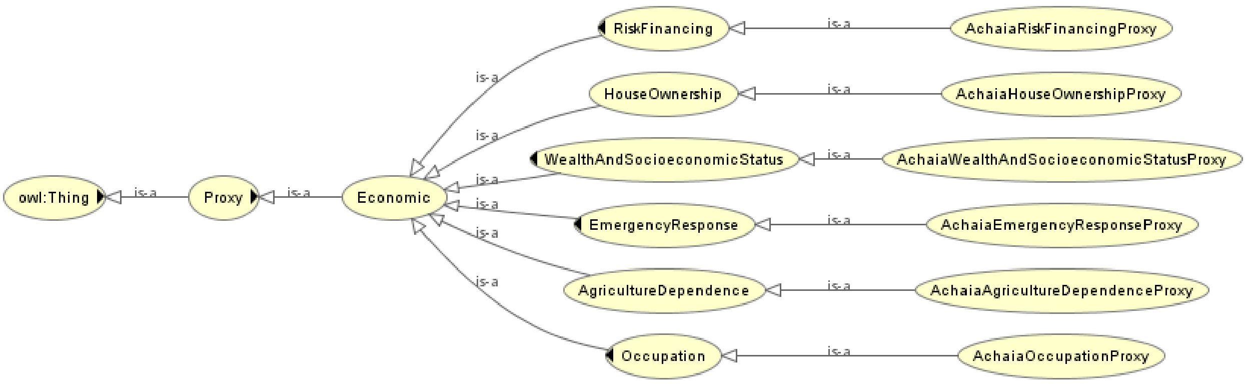


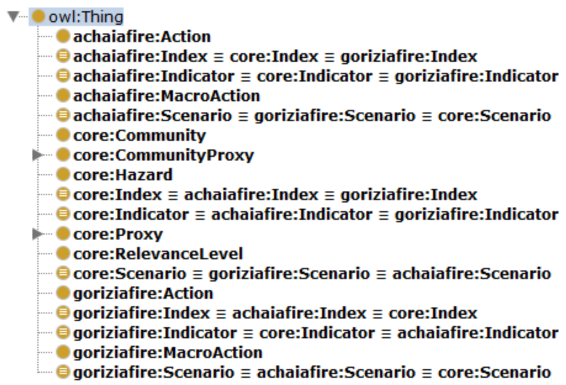
Figure 4. Economic Proxy Example

The core ontology, on its own, is quite concise but it is possible to gather information about all communities and scenarios by importing their corresponding ontologies. Some example ontologies have been added using real data gathered by each community's authorities, and therefore, it currently enumerates 135 classes, of which 41 are not imported, while there are 6 "EquivalentClass" axioms relating to some other imported classes. There are also 151 "SubClass" axioms connecting the imported ontologies to the core one, as well as 13 object properties, 6 data properties and 95 instantiations of classes (individual count) (*Table 1*).

