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**Definition of a methodology for ranking vulnerability of cultural heritage**

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Authors: Riccardo Cacciotti, Miloš Drdácký.
With the contribution of all partners

# CONTENTS

# 1. Introduction

This deliverable investigates vulnerability evaluation of selected cultural heritage categories exposed to extreme events linked to climate change.

The document is structured as follows: section 2 presents the methodology and the conceptual model proposed for vulnerability assessment; section 3 outlines the requirements and criteria for determining the vulnerability of cultural landscapes, ruined hamlets and parks and gardens. Section 4 presents the most relevant vulnerability indicators that enable assessing vulnerability to flash flood, landslide, wind storm and fire for the selected cultural heritage typologies. Finally section 5, provides indications on how to evaluate the indicators and aggregate them into a vulnerability index, needed for vulnerability ranking.

The Annex provides simplified guidelines for evaluating the physical vulnerability of cultural heritage assets; these will be employed in the STRENCH project as a preliminary attempt to determine the vulnerability of the investigated case studies.

# 2. Methodology

Understanding vulnerability constitutes a necessary step towards risk reduction and the pursuing of disaster resilience [1]. Since vulnerability is a multi-dimensional, dynamic, scale-dependent and site-specific variable, different methods can be adopted for its assessment. It is possible to distinguish between empirical and analytical methods (Table 1). The former category individuates those methods based on the analysis of observed damage, expert opinion and score assignment. Starting from the investigation of occurred damages, vulnerability can be directly related to different hazard intensities. In addition, grounded on expert opinions vulnerability can be related to particular scenarios i.e. hazard intensities and system characteristics (e.g. type of constructions, social groups, household income etc.). The potential damage in relation to hazard can be evaluated by assigning scores to different parameters characterizing vulnerability. On the other hand, analytical methods involve the study of the characteristics of a system employing engineering design criteria analysis and other complex methods such as computer simulations and laboratory testing. These methods are time consuming and expensive, as detailed data is required. For this reason, analytical evaluation is usually intended for the analysis of individual components of a system (e.g. single structures) [2].

| *Group* | *Description* | *Method* |
|---|---|---|
| **Empirical** | Based on observation and experience. | Vulnerability matrix, curves and indicators |
| | For events that are relatively frequent and widespread. | |
| | In many situations expert opinion will be the most feasible option for obtaining vulnerability information, either because there is no prior damage information or enough funding to apply analytical methods. | |
| | This method involves the consultation of a group of experts on vulnerability to give their opinion e.g. on the percentage damage they expect for the different structural types with different intensities of hazard. | |
| **Analytical** | Based on engineering design criteria. | Physical models, computer simulations |
| | Information on the intensity of the hazard should be more detailed. | |
| | Resource demanding (time and money) but allow for a better understanding of the relation between hazard intensity and degree of damage for an exposed structure with definite characteristics. | |
| | Due to data/resources requirement, they can only be used for assessment of individual structures. | |

Table 1. Vulnerability assessment methods.

The variety of evaluation methodologies and the heterogeneity of definitions of vulnerability have been highlighted and demonstrated in several publications [3, 4]. Considering the physical

dimension, the most commonly used assessment methods are represented by vulnerability matrices, vulnerability curves and vulnerability indicators [5].
Vulnerability matrices represent a qualitative method for vulnerability assessment, based on empirical data or expert judgment. These are not always stand-alone but guide to more detailed vulnerability assessment approaches. They contribute to the understanding of the interaction between the process and the elements at risk. For example, the relation between hazard intensity and degree of damage can be presented in a vulnerability table or matrix, especially when the hazard intensity has no intermediate values (e.g. the Modified Mercalli Intensity for earthquake hazard). Vulnerability matrices make the relationship between process and consequence clear and easy to understand by non-experts. Information regarding financial value, costs of damage and also exact intensity is not required for the development of matrices. The subjectivity of this method, however, is very high. The description of damage level as high, medium or insignificant may differ among experts. Therefore, transferability and comparison among assessments are often limited.
Vulnerability curves are the most common method for assessing physical vulnerability [4]. Vulnerability functions (or curves) are used for assessing physical vulnerability in a quantitative way. Tarbotton et al. [6] define empirical vulnerability functions as "a continuous curve associating the intensity of the hazard (X-axis) to the damage response of a building (Y-axis)". Vulnerability functions, in fact, represent the interactions between the damaging event and the elements at risk through curves expressing the possible resistance of the elements to an impact. Require less detailed data. They provide a quantitative representation of physical vulnerability. However, curves do not provide information about the building characteristics and consequently the building type, structural features, location orientation. Furthermore, they require information on the intensity of the process on each building. Reliability depends on the quality and the quantity of the available empirical data. A significant source of uncertainty in the development of vulnerability curves derives from curve fitting.

The method of vulnerability indicators includes the selection of relevant variables, their weighting and finally, their aggregation in a vulnerability index. Indicator-based methodologies are not based on empirical data and for this reason they can be implemented in locations with no event record. Although the required data are of high resolution and detail they do not require experts for their collection. The assignment of a vulnerability index to buildings makes the prioritisation of resources easier for the decision makers. Building characteristics are taken into consideration and for the case that also empirical data on damages are available, the interaction of the process with different building characteristics can be investigated and empirical weighting may be possible. Use of vulnerability indicators may bear uncertainties, referring to their selection, standardisation, weighting and aggregation, as well as the availability of required data as the main challenges. Studies using indicators is neglecting the intensity of the process. Data required are too detailed (per building) and may be collected only after time-consuming field work.

The vulnerability index methodology is here exploited in order to establish a conceptual model supporting the ranking of vulnerability for selected cultural heritage typologies.

## 2.1. Conceptual framework for vulnerability assessment

STRENCH focuses on the investigation of risk reduction strategies for cultural landscapes, ruined hamlets and parks and gardens in relation to selected hazards such as flash flood, landslides, wind storms and fires. One of the primary aims is to provide a methodology for ranking vulnerabilities for the investigated cultural heritage assets and disaster scenarios. In order to achieve this, it is required to establish a solid conceptual framework for the determination of those variables which are fundamental in the identification and ranking of vulnerability and, consequently, in the prioritization of resources. For this purpose, the Multi- Criteria Decision Making (MCDM) tool named MIVES is here employed.

The MIVES method (Metodo Integrado de Valor para una Evaluacion Sostenible, in English: Integrated Value Model for Sustainability Assessment) involves the following elements [7]: (a) a specific holistic discriminatory tree of requirements; (b) the assignation of weights for each requirement, criteria and indicator; (c) the value function concept to obtain particular and global indexes; and (d) seminars with experts using Analytic Hierarchy Process (AHP) to define the aforementioned parts. The assessment using the MIVES method should be carried out following these steps: (S1) define the problem to be solved and the decisions to be made; (S2) produce a basic diagram of the decision model, establishing all those aspects that will be part of a requirements tree that may include qualitative and quantitative variables; (S3) establish the value functions to convert the qualitative and quantitative variables into a set of variables with the same units and scales; (S4) define the importance or relative weight of each of the aspects to be taken into account in the assessment; (S5) define the various design alternatives that could be considered to solve the previously identified problem; (S6) evaluate and assess those alternatives by using the previously created model; and (S7) make the right decisions and choose the most appropriate alternative. This whole procedure describes the necessary activities for the determination of the vulnerability index using indicators. For the sake of establishing the conceptual model necessary for the ranking of vulnerability, the focus is put particularly on the second step of the method, i.e. the establishment of the requirement tree.

