A semantic approach for modeling community vulnerability data

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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. Across disciplines and research frameworks, vulnerability is often linked with related concepts such as risk, hazard, exposure and resilience. Moreover, 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).

Motivation

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 In some cases, even if the data exist, it might be outdated.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. 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.

Vulnerability in RESILOC

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'. 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). 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.

Semantic Architecture

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 semantic architecture is designed as a network of ontologies organizes in three layers.

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. 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.

Community Layer
Each community can 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.

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. 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.

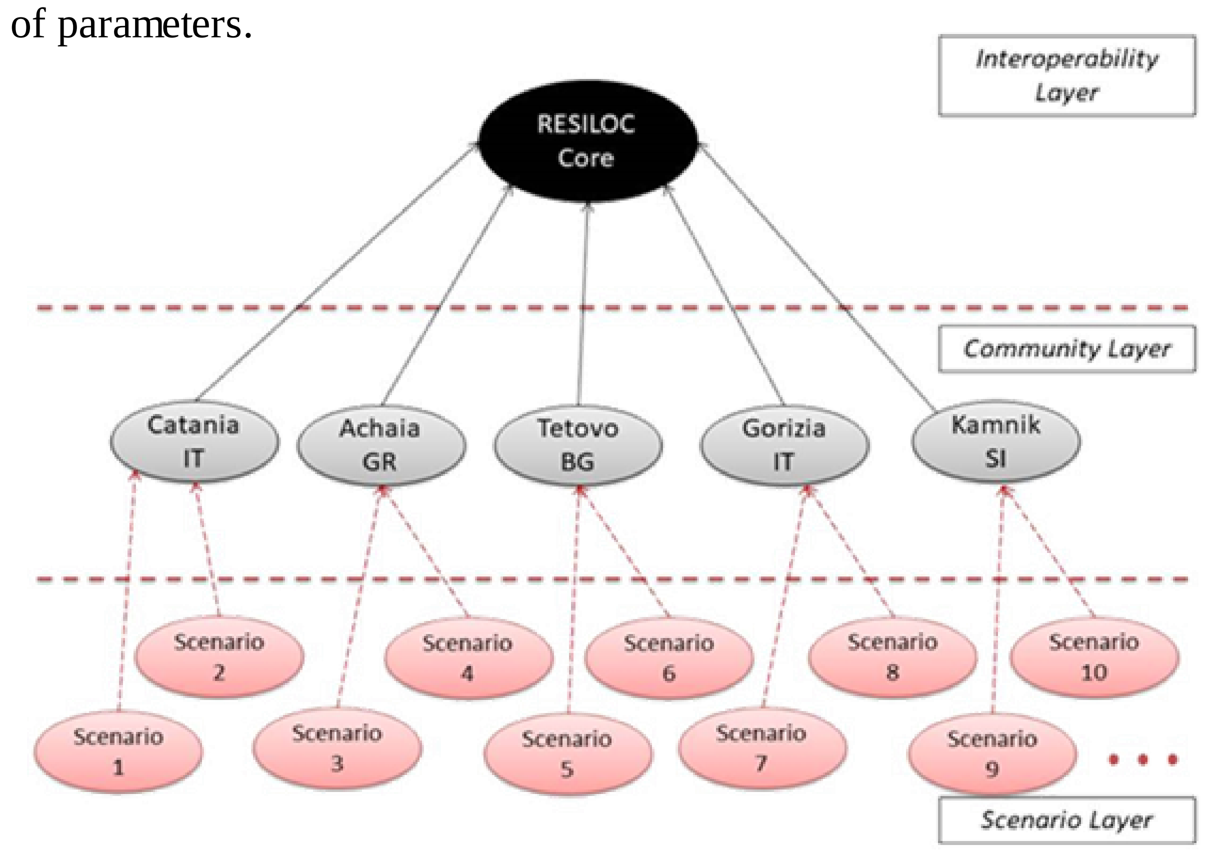

Figure 1. RESILOC Vulnerability Ontology Network.

Table 1. Core ontology metrics.

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

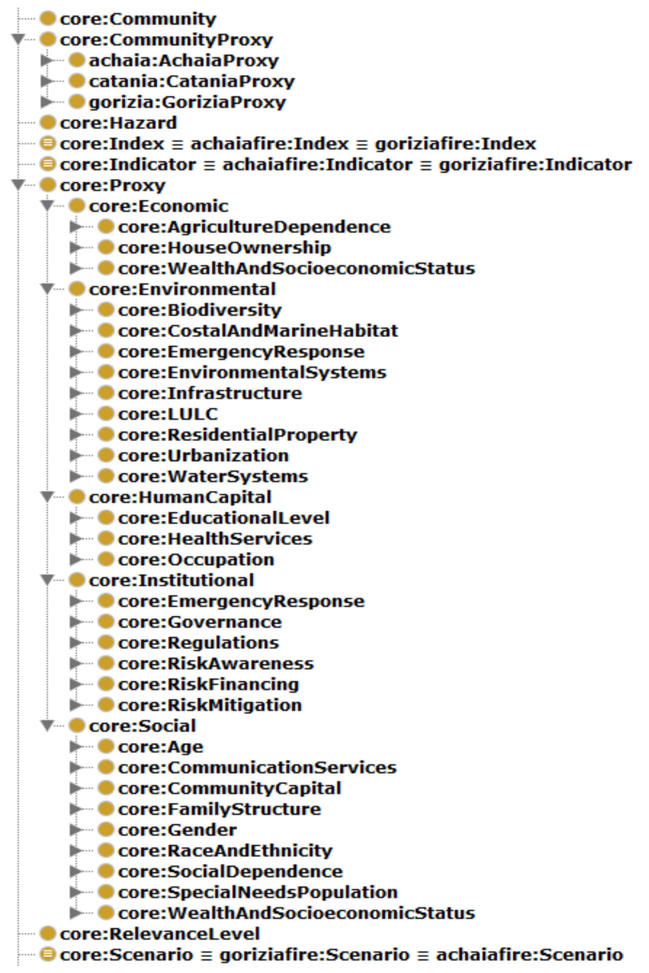

Figure 2. Core ontology hierarchy.

Conclusions

In this paper, 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, 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. 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. Given a specific community, a similarity metric is applied to find the most relevant communities. This would also allow us, given a specific community, to identify the community that is most similar to the first one even if some data is missing (e.g., by considering the available dimensions in the distance function).

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