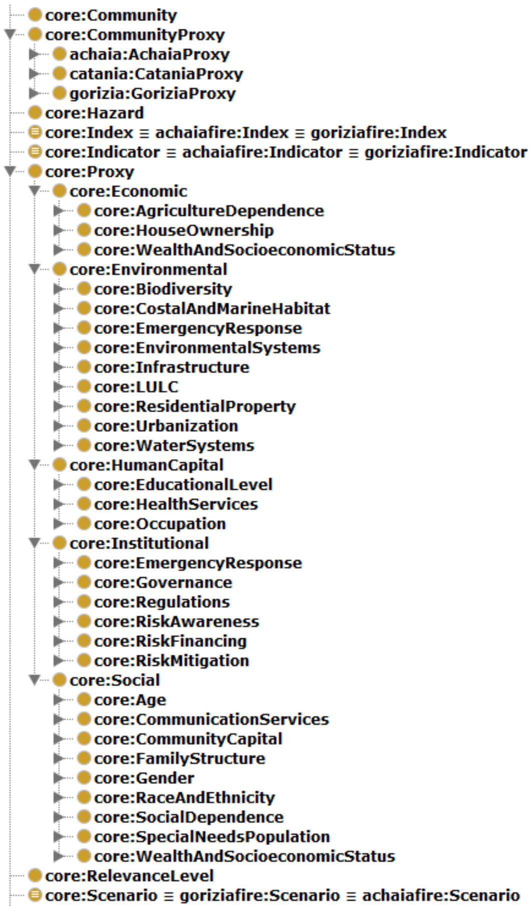
Table 1. Core ontology metrics

Metrics	Total Value	Imported
Class count	135	94
SubClass axioms count	151	35
Object property count	13	5
Object property – Domain axioms count	12	-
Object property – Range axioms count	11	-
Data property count	6	0
Data property – Domain axioms count	6	-
Data property – Range axioms count	2	-
Individual count	95	7
Equivalent classes count	6	-
DL expressivity	ALHF(D)	-

The core elements of the interoperability layer and the core ontology, besides the imported ones, are the following classes: *Community*, *CommunityProxy*, *Hazard*, *Index*, *Indicator*, *Scenario*, *Proxy* and *RelevanceLevel*. Some additional, equally important concepts are represented as subclasses of the *Proxy* class (Figure 5).



(a) All ontologies' hierarchy inside the core ontology



(b) Hierarchy of the main concepts in the core ontology

Figure 5. RESILOC core ontology's hierarchy

Community Layer

Each community is able to specialize the core ontology according to its own procedures, policies and regulations that are followed at community level. For each community, a low-level ontology is specified to cover all the local aspects. Each community will be able to define its own vulnerability data (e.g., proxies) in order to describe a certain vulnerability indicator according to local/regional/national procedures, the availability of data and relevance for the community authorities and actors. For instance, the city of Catania may use the proxy "Human Development Index - HDI" (United Nations Development Programme) to represent the 'Wealth and Socioeconomic status' indicator while the municipality of West Achaia may use the proxy "Human Poverty Index – HPI" to represent the same indicator.

The classes in the community model are similar to the Proxy classes of the interoperability layer. However, there is a third level of actual proxies as individuals of the indicator class they are related to. For example, the proxy "Ratio of Skilled and Unskilled Population" is under the 'Occupation' indicator of the economic dimension and therefore is an individual of that class (*Figure 6*). Multiple proxies can represent one indicator, and multiple indicators can represent one or more dimensions.

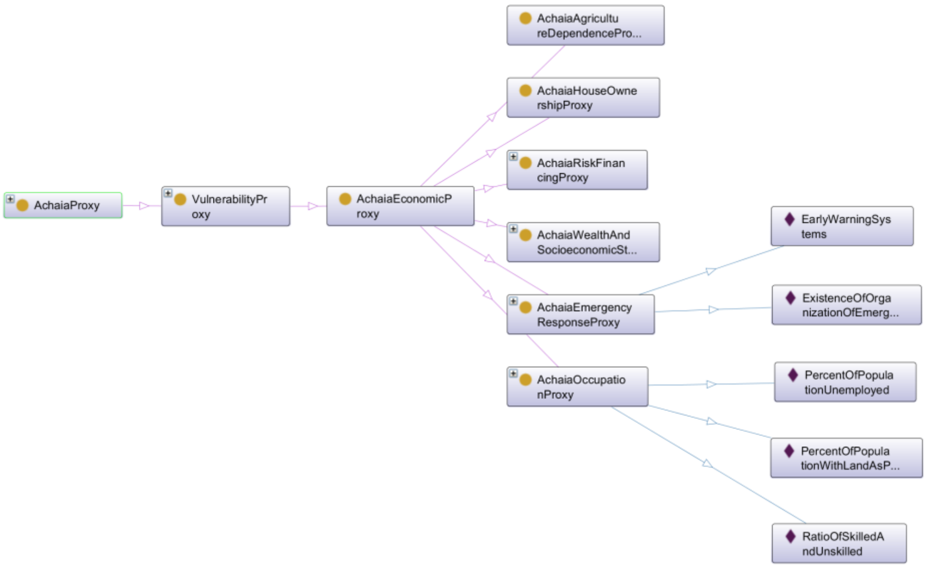


Figure 6. Achaia Economic Proxies as Individuals

A type of ontology imported to the core ontology is the community one. To better understand the model, we present the ontology created for the municipality of West Achaia and use information gathered from the community. It contains information about the proxies of a certain community and their values using 35 classes, 3 data properties and 78 instantiations (*Table 2)*.