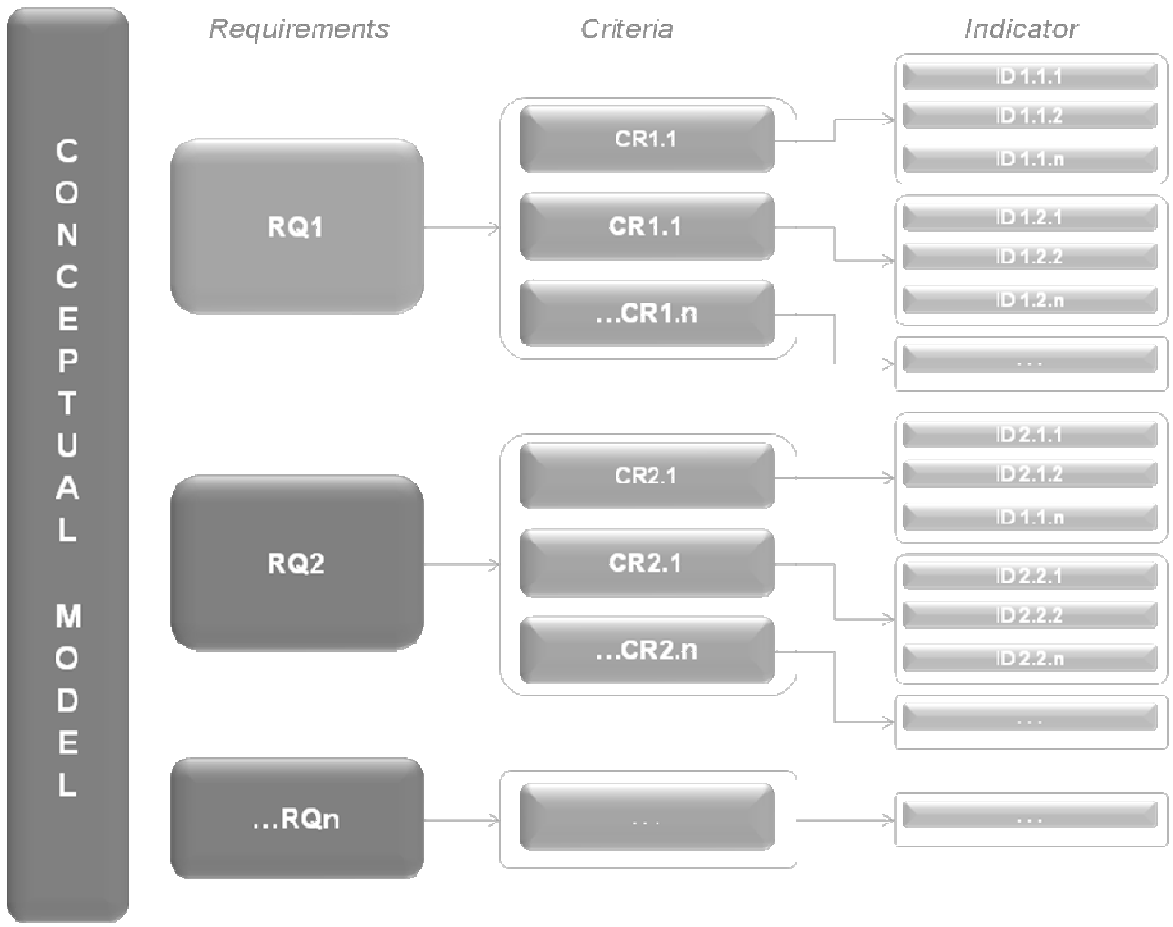



Fig. 1. Conceptual model for vulnerability ranking.

| *Element* | *Description* | *Examples* |
|---|---|---|
| **Requirement** | It defines the first level of the decision-making tree. | Dimensions of the problem: e.g. economic, environmental, social. |
| **Criterion** | It organises the second hierarchical level, providing the structure for the analysis of each alternative. | General and qualitative aspects: e.g. emissions, conservation state, funding availability. |
| **Indicator** | It identifies concrete variables which can be aggregated to assess the problem. | Measurable variables: building costs, year of construction, presence of crop. |

Table 2. Identification of the elements composing the conceptual model.

The requirements tree (Fig.1) is a hierarchical diagram in which the various characteristics of the processes to be evaluated are defined in an organized manner. It features three different levels: requirements, criteria and indicators. In the first levels, namely the requirements and criteria, general and qualitative aspects are defined. Requirements indicate "something that you must do, or something you need" [8] while criteria represent "a standard on which a judgment or decision may be based" [9]. Requirements and criteria are defined in order to permit (1) having a global view of the problem, (2) organizing the ideas and (3) facilitating the comprehension of the model to any stakeholder involved in the decision process. In the last level of the requirement tree, the indicators, concrete and measurable aspects are considered. Requirements, criteria and indicators have the objective of representing what we want to evaluate, avoiding the repetition of certain aspects or avoiding the use aspects which are out of scope. Indicators selected should therefore be representative, differentiating, complementary, relative, quantifiable and traceable. The tree must have a minimum number of indicators, which must be representative and independent of each other, to ensure that, together with the assigned weights, it offers a reliable assessment scenario. The next section discusses each of the levels for the evaluation and ranking of vulnerability for cultural heritage assets.

# 3. Requirements and criteria for determining vulnerability of cultural landscapes, ruined hamlets and parks and gardens

The first step towards the establishment of the requirement tree is the definition of the problem to be solved and the decisions to be made. As previously mentioned, vulnerability is a complex concept characterized by context specificity, multi-dimensionality and multi-disciplinarity. Birkmann [10] highlights in fact that although the aim is to measure vulnerability, there still exists a lack of its precise definition. Thywissen [11] lists 22 definitions of risk and 36 definitions of vulnerability to natural disasters, which emerged between 1983 and 2005. Such abundance of definitions derives from the fact that vulnerability is commonly conceived as a function of a specific purpose and it is dependent upon the nature of the decision that must be made or objectives [12]. Vulnerability is constructed rather than innate and it usually implies something about the relationship between the subject and the object as well as the relevant characteristics of either or both the object and the subject of the argument. For example, vulnerability might refer to the loss or damage to property, to crop failure, to the coping ability of a system or to household impoverishment. Furthermore, vulnerability is multidimensional as it can be characterised by parameters that capture different facets or dimensions of susceptibility (e.g. physical, social, economic, environmental, and institutional). Furthermore, additionally to social, physical and economic vulnerabilities are the organizational, cultural, systemic, territorial and institutional vulnerabilities [13]. Another facet is the functional vulnerability, which characterises the potential

damage that activities and functions may suffer. It depends on the damage caused on goods, persons and secondary functions as well as the capacity the society can restore the activity [14]. Lastly vulnerability is scale-dependent (for example a system considered invulnerable, say a city, may include vulnerable sub-systems, such as specific buildings) and dynamic (vulnerability varies with seasonal changes and time as well as a function of event history).
Risk is commonly intended a combination of probability and consequences [15]. The main task of decision makers and managers is to determine how bad the consequences can be under particular scenarios. It is actually shown that not merely the magnitude of the event but rather the conditions within systems strongly determine whether these are likely to suffer major harm, loss or damage [16]. Such conditions of the system are identified by its vulnerability. In the context of disasters, vulnerability has been defined as the degree to which a system, or part of a system, may react adversely during the occurrence of a hazardous event [17]. As far as the physical vulnerability is concerned, vulnerability represents the degree of loss to a given element, or set of elements, within the area affected by a hazard [5].
Vulnerability, in practical terms, can be interpreted as the combination of three main factors of a system: 1) susceptibility, 2) exposure and 3) resilience (Fig.2) [18]. These represent the main elements that need to be characterised in order to provide an evaluation of vulnerability. Hence, it is possible to identify the three factors constituting vulnerability as the main requirements for the hierarchy tree.

Fig. 2. Definition of the problem.

It should be underlined that, in the context of the proposed model, the following assumptions apply: mainly physical vulnerability is considered, thus the susceptibility criteria selected mostly focus on that dimension; although social, economic and infrastructure exposures are mentioned in order to account for their significant contribution to vulnerability evaluation, the role of cultural exposure is evidenced in the model so to reflect the main aim of the project.

## 3.1. Susceptibility criteria

Susceptibility or sensitiveness identifies the fragility, deficiency or predisposition of a system to be adversely affected by the occurrence of an event. In other words, the susceptibility requirement defines the degree to which a cultural heritage asset is affected by an event.

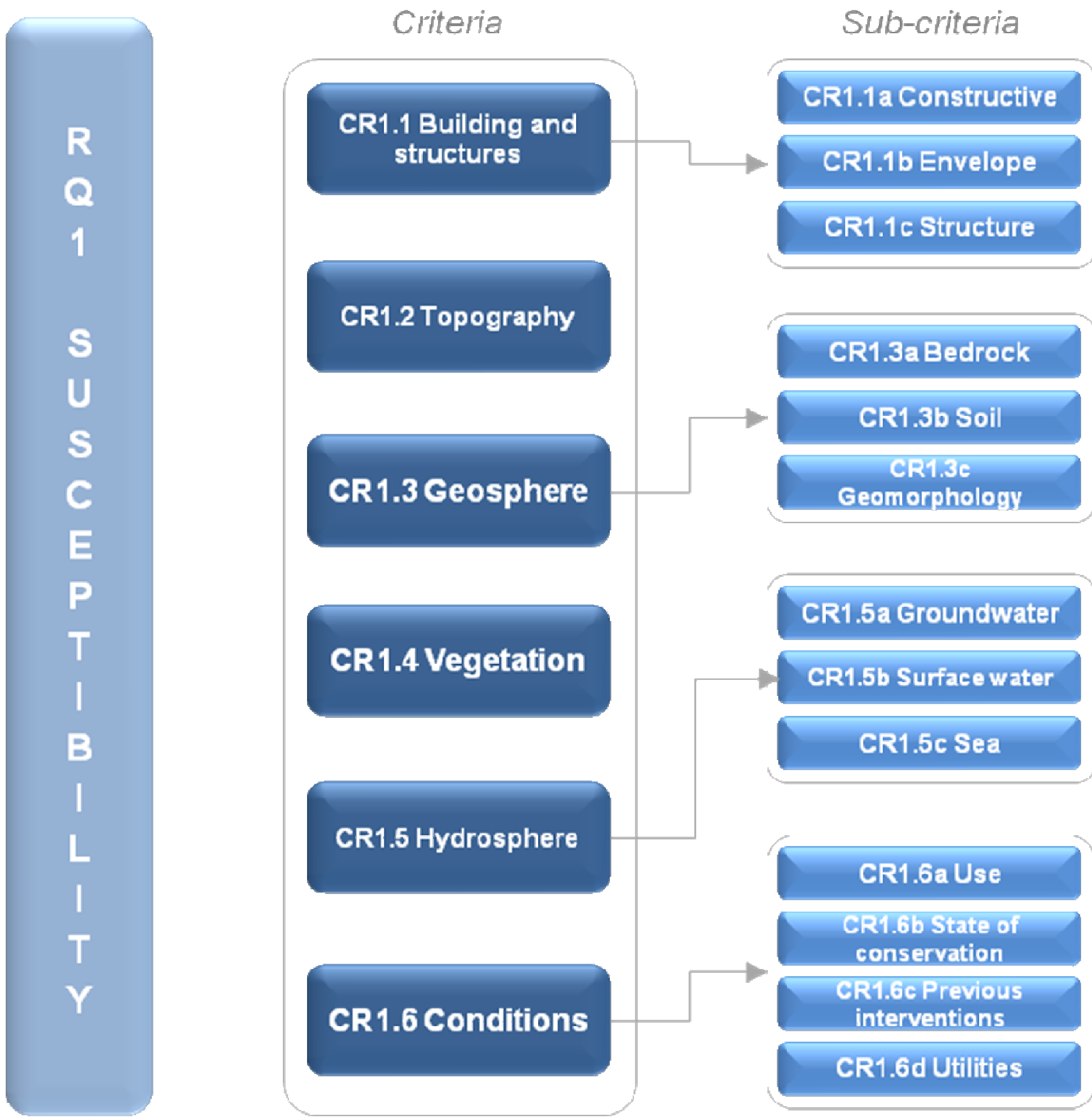



Fig.3. Susceptibility criteria (and sub-criteria).