Table 2. Community example ontology metrics

Metrics	Value
Class count	35
SubClass axioms count	37
Object property count	0
Object property – Domain axioms count	0
Object property – Range axioms count	0
Data property count	3
Data property – Domain axioms count	3
Data property – Range axioms count	2
Individual count	78
Equivalent classes count	0
DL expressivity	ALF(D)

It is noticeable that there are no object properties used because, within this particular model, there is no need for such relations to be determined.

The main elements found in this level's ontology are classes *AchaiaProxy*, *VulnerabilityProxy*, *AchaiaEconomicProxy*, *AchaiaEnvironmentalProxy*, *AchaiaHumanCapitalProxy*, *AchaiaInstitutionalProxy* and *AchaiaSocialProxy*, as well as several more that can be seen in Figure 7.

Scenario Layer

A set of community-specific scenarios is modelled to represent different incidents where the community vulnerability needs to be evaluated against a certain risk. Each one of these scenarios may describe the semantic parameters of either a real incident or a virtual event that a community may want to respond to. For example, the Achaia community that suffers from coastal forest fire incidents is able to re-use the terminology of the upper layers (i.e., Core ontology and Community Layer) to semantically represent a Fire Incident scenario by defining a set of parameters.

Some of the parameters that can be included in this scenario may refer to the community proxies that are related to this scenario, connections between proxies and indicators or between indicators and dimensions in this specific scenario, actions and macro-actions that need to be taken, the way that proxies are linked with those actions, etc. In particular, the Scenario Layer provides the proper semantic vocabulary to the communities to further specialize the scenarios of interest. It also allows the communities to link proxies with certain actions that may affect them facilitating the monitoring process during a real or a simulated incident.

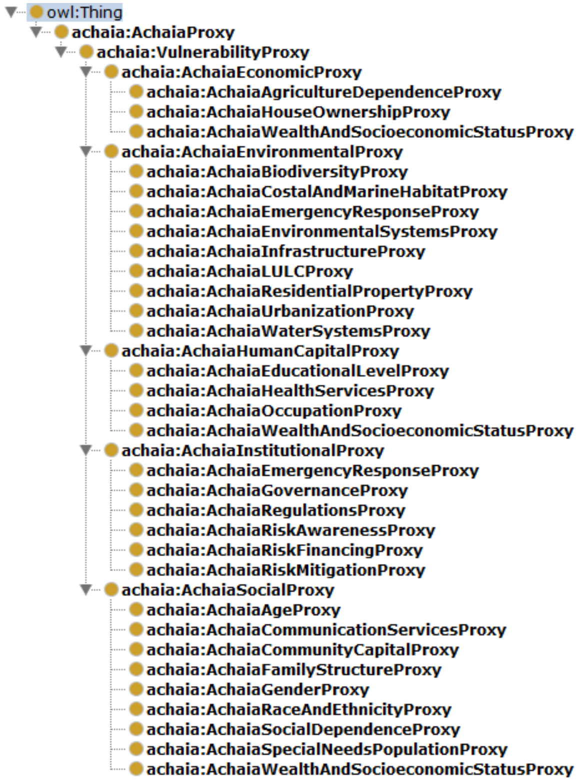


Figure 7. Example of a community ontology's hierarchy

Since, even in the same community, the way indicators, dimensions and proxies are related is more than likely different for each type of hazard, their relationships must be defined for every scenario. Therefore, the classes of indicator, index, action, and macro-action are present and linked through several object properties (Figure 8).

Using the same information obtained by the Municipality of West Achaia, an example showing data in case of a fire, we present the scenario layer's ontology model, containing 5 classes, 6 object properties, 2 data properties and 7 instantiations (*Table 3*). Even though it is not very populated, in combination with the rest of the ontology network, it provides useful tools for the representation of vulnerability in a community during an emergency scenario.

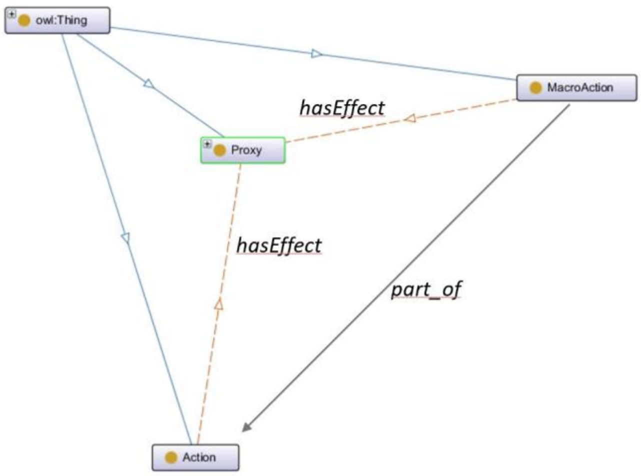


Figure 8. Relationship between Proxies and scenario actions

Table 3. Scenario example ontology metrics

Metrics	Value
Class count	5
SubClass axioms count	0
Object property count	6

Object property – Domain axioms count	4
Object property – Range axioms count	4
Data property count	2
Data property – Domain axioms count	1
Data property – Range axioms count	0
Individual count	7
Equivalent classes count	0
DL expressivity	ALF(D)

The core concepts of this ontology type are the *Action*, *Index*, *Indicator*, *MacroAction* and *Scenario* as seen in *Figure 9*.

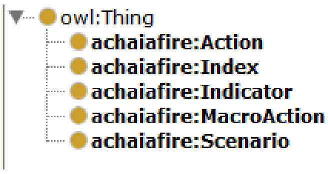


Figure 9. Example of a scenario ontology's hierarchy

All the above middle- and low-level ontologies are aligned with the core ontology to support the semantic integration process. As a result, the core ontology provides the base where a set of community-specific semantic models are mapped to. Finally, a set of semantic reasoning functionalities that the proposed ontology network can address is given in the following table (Table 4).

Table 4. Potential semantic reasoning functionalities

Semantic reasoning scenarios
Get the wealth proxies/indicators for a specific community.
Infer all the social indicators for a specific community.
Infer all the economic proxies for all the communities.
Estimate the value of a combined indicator based on weighted values.
Retrieve all the different proxies that are used for a specific indicator across all the communities.
Expand the physical indicators list with a new type of indicator.
What are the relevant indicators for a particular scenario?
Which indicators and dimensions are affected by a specific proxy?
What are the actions included as part of a specific macro-action?
Given a particular scenario, what are the proxies affecting an indicator?
Calculate an indicator value for a specific scenario based on a given formula.

CONCLUSION AND NEXT STEPS

In this paper, we discussed the relation between the concepts of vulnerability and resilience and we proposed a semantic framework to address the challenge of vulnerability assessment considering (i) the difficulty to assess vulnerability in absolute terms, and (ii) the lack of required data.

As a next step, the proposed framework will be validated with real data provided by 5 local communities that participate in the RESILOC project (i.e., Municipalities of Gorizia – IT, Catania – IT, West Achaia – GR, Tetovo – BG, Kamnik – SL). The ontologies mentioned above have been populated with data already collected from those communities, referring to the vulnerability proxies, indicators and dimensions, and they reflect the availability and heterogeneity of the data given by experts from the local communities. The population of the models is automated through a set of dedicated user interfaces that have been requested by the respective communities considering the existing types, format and structure of the available vulnerability data (i.e., Comma Separated Value files that should be automatically handled by the system).