The susceptibility of a cultural heritage system (e.g. cultural landscapes, ruined hamlets, parks and gardens) to climate change induced hazards can be analysed taking into consideration the following criteria (Fig.3):

- CR1.1) Building and structures present on-site. Buildings are the elements of a landscape primarily built for sheltering any form of human activities, and structures are the functional elements constructed for other purposes. Engineering systems are also structures. These features include houses, barns, stables, schools, churches, factories, bridges, windmills, gazebos, silos, dams, power lines, culverts, retaining walls, dikes, and foundations. Depending on the conditions, typology and characteristics of the structure considered, its response to climate impact varies. Criteria related to this requirement are therefore associated to the following sub-criteria:
    - constructive properties (e.g. material, age, dimensions),
    - envelope characteristics (e.g. presence of openings, roof type),
    - structural aspects (e.g. components typology, bearing structure typology).

- CR1.2) Topography of the site, which identifies the three-dimensional configuration of the landscape surface characterized by features, orientation, and elevation (e.g. altitude, slope characteristics etc).

- CR1.3) Characterisation of the geosphere, including:
    - geomorphologic characteristics of the site (formations, geological properties etc.),
    - soil and bedrock properties (e.g. presence of rock or clay soil).
- CR1.4) Vegetation characteristics (type of vegetation, age, susceptibility to biotic and abiotic agents).

- CR1.5) Characterisation of the hydrosphere, including the evaluation of data related to:
    - ground
    - or surface water,
    - sea.

- CR 1.6) Conditions of the cultural heritage asset. Under this criterion, the investigation focuses on aspects related to:
    - use,
    - state of conservation (e.g. presence of damage),
    - previous interventions or modification
    - and utilities (e.g. location of electricity or heating controls).

## 3.2. Exposure criteria

Exposure refers to the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by the occurrence of a disaster [19].

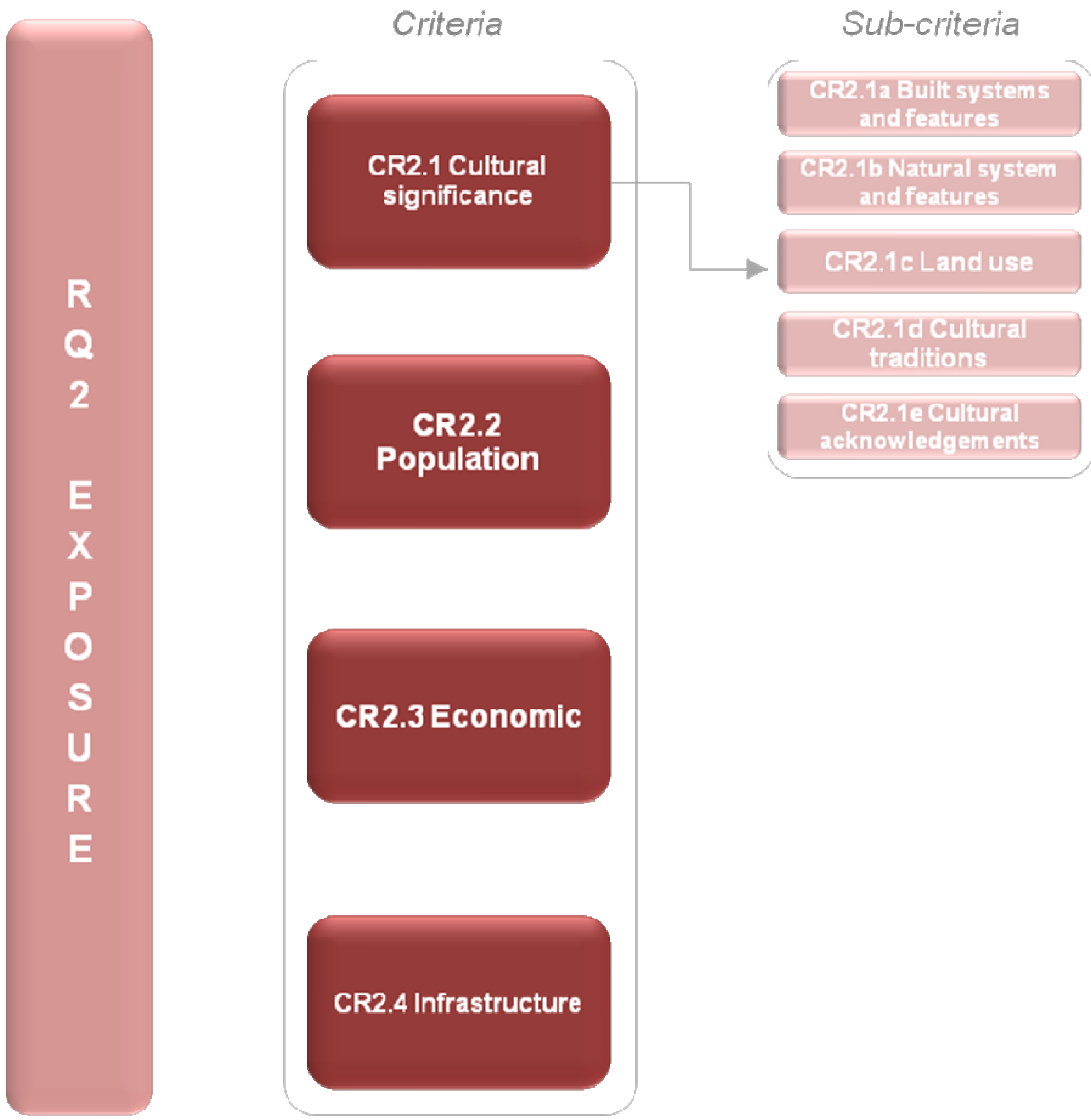



Fig.4. Exposure criteria (and sub-criteria).

The exposure of cultural heritage assets can be evaluated taking into account a number of different criteria. The ones featured in the proposed model focus in particular on the cultural significance of the asset, however still considering the social and economic dimensions which are also fundamental in the vulnerability assessment of cultural heritage properties (Fig.4). The criteria proposed for the conceptual vulnerability assessment model include the following:

- CR2.1) Cultural significance. It involves the characterisation of:
    - built systems and features (small-scale features such as benches, fences, monuments, road markers, flagpoles, signs, foot bridges, curbstones, trail ruts, culverts, and foundations),
    - natural systems and features (processes and materials in nature that have influenced historical modification or use of the land. This can include human response to geomorphology, geology, hydrology, ecology, climate, and native vegetation. It includes views and vistas such as a lookout structure or a view framed by vegetation),
    - land use (activities in the landscape that have formed, modified, shaped, or organized the landscape as a result of human interaction. Examples of land use features include fields, pastures, orchards, open range, terraces, commons, cemeteries, playing fields, parks, mining areas, quarries, and logging areas),
    - cultural traditions (these indicate practices that have influenced the development of a landscape in terms of land use, patterns of land division, building forms, stylistic preferences, and the use of materials),
    - cultural acknowledgments (e.g. protection status of the site).

- CR2.2) Population (e.g. livelihoods, density, demographic properties).

- CR2.3) Economic (e.g. real estate value, commercial value, income production)

- CR2.4) Infrastructure (e.g. presence of relevant communication or transport network on site).

### 3.3. Resilience criteria

Resilience identifies the ability of a system to absorb changes without a transition to a different state [20]. It constitutes a fundamental aspect of vulnerability which contributes to its reduction. It is represented by those elements of a cultural heritage system characterising its coping, adapting and restoring ability.