Building upon the capabilities offered by the semantic layer (e.g., taxonomy of proxies/indicators/dimensions, multi-level integration), we propose the identification of similar communities following a Machine Learning approach based on data clustering (Long, B., Zhang, Z., S. Yu, P., 2010). In particular, we plan to cluster communities based on the values calculated during the vulnerability assessment process. Hence, each community will come with a set of values, one for each vulnerability dimension. As a next step, a data clustering algorithm will be applied to cluster similar communities.

ACKNOWLEDGMENTS

This work has been supported by the RESILOC project. RESILOC has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 833671.

REFERENCES

Adger, W. N. (2000). Social and ecological resilience: Are they related? Progress in Human Geography, 24(3), 347–364. https://doi.org/10.1191/030913200701540465

Adger, W. N. (2006). Vulnerability. Global Environmental Change, 16(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Barnett, J., Lambert, S., & Fry, I. (2008). The Hazards of Indicators: Insights from the Environmental Vulnerability Index. Annals of the Association of American Geographers, 98(1), 102–119. https://doi.org/10.1080/00045600701734315

Bechhofer, S. (2009). OWL: Web ontology language. Encyclopaedia of Database Systems, pp. 2008-2009. Springer US.

Berners-Lee, T., Hendler, J., & Lassila, O. (2001). The semantic web. Scientific American, 284(5), 34-43.

Birkmann, J., Cardona, O. D., Carreño, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., Kienberger, S., Keiler, M., Alexander, D., Zeil, P., & Welle, T. (2013). Framing vulnerability, risk and societal responses: The MOVE framework. Natural Hazards, 67(2), 193–211. https://doi.org/10.1007/s11069-013-0558-5.

Birkmann, Joan. (2006). Indicators and criteria for measuring vulnerability: Theoretical bases and requirements. Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies, 55–77.

Burton, C. G.(2012). The Development of Metrics For Community Resilience to Natural Disasters. (Doctoral dissertation)

Burton, C., Rufat, S., & Tate, E. (2018). Social Vulnerability. In S. Fuchs & T. Thaler (Eds.), Vulnerability and Resilience to Natural Hazards (pp. 53–81). Cambridge University Press; Cambridge Core.

Cutter, S. L. (1996). Vulnerability to environmental hazards. Progress in Human Geography, 20(4), 529–539. https://doi.org/10.1177/030913259602000407

Cutter, S. L. (2008). A Place-Based Model for Understanding Community Resilience to Natural Disasters. Global Environmental Change, 18(4), 598-606.

Cutter, S. L. (2016). Resilience to What? Resilience for Whom? The Geographical Journal, 182(2), 110–113. https://doi.org/10.1111/geoj.12174

Cutter, S. L. (2018). Linkages between Vulnerability and Resilience. In S. Fuchs & T. Thaler (Eds.), Vulnerability and Resilience to Natural Hazards (pp. 257–270). Cambridge University Press; Cambridge Core. https://www.cambridge.org/core/books/vulnerability-and-resilience-to-natural-hazards/linkages-between-vulnerability-and-resilience/E2DE832A4442FDA7375024C17163B5B4

Cutter, S. L., & Emrich, C. T. (2017). Social Vulnerability Index (SoVI®): Methodology and Limitations. Retrieved from https://data. femadata. com.

Cutter, S. L., Ash, K. D., & Emrich, C. T. (2014). The geographies of community disaster resilience. Global Environmental Change, 29, 65–77. https://doi.org/10.1016/j.gloenvcha.2014.08.005

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global Environmental Change, 18(4), 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social Vulnerability to Environmental Hazards*. Social Science Quarterly, 84(2), 242–261. https://doi.org/10.1111/1540-6237.8402002

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster Resilience Indicators for Benchmarking Baseline Conditions. Journal of Homeland Security and Emergency Management, 7(1). https://doi.org/10.2202/1547-7355.1732

Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina. Annals of the Association of American Geographers, 90(4), 713–737. https://doi.org/10.1111/0004-5608.00219

Disaster Risk and Resilience. UN.org. https://www.un.org/en/development/desa/policy/untaskteam_undf/thinkpieces/3_disaster_risk_resilience.pdf

ECLAC (2011), Study on the vulnerability and resilience of Caribbean Small Island Developing States (SIDS), available online at http://www.cepal.org/publicaciones/xml/4/45364/LCARL.354.pdf (accessed Feb. 12, 2021).