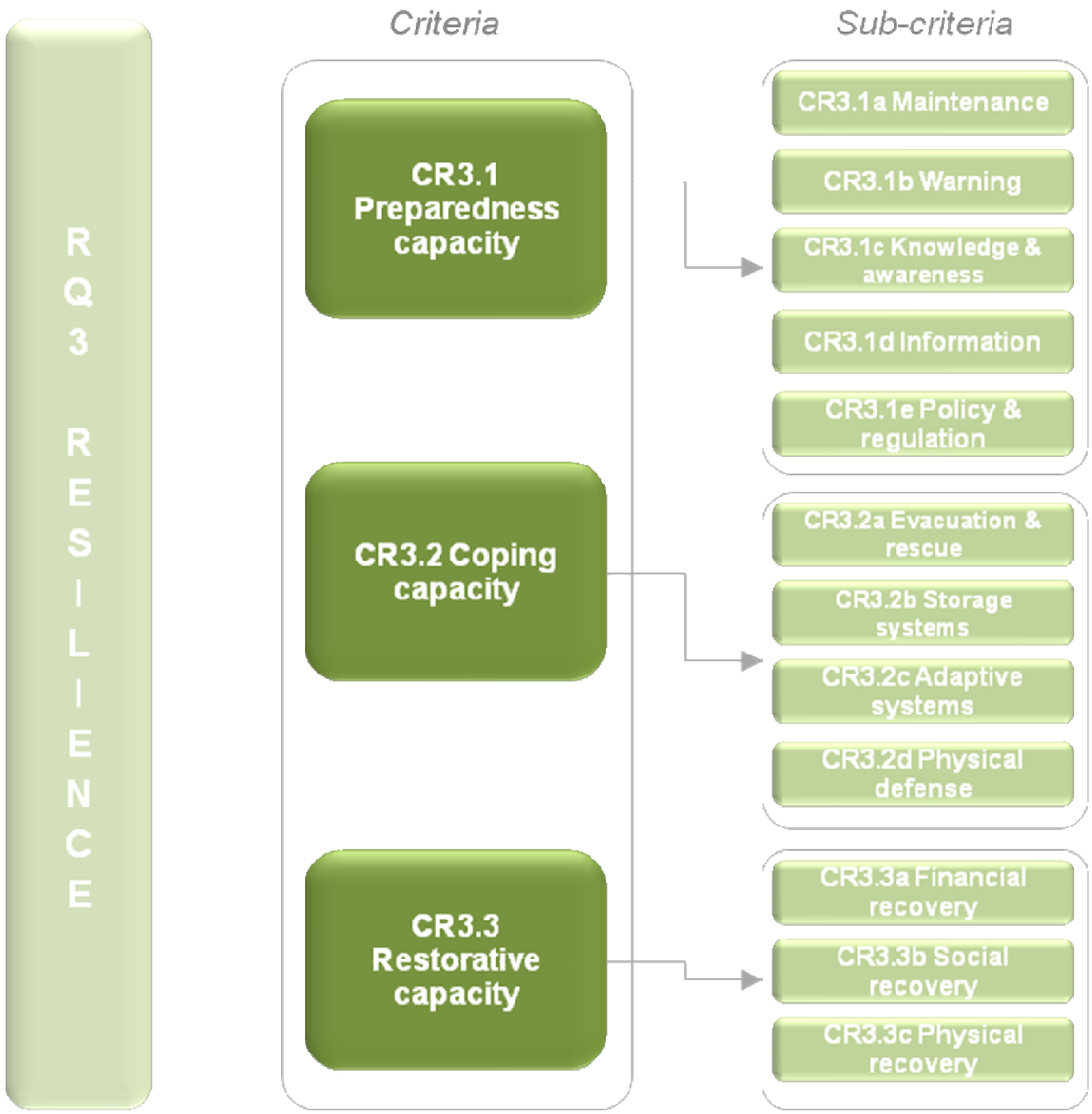



Fig.5. Resilience criteria (and sub-criteria).

Resilience of cultural heritage can be assessed by taking into account variables related to the following criteria (Fig.5):

- CR3.1) Preparedness capacity. It includes:
    - maintenance,
    - warning systems,
    - knowledge and awareness (e.g. training, dissemination, drills),
    - information,
    - policy and regulation.

- CR3.2) Coping capacity i.e. adaptive capacity or the ability to adapt to the event. It involves the investigation of properties related to:
    - evacuation and rescue,
    - storage systems (e.g. dams),
    - adaptive systems (e.g. drainage) and
    - physical defence systems (e.g. barriers).

- CR3.3) Restorative capacity i.e. the ability of the system to recover. It includes sub-criteria which identify aspects concerning:
    - financial recovery,
    - social recovery
    - physical recovery.

# 4. Vulnerability indicators for flash flood, landslide, wind storm and fire

Following the identification of requirements and criteria, these must be evaluated and weighted in order to reach a final vulnerability assessment necessary for ranking and prioritising resources. In particular, vulnerability indicators should be defined in order to enable the evaluation of the contribution of each criterion to the overall vulnerability of the system. Vulnerability indicators can be defined as variables which are operational representations of a characteristic or quality of the system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an event linked to a hazard of a natural origin [10].
Generally, vulnerability indicators should present peculiar qualities, in order to provide solid information (Table 3); among the most significant ones, indicators must be measurable, relevant, understandable, accurate and reproducible [5].

| *Quality* | *Description* |
|---|---|
| **Measurable** | Indicators should preferably be easily measurable. This is not often the case. The difference between “good” and “medium” condition is not clear and not measurable in quantitative terms. The scores may be dependent on the judgement of the data collector and may not always be objective. |
| **Relevant** | Indicators must be relevant to the assessment. They have might be chosen according to the needs of the end users although the latter could be more involved in the selection process in the future. The weighting, however, is done directly by the end users, offering flexibility to the method as well as subjectivity.. |
| **Understandable** | Indicators should be easy to interpret. No experts should be required for their collection. Although this is may be seen as an advantage, the judgement of the collector may influence the result significantly and increase uncertainties. |
| **Accurate** | Indicators must have the capacity to express precise evaluations. However, this is not always the case.. |
| **Reproducible** | Indicators should be reproducible and not be context specific. This would enable applicability to different scenarios |

Table 3. Qualities for vulnerability indicators.

The sections below summarise the indicators related to the hazards investigated in STRENCH, i.e. flash flood, landslide, wind storm and fire. Indicators are selected based on relevant literature and are further adapted to the selected hazards and cultural heritage typologies by expert opinion. It should be underlined that only the most relevant indicators are considered in order to provide a general overview. Furthermore, as mentioned in section 3, it should be stressed out that only the physical dimension of susceptibility is considered.

## 4.1. List of possible indicators from literature for flash flood

| *Indicator* | *Requirement* | *Criterion* | *Description* |
|---|---|---|---|
| **ID .....Material type** | Susceptibility | Building and structures | Typology of building materials |
| **ID .....Number of floors** | Susceptibility | Building and structures | |
| **ID .....Height of ground floor** | Susceptibility | Building and structures | |
| **ID .....Height from foundations** | Susceptibility | Building and structures | |
| **ID .....Height from road** | Susceptibility | Building and structures | |
| **ID .....Age** | Susceptibility | Building and structures | |
| **ID .....Wall thickness** | Susceptibility | Building and structures | |
| **ID .....Orientation** | Susceptibility | Building and structures | Orientation of the building |
| **ID .....Geometry** | Susceptibility | Building and structures | Geometry of the building |
| **ID .....Presence of openings** | Susceptibility | Building and structures | Identification of openings in the envelope (e.g. windows, doors, roof openings etc.). |
| **ID .....Height of openings** | Susceptibility | Building and structures | |
| **ID .....Roof type** | Susceptibility | Building and structures | Typology of roof (e.g. flat, pitched, dome etc.). |
| **ID .....Facade material** | Susceptibility | Building and structures | Typology of material(s) used for the facades. |
| **ID .....Existence of basement** | Susceptibility | Building and structures | |
| **ID .....Building type** | Susceptibility | Building and structures | Type of building (house, church, tower etc.) |
| **ID .....Presence of** | Susceptibility | Building and structures | Projections from buildings (e.g. balconies, bow-windows, spires etc.) |

| | | | |
|---|---|---|---|
| **protruding parts** | | | |
| **ID .....Presence of auxiliary structures** | Susceptibility | Building and structures | |
| **ID .....Altitude** | Susceptibility | Topography | Altitude with respect to the surrounding sites (e.g. location on a slope, in a valley etc.). |
| **ID .....Presence of slopes** | Susceptibility | Topography | |
| **ID .....Presence of valleys** | Susceptibility | Topography | |
| **ID .....Distance from slope** | Susceptibility | Topography | |
| **ID .....Vegetation type** | Susceptibility | Vegetation | Type of vegetation (higher plants, crops, botanical gardens etc.) including vegetation cover type. |
| **ID .....Presence of mature plants** | Susceptibility | Vegetation | This indicates poor adaptation to changing climate conditions (these are senescent plants, less resilient than young ones |
| **ID ..... Sensitivity to phytosanitary problems.** | Susceptibility | Vegetation | Sensitivity to certain phytosanitary problems. |
| **ID .....Distance from river** | Susceptibility | Hydrosphere | |
| **ID .....Distance from coast** | Susceptibility | Hydrosphere | |
| **ID .....Forest area** | Susceptibility | Use | |
| **ID .....Overused land** | Susceptibility | Use | |
| **ID .....Degraded land** | Susceptibility | Use | |
| **ID .....Use of basement** | Susceptibility | Use | |
| **ID .....Use of ground floor** | Susceptibility | Use | |
| **ID .....Damage level** | Susceptibility | Conditions | Damages currently observed |
| **ID .....Type of modification** | Susceptibility | Conditions | Past interventions and modifications to the original layout or characteristics of the site |

| | | | |
|---|---|---|---|
| **ID .....Location of heating** | Susceptibility | Conditions | |
| **ID .....Location of electricity central** | Susceptibility | Conditions | |
| **ID .....Presence of built heritage** | Exposure | Cultural significance | Presence of built heritage objects such as monuments and historic buildings. |
| **ID .....Presence of natural heritage** | Exposure | Cultural significance | Presence of natural heritage objects such as land formations, vistas and flora. |
| **ID .....Cultural value** | Exposure | Cultural significance | Based on the recognised status of the site (e.g. protected/unprotected, listed, UNESCO site etc.). |
| **ID .....Presence of protected area** | Exposure | Cultural significance | Presence of protected areas or elements within the perimeter of the property |
| **ID .....Total resident population** | Exposure | Population | Presence of people on site. |
| **ID .....Population density** | Exposure | Population | Density of population on site |
| **ID .....Infrastructure quality** | Exposure | Infrastructure | |
| **ID .....Infrastructure importance** | Exposure | Infrastructure | Relevance of infrastructure on site (e.g. local road, national road, highway etc.) |
| **ID .....Presence of maintenance plans** | Resilience | Maintenance | |
| **ID .....Presence of early warning systems** | Resilience | Warning | |
| **ID .....Education/literacy level** | Resilience | Knowledge & awareness | |
| **ID .....Training level** | Resilience | Knowledge & awareness | |
| **ID .....Existence of flood map** | Resilience | Information | |

| | | | |
|---|---|---|---|
| **ID .....Availability of meteorological data** | Resilience | Information | |
| **ID .....Presence of flood insurance** | Resilience | Policy and regulation | |
| **ID .....Ownership type** | Resilience | Policy and regulation | |
| **ID .....Existence of evacuation plans** | Resilience | Evacuation and rescue | |
| **ID .....Existence of rescue plans** | Resilience | Evacuation and rescue | |
| **ID .....Presence of evacuation routes and facilities** | Resilience | Evacuation and rescue | |
| **ID .....Presence of dams** | Resilience | Storage systems | |
| **ID .....Presence of drainage system** | Resilience | Adaptive systems | |
| **ID .....Drainage system conditions** | Resilience | Adaptive systems | |
| **ID .....Presence of wall surrounding property** | Resilience | Physical defence | |
| **ID .....Presence of Natural/artificial embankment/protection** | Resilience | Physical defence | |
| **ID .....Presence of surrounding vegetation** | Resilience | Physical defence | |
| **ID .....Availability of financial aid** | Resilience | Financial recovery | |
| **ID .....Quality of healthcare** | Resilience | Social recovery | |

| | | | |
|---|---|---|---|
| system | | | |
| ID .....Presence of diversified livelihood | Resilience | Social recovery | |
| ID .....Presence of disaster management committee | Resilience | Physical recovery | |

## 4.2. List of possible indicators from literature for landslides

| *Indicator* | *Requirement* | *Criterion* | *Description* |
|---|---|---|---|
| **ID .....Material type** | Susceptibility | Building and structures | Typology of building materials |
| **ID .....Number of floors** | Susceptibility | Building and structures | |
| **ID .....Height of ground floor** | Susceptibility | Building and structures | |
| **ID .....Height from foundations** | Susceptibility | Building and structures | |
| **ID .....Quality of construction** | Susceptibility | Building and structures | |
| **ID .....Age** | Susceptibility | Building and structures | |
| **ID .....Orientation** | Susceptibility | Building and structures | Orientation of the building |
| **ID .....Geometry** | Susceptibility | Building and structures | Geometry of the building |
| **ID .....Presence of openings** | Susceptibility | Building and structures | Identification of openings in the envelope (e.g. windows, doors, roof openings etc.). |
| **ID .....Height of openings** | Susceptibility | Building and structures | |
| **ID .....Location of openings** | Susceptibility | Building and structures | Openings located on river side or slope side etc. |
| **ID .....Roof type** | Susceptibility | Building and structures | Typology of roof (e.g. flat, pitched, dome etc.). |
| **ID .....Existence of basement** | Susceptibility | Building and structures | |
| **ID .....Building type** | Susceptibility | Building and structures | Type of building (house, church, tower etc.) |
| **ID .....Foundation type** | Susceptibility | Building and structures | Type of foundations (e.g. pile, pads, raft etc.) |
| **ID .....Presence of auxiliary** | Susceptibility | Building and structures | |

| | | | |
|---|---|---|---|
| structures | | | |
| ID .....Distance from slope | Susceptibility | Topography | |
| ID .....Slope curvature | Susceptibility | Topography | Convex or concave |
| ID .....Slope angle | Susceptibility | Topography | |
| ID .....Slope aspect | Susceptibility | Topography | Slope face orientation |
| ID .....Vegetation type | Susceptibility | Vegetation | Type of vegetation (higher plants, crops, botanical gardens etc.) including vegetation cover type. |
| ID .....Presence of mature plants | Susceptibility | Vegetation | This indicates poor adaptation to changing climate conditions (these are senescent plants, less resilient than young ones |
| ID ..... Sensitivity to phytosanitary problems. | Susceptibility | Vegetation | Sensitivity to certain phytosanitary problems. |
| ID .....Soil type | Susceptibility | Geosphere | |
| ID .....Geology | Susceptibility | Geosphere | |
| ID .....Land use | Susceptibility | Use | |
| ID .....Use of basement | Susceptibility | Use | |
| ID .....Use of ground floor | Susceptibility | Use | |
| ID .....Presence of nearby human activities | Susceptibility | Use | Sites endangered by dynamic forces and vibrations (near quarries, heavy traffic etc.). |
| ID .....Damage level | Susceptibility | Conditions | Damages currently observed |
| ID .....Type of modification | Susceptibility | Conditions | Past interventions and modifications to the original layout or characteristics of the site |
| ID .....Location of heating | Susceptibility | Conditions | |
| ID .....Location of electricity central | Susceptibility | Conditions | |

| | | | |
|---|---|---|---|
| **ID .....Location of water supply network** | Susceptibility | Conditions | |
| **ID .....Conditions electricity network** | Susceptibility | Conditions | |
| **ID .....Conditions of heating system** | Susceptibility | Conditions | |
| **ID .....Presence of built heritage** | Exposure | Cultural significance | Presence of built heritage objects such as monuments and historic buildings. |
| **ID .....Presence of natural heritage** | Exposure | Cultural significance | Presence of natural heritage objects such as land formations, vistas and flora. |
| **ID .....Cultural value** | Exposure | Cultural significance | Based on the recognised status of the site (e.g. protected/unprotected, listed, UNESCO site etc.). |
| **ID .....Presence of protected area** | Exposure | Cultural significance | Presence of protected areas or elements within the perimeter of the property |
| **ID .....Total resident population** | Exposure | Population | Presence of people on site. |
| **ID .....Population density** | Exposure | Population | Density of population on site |
| **ID .....Infrastructure quality** | Exposure | Infrastructure | |
| **ID .....Infrastructure importance** | Exposure | Infrastructure | Relevance of infrastructure on site (e.g. local road, national road, highway etc.) |
| **ID .....Presence of maintenance plans** | Resilience | Maintenance | |
| **ID .....Presence of early warning systems** | Resilience | Warning | |
| **ID .....Education/literacy level** | Resilience | Knowledge & awareness | |

| | | | |
|---|---|---|---|
| ID .....Training level | Resilience | Knowledge & awareness | |
| ID .....Existence of flood map | Resilience | Information | |
| ID .....Availability of meteorological data | Resilience | Information | |
| ID .....Presence of flood insurance | Resilience | Policy and regulation | |
| ID .....Ownership type | Resilience | Policy and regulation | |
| ID .....Existence of evacuation plans | Resilience | Evacuation and rescue | |
| ID .....Existence of rescue plans | Resilience | Evacuation and rescue | |
| ID .....Presence of evacuation routes and facilities | Resilience | Evacuation and rescue | |
| ID .....Presence of drainage system | Resilience | Adaptive systems | |
| ID .....Drainage system conditions | Resilience | Adaptive systems | |
| ID .....Presence of wall surrounding property | Resilience | Physical defence | |
| ID .....Presence of Natural/artificial embankment/protection | Resilience | Physical defence | |
| ID .....Presence of surrounding vegetation | Resilience | Physical defence | |
| ID... Presence of slope | Resilience | Physical defence | |

| | | | |
|---|---|---|---|
| strengthening/protective systems | | | |
| ID .....Availability of financial aid | Resilience | Financial recovery | |
| ID .....Quality of healthcare system | Resilience | Social recovery | |
| ID .....Presence of diversified livelihood | Resilience | Social recovery | |
| ID .....Presence of disaster management committee | Resilience | Physical recovery | |

## 4.3. List of possible indicators from literature for wind storm

| *Indicator* | *Requirement* | *Criterion* | *Description* |
|---|---|---|---|
| **ID .....Material type** | Susceptibility | Building and structures | Typology of building materials |
| **ID .....Quality of construction** | Susceptibility | Building and structures | |
| **ID .....Age** | Susceptibility | Building and structures | |
| **ID .....Orientation** | Susceptibility | Building and structures | Orientation of the building |
| **ID .....Geometry** | Susceptibility | Building and structures | Geometry of the building |
| **ID .....Slenderness** | Susceptibility | Building and structures | Ratio height over base width |
| **ID .....Presence of openings** | Susceptibility | Building and structures | Identification of openings in the envelope (e.g. windows, doors, roof openings etc.). |
| **ID .....Presence of vibration prone elements and structures** | Susceptibility | Building and structures | Presence of structural and architectonic elements, in particular roofs and spires or windows and window glazing |
| **ID .....Roof type** | Susceptibility | Building and structures | Typology of roof (e.g. flat, pitched, dome etc.). |
| **ID .....Building type** | Susceptibility | Building and structures | Type of building (house, church, tower etc.) |
| **ID .....Vegetation type** | Susceptibility | Vegetation | Type of vegetation (higher plants, crops, botanical gardens etc.) |
| **ID .....Presence of mature plants** | Susceptibility | Vegetation | This indicates poor adaptation to changing climate conditions (these are senescent plants, less resilient than young ones |
| **ID ..... Sensitivity to phytosanitary problems.** | Susceptibility | Vegetation | Sensitivity to certain phytosanitary problems. |
| **ID .....Soil type** | Susceptibility | Geosphere | This is particularly relevant for soil susceptibility of soil to wind erosion. |

| | | | |
|---|---|---|---|
| **ID .....Land use** | Susceptibility | Use | |
| **ID .....Damage level** | Susceptibility | Conditions | Damages currently observed |
| **ID .....Type of modification** | Susceptibility | Conditions | Past interventions and modifications to the original layout or characteristics of the site |
| **ID .....Presence of built heritage** | Exposure | Cultural significance | Presence of built heritage objects such as monuments and historic buildings. |
| **ID .....Presence of natural heritage** | Exposure | Cultural significance | Presence of natural heritage objects such as land formations, vistas and flora. |
| **ID .....Cultural value** | Exposure | Cultural significance | Based on the recognised status of the site (e.g. protected/unprotected, listed, UNESCO site etc.). |
| **ID .....Presence of protected area** | Exposure | Cultural significance | Presence of protected areas or elements within the perimeter of the property |
| **ID .....Total resident population** | Exposure | Population | Presence of people on site. |
| **ID .....Population density** | Exposure | Population | Density of population on site |
| **ID .....Infrastructure quality** | Exposure | Infrastructure | |
| **ID .....Infrastructure importance** | Exposure | Infrastructure | Relevance of infrastructure on site (e.g. local road, national road, highway etc.) |
| **ID .....Presence of maintenance plans** | Resilience | Maintenance | |
| **ID .....Presence of early warning systems** | Resilience | Warning | |
| **ID .....Presence of wall surrounding property** | Resilience | Physical defence | |
| **ID .....Presence of Natural/artificial** | Resilience | Physical defence | |

| | | | |
|---|---|---|---|
| **embankment/protection** | | | |
| **ID .....Presence of surrounding vegetation** | Resilience | Physical defence | |
| **ID .....Availability of financial aid** | Resilience | Financial recovery | |
| **ID .....Presence of disaster management committee** | Resilience | Physical recovery | |

## 4.4. List of possible indicators from literature for fire

| *Indicator* | *Requirement* | *Criterion* | *Description* |
|---|---|---|---|
| **ID .....Material combustibility coefficient** | Susceptibility | Building and structures | Combustibility coefficient is related to combustion speed and inflammability |
| **ID .....Material activation coefficient** | Susceptibility | Building and structures | Activation coefficient is related to the ignition susceptibility of the materials |
| **ID .....Gap between aligned openings** | Susceptibility | Building and structures | It considers the number of gaps with a distance lower than 1.10 m, the minimum admissible distance to avoid fire propagation |
| **ID .....Building type** | Susceptibility | Building and structures | Type of building (house, church, tower etc.) |
| **ID .....Natural fire load level** | Susceptibility | Vegetation | It evaluates the type and quantity of fire load present on site considering inflammable natural materials like dried plants |
| **ID .....Soil type** | Susceptibility | Geosphere | |
| **ID .....Land use** | Susceptibility | Use | |
| **ID .....Damage level** | Susceptibility | Conditions | Damages currently observed |
| **ID .....Type of modification** | Susceptibility | Conditions | Past interventions and modifications to the original layout or characteristics of the site |
| **ID .....Electric installation classification** | Susceptibility | Conditions | The electrical installations are divided into three classifications: refurbished installations, partially refurbished installations and non-refurbished installations. |
| **ID .....Gas supplying type** | Susceptibility | Conditions | |
| **ID .....Gas installation location** | Susceptibility | Conditions | |
| **ID .....Gas installation ventilation conditions** | Susceptibility | Conditions | |

| | | | |
|---|---|---|---|
| **ID .....Presence of built heritage** | Exposure | Cultural significance | Presence of built heritage objects such as monuments and historic buildings. |
| **ID .....Presence of natural heritage** | Exposure | Cultural significance | Presence of natural heritage objects such as land formations, vistas and flora. |
| **ID .....Cultural value** | Exposure | Cultural significance | Based on the recognised status of the site (e.g. protected/unprotected, listed, UNESCO site etc.). |
| **ID .....Presence of protected area** | Exposure | Cultural significance | Presence of protected areas or elements within the perimeter of the property |
| **ID .....Total resident population** | Exposure | Population | Presence of people on site. |
| **ID .....Population density** | Exposure | Population | Density of population on site |
| **ID .....Infrastructure quality** | Exposure | Infrastructure | |
| **ID .....Infrastructure importance** | Exposure | Infrastructure | Relevance of infrastructure on site (e.g. local road, national road, highway etc.) |
| **ID .....Presence of maintenance plans** | Resilience | Maintenance | |
| **ID Fire detection, alert and alarm type** | Resilience | Warning | Fire detection alert and alarm considers the existence of automatic, manual or combined fire detection systems, |
| **ID .....Education/literacy level** | Resilience | Knowledge & awareness | |
| **ID .....Training level** | Resilience | Knowledge & awareness | |
| **ID .....Existence of evacuation plans** | Resilience | Evacuation and rescue | |
| **ID .....Existence of rescue plans** | Resilience | Evacuation and rescue | |
| **ID .....Presence of** | Resilience | Evacuation and rescue | It considers the number of exits, the width of the door or access |

| | | | |
|---|---|---|---|
| **evacuation routes and facilities** | | | openings, the inclination of the stairs and access roads and the existence of signalling and illumination for emergency routes. |
| **ID ..... quality of site accessibility** | Resilience | Adaptive systems | |
| **ID .....Hydrant location** | Resilience | Adaptive systems | |
| **ID .....Reliability of water supply system** | Resilience | Adaptive systems | |
| **ID ..... Presence of fire compartmentalization** | Resilience | Physical defence | |

# 5. Vulnerability evaluation and ranking

Following the identification of indicators, in order to obtain a final vulnerability index and thus enabling ranking, the MIVES method foresees the implementation of the following steps: (S3) establish the value functions to convert the qualitative and quantitative variables into a set of variables with the same units and scales; (S4) define the importance or relative weight of each of the aspects to be taken into account in the assessment; (S5) define the various design alternatives that could be considered to solve the previously identified problem; (S6) evaluate and assess those alternatives by using the previously created model; and (S7) make the right decisions and choose the most appropriate alternative [7].

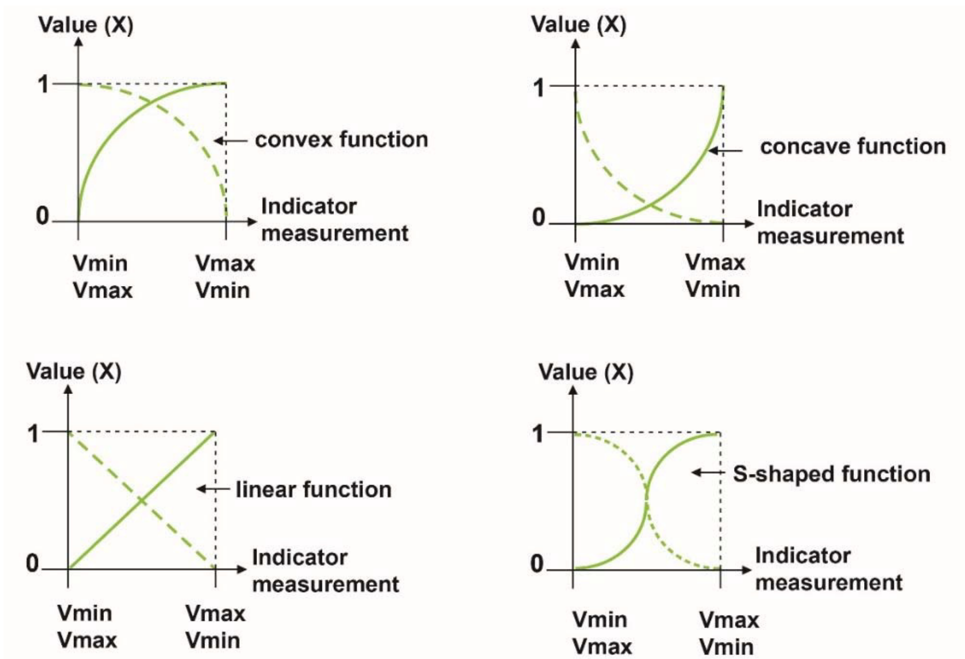



Fig.6. Different types of value function shapes. Source: [21].

Indicators are of different nature and present diverse units of measure [21]. It is necessary to standardize them into units of value or satisfaction, which is basically what the value function does. Different value functions (concave, convex, linear, S-shaped) can be used (Fig.6), where the vertical axis represents the minimum (0) or the maximum (1) level of satisfaction and the abscissa represents the variable of the indicator. For each indicator a value function should be created, to evaluate the different alternatives (Fig. 7). In cases where the value function is not clear, it is defined by a working group. Methodology for determining the value function can be found in the literature [22].

| Indicator | Value description | Value |
|---|---|---|
| ID.... Damage level | None<br>Low<br>Moderate<br>High | 0.00<br>0.2<br>0.75<br>1 |
| ID.... Cultural value | Grade I<br>Grade II<br>Grade III<br>Grade IV<br>None | 1.00<br>0.86<br>0.61<br>0.27<br>0.00 |
| ID.... Presence of drainage system | Presence<br>Absence | 1.00<br>0.00 |

Fig.7. Examples of evaluation of different alternatives for indicator's values.

As a second step, analytic Hierarchy Process (AHP) can be used for the weights assignment, by establishing the relative importance of each branch of the requirements tree. Weight assignment is performed by comparing elements at the same level and in the same branch of the requirements tree. Thus, the indicator weights are calculated according to other indicators belonging to the same criterion. In the same manner, a criterion weight is calculated by other criteria belonging to the same requirement. Adjustments can be made considering the opinion of the expert panel.

Finally, the aggregation of indicators can be done through numerous statistical formulas [5, 23], for example using a weighted linear combination method which is an analytical technique used in dealing with multi-criteria decision making (MCDM):

$$VI = \sum_{1}^{m} w_m \cdot I_m S_n$$

Where *w* represents the *m* different weights, *I* the *m* indicators and *S* the *n* scores of the indicators [5]. The final index gives a number from 0 to 1, signifying low to high vulnerability. The values individuated for this index allow finally vulnerability ranking for different cultural heritage objects. **Please note that the weighting is not static since the needs of the end users may vary. Therefore, each user of the method should be able to set their own priorities and change the weighting accordingly.**

The application of this methodology in the field of cultural heritage protection allows drafting vulnerability maps which, in turn, could support adequate decision making in disaster situations (Fig.8, 9 and 10).

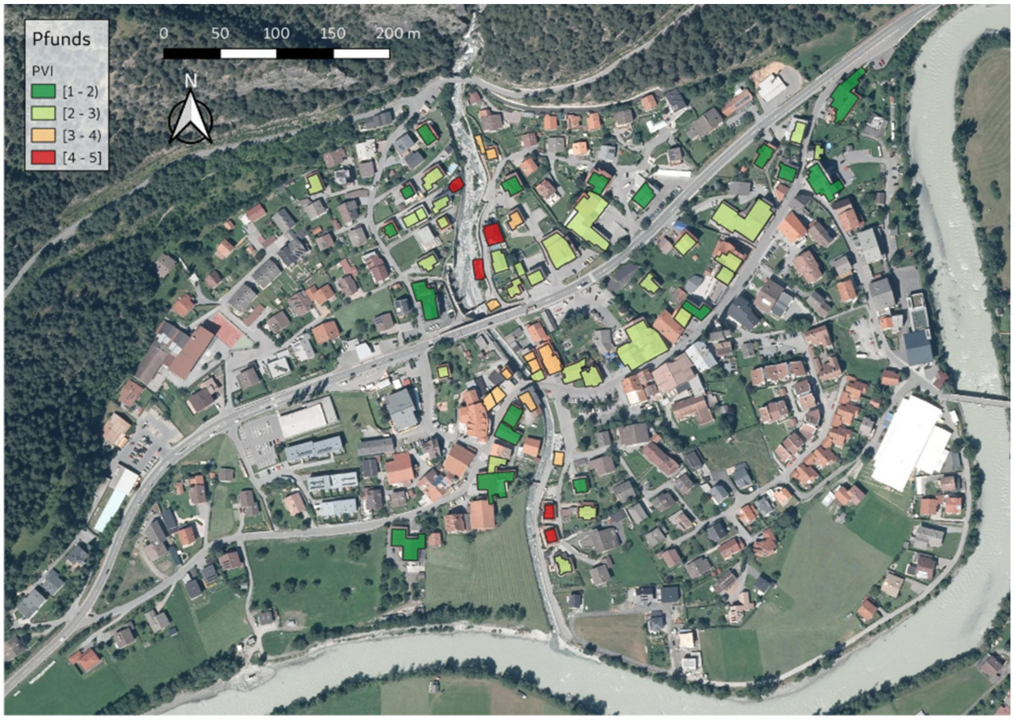



Fig.8. PVI for Stubenbach (municipality of Pfunds, Austria, source: [24].

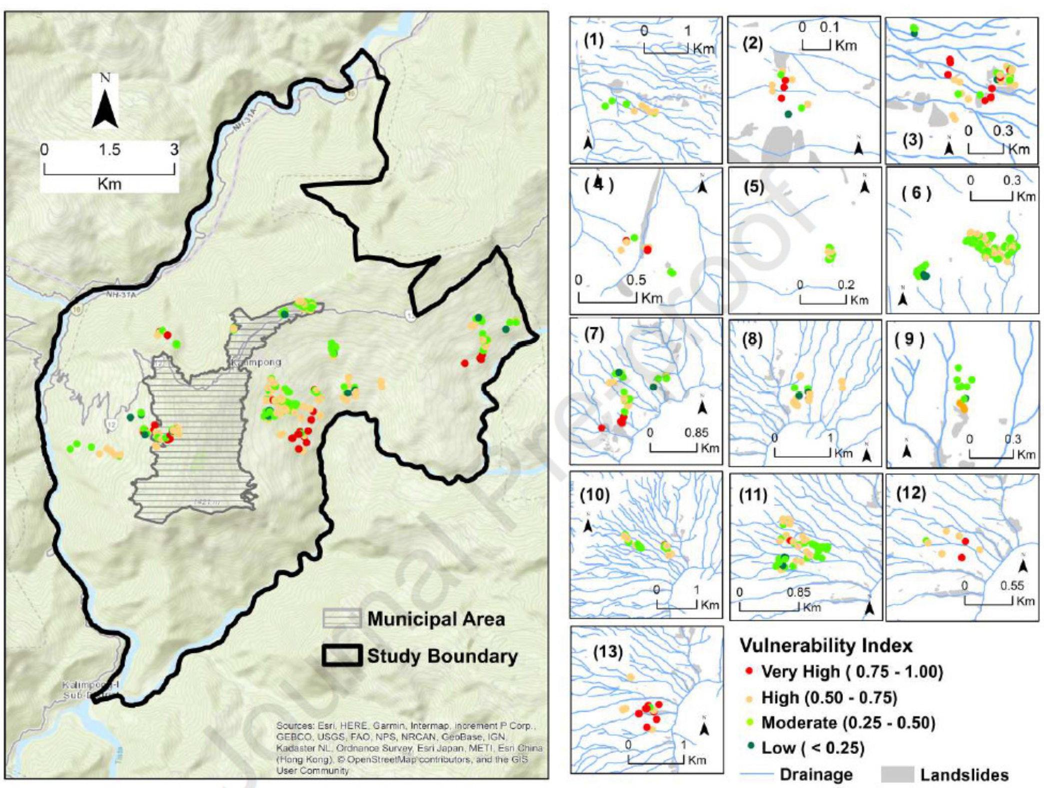



Fig.9. Landslide hazard in the Himalayan Region of India, source: [25].

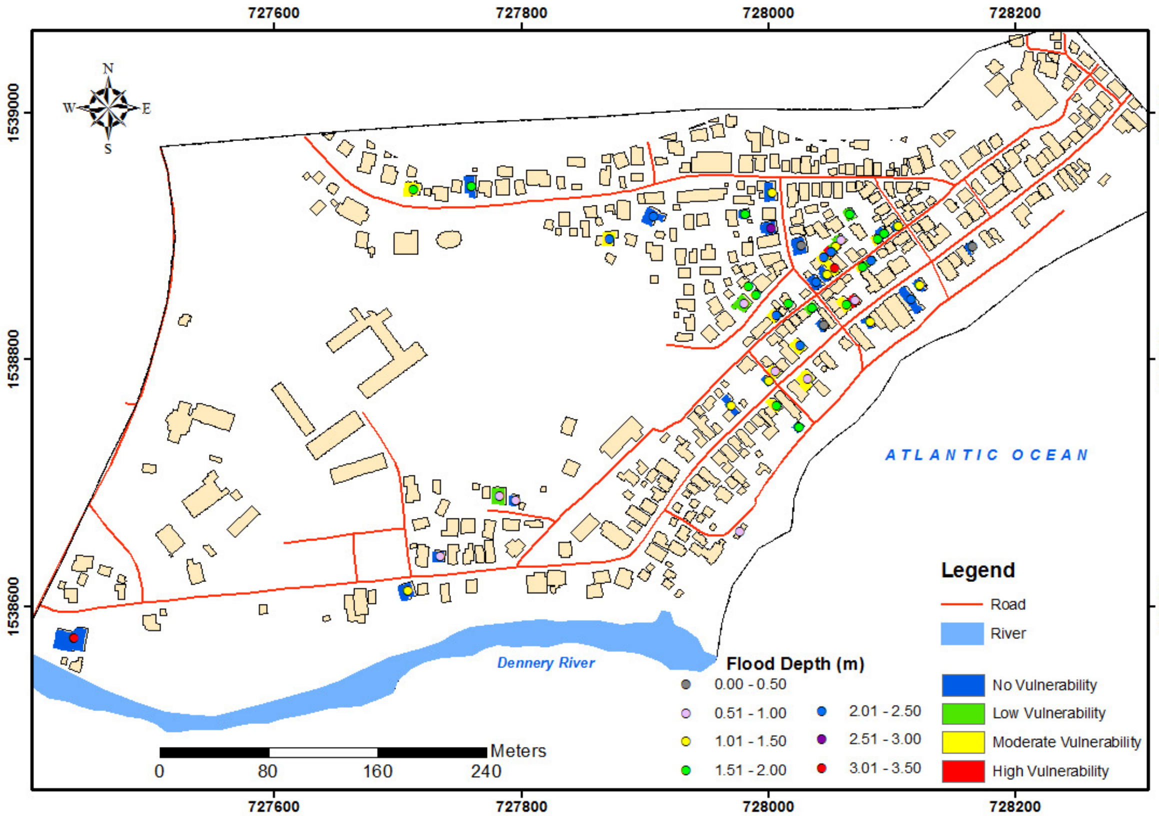



Fig.10. Distribution of the maximum flood depth points in respondents´ houses, source: [26].

# 6. References


[1] Kasperson, J.X., Kasperson, R.E., Turner, B.L. II, Schiller, A.M.D., Hsieh, W. ,"Vulnerability to global environmental change",in Kasperson, 2005; pp.245-85.

[2] Ciurean, R.L., Schröter, D. & Glade, T., 2013, Conceptual frameworks of vulnerability assessments for natural disasters reduction, INTECH Open Access Publisher, Croatia. https://doi.org/10.5772/55538.

[3] Fuchs, S., Tsao, T.-C., and Keiler, M.: Quantitative Vulnerability Functions for use in Mountain Hazard Risk Management, in: 12th Congress INTERPRAEVENT 2012, Grenoble, France, 885–896, 2012.

[4] Papathoma-Köhle, M., Kappes, M., Keiler, M., and Glade, T.: Physical vulnerability assessment for alpine hazards: state of the art and future needs, Nat. hazards, 58, 645–680, http://link.springer. com/10.1007/s11069-010-9632-4, 2011.

[5] Papathoma-Köhle, M.: Vulnerability curves vs. vulnerability indicators: application of an indicator-based methodology for debris flow hazards, Nat. Hazards Earth Syst. Sci., 16, 1771–1790, https://doi.org/10.5194/nhess-16-1771-2016, 2016.

[6] Tarbotton C, Dall'Osso f, Dominey-Howes D, Goff J (2015) The use of empirical vulnerability functions to assess the response of buildings to tsunami impact: comparative review and summary of best practice. Earth Sci Rev 142:120–134.

[7] Pons, O.; de la Fuente, A.; Aguado, A. The Use of MIVES as a sustainability assessment MCDM method for architecture and civil engineering applications. Sustainability 2016, 8, 460.

[8] https://dictionary.cambridge.org/ (Accessed 28/10/2020).

[9] https://www.merriam-webster.com/ (Accessed 28/10/2020).

[10] Birkmann, J. (Ed.), 2006. Measuring Vulnerability to Natural Hazards— Towards Disaster-Resilient Societies. UNU Press, Tokyo, New York.

[11] Thywissen, K., 2006. Core terminology of disaster reduction: a comparative glossary. In: Birkmann, J. (Ed.), Measuring Vulnerability to Natural Hazards—Towards Disaster Resilient Societies. UNUPress, Tokyo, New York, Paris.

[12] Green, C. ( 2004) 'The Evaluation of Vulnerability to Flooding ', Disaster Prevention and Management 13(4): 323-9.

[13] Tapsell McCarthy, S., Faulkner, H., Alexander, M., S. (2010) Social Vulnerability and natural hazards. Available from: http://caphaznet.org/outcomes-results.

[14] Leone, F., Aste, J.P. 1996. Vulnerability assessment of elements exposed to mass-movement: Working toward a better risk perception. In book: Landslides (pp.263 - 269)Edition: Senneset K.Publisher: Ed. Balkema.

[15] ISO/IEC GUIDE 73:2002 Risk management — Vocabulary — Guidelines for use in standards.

[16] Birkman, J, 2013. Measuring vulnerability to natural hazards : towards disaster resilient societies / edited by Jörn Birkmann. — Second edition, United Nations University, Japan.

[17] PROAG, V. (2014). The concept of vulnerability and resilience. Procedia Economics and Finance, 369-376.

[18] Daungthima, W.; Kazunori, H. Assessing the flood impacts and the cultural properties vulnerabilities in Ayutthaya, Thailand. Procedia Environ. Sci. 2013, 17, 739–748.

[19] IPCC, 2014. AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability.

[20] Cloete, Chris. (2012). Assessing urban resilience. WIT Transactions on Information and Communication Technologies. 44. 341-351. 10.2495/RISK120291.

[21] Gandini A, Egusquiza A, Garmendia L, San-José J-T (2018) Vulnerability assessment of cultural heritage sites towards flooding events. IOP Conf. Series: Materials Science and Engineering 364 (2018) 012028 doi:10.1088/1757-899X/364/1/012028.

[22] Alarcon B, Aguado A, Manga R, Josa A (2011) A value function for assessing sustainability: application to industrial buildings. Sustainability 3.

[23] Kappes, M. S., M. Keiler, K. von Elverfeldt, and T. Glade (2012), Challenges of analyzing multi-hazard risk: A review, Nat. Hazards, 64(2), 1925– 1958.

[24] Papathoma-Köhle, M.; Schlögl, M.; Fuchs, S. Vulnerability indicators for natural hazards: An innovative selection and weighting approach. Sci. Rep. 2019, 9, 1–14.

[25] Bera, S., Gurub, B., Oommenc, T., 2020. Indicator-based approach for assigning physical vulnerability of the houses to landslide hazard in the Himalayan region of India, International Journal of Disaster Risk Reduction 50, 101891.

[26] Uwakwe, A.W., 2015. Assessment of physical vulnerability to flood in Saint Lucia. Case studies: Castries old Central Business District and Dennery Village, Thesis https://www.cdema.org/virtuallibrary/images/Anne%20Chinyere%20Uwakwe-s6012345.pdf

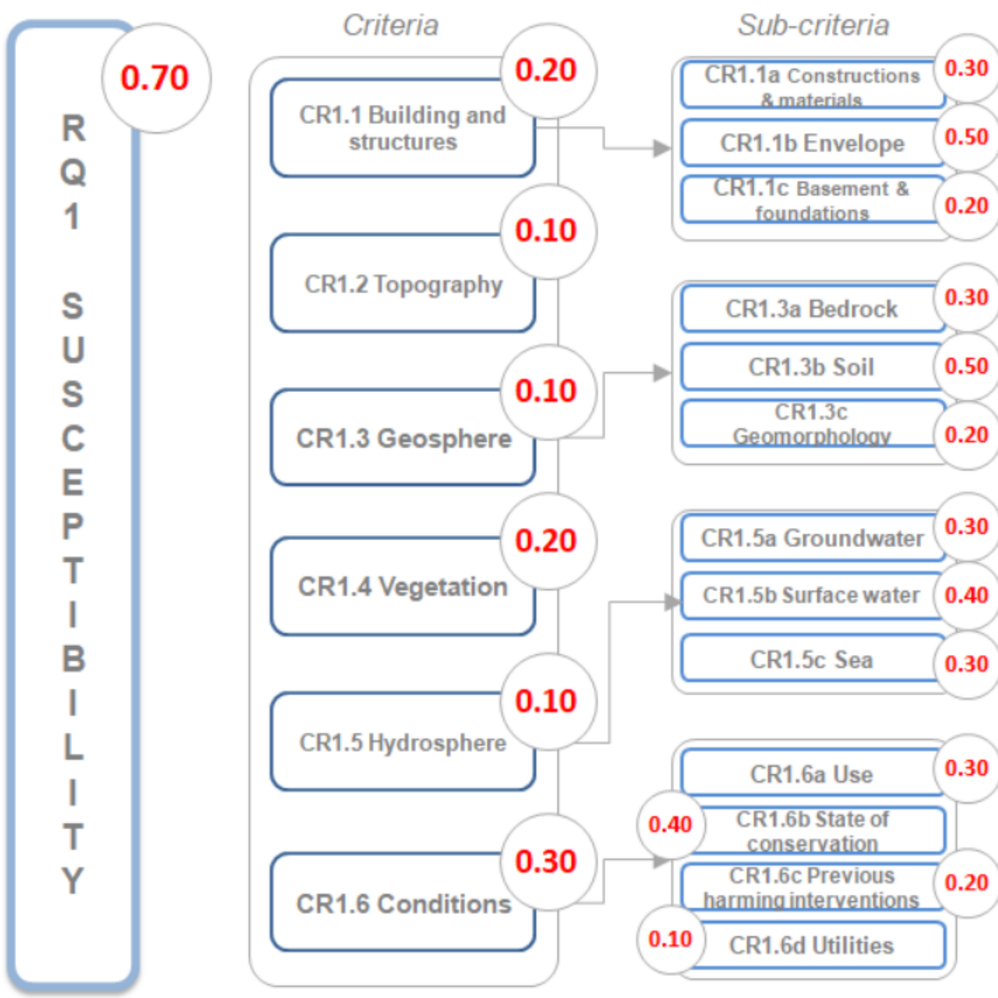
# 7. ANNEX- STRENCH GUIDELINES FOR VULNERABILITY EVALUATION

## 7.1. Introduction

In STRENCH, the evaluation of the vulnerability of