ECOSTRESS Project, (2015). Relative Social Vulnerability Index and SWOT Analysis of Coastal Case Studies in the Upper Adriatic, performed by ISIG within the Project ECOSTRESS (Ecological COastal Strategies and Tools for Resilient European SocietieS) (2013-2015); project co-financed by the European Union ECHO/SUB/2013/671461

Fekete, A., & Montz, B. (2018). Vulnerability. In S. Fuchs & T. Thaler (Eds.), Vulnerability and Resilience to Natural Hazards (pp. 14–31). Cambridge University Press; Cambridge Core. https://www.cambridge.org/core/books/vulnerability-and-resilience-to-natural-hazards/vulnerability/4252FD6BFDE7FC319EFD8554AB9852B6

Fekete, A. (2019). Social Vulnerability (Re-)Assessment in Context to Natural Hazards: Review of the Usefulness of the Spatial Indicator Approach and Investigations of Validation Demands. International Journal of Disaster Risk Science, 10(2), 220–232. https://doi.org/10.1007/s13753-019-0213-1

Fuchs, S., & Thaler, T. (Eds.). (2018). Vulnerability and resilience to natural hazards. Cambridge University Press.

Fuchs, S., Frazier, T., & Siebeneck, L. (2018). Physical Vunerability. In S. T. Fuchs, Vulnerability and Resilience to Natural Hazards (pp. 32-52). Cambridge: Cambridge University Press.

Guillard-Gonçalves, C., & Zêzere, J. L. (2018). Combining Social Vulnerability and Physical Vulnerability to Analyse Landslide Risk at the Municipal Scale. Geosciences, 8(8), 294, 1-17.

Human Development Index (HDI). United Nations Development Programme. hdr.undp.org. http://hdr.undp.org/en/content/human-development-index-hdi (accessed Feb. 12, 2021).

Long, B., Zhang, Z., S. Yu, P. (2010) Relational Data Clustering: Models, Algorithms and Applications, CRC Press

Manca, Benczur and Giovannini, (2017). Building a scientific narrative towards a more resilient EU society, Part 1: a conceptual framework, JRC Science for Policy Report, Luxembourg: Publications Office of the European Union, EUR 28548 EN, doi:10.2760/635528

Musen, M.A., The Protégé project: A look back and a look forward. AI Matters. Association of Computing Machinery Specific Interest Group in Artificial Intelligence, 1(4), June 2015. DOI: 10.1145/2557001.25757003.

OWL 2 Web Ontology Language Primer (Second Edition). w3.org. https://www.w3.org/TR/owl2-primer/. (accessed Feb. 19, 2021)

Protégé. http://protege.stanford.edu. (accessed Feb. 19, 2021)

Resilient Europe and Societies by Innovating Local Communities – The RESILOC project. https://www.resilocproject.eu/ (accessed Feb. 12, 2021).

Sharifi, A. (2016). A critical review of selected tools for assessing community resilience. Ecological Indicators, 69, 629–647. https://doi.org/10.1016/j.ecolind.2016.05.023

SPIN: SPARQL Inferencing Notation. https://spinrdf.org/ (accessed Feb. 12, 2021).

Suárez-Figueroa, M., Gómez-Pérez, A. and Villazón-Terrazas, B. (2009). "How to write and use the Ontology Requirements Specification Document. On the move to meaningful internet systems: OTM 2009. Part of the Lecture Notes in Computer Science book series," 2009.

UNDRR, Making Cities Resilient platform: https://www.unisdr.org/campaign/resilientcities/cities/slovenia/kamnik/kamnik

W3C OWL 2 Web Ontology Language Document Overview (Second edition). W3.org. https://www.w3.org/TR/owl2-overview/ (accessed Feb. 12, 2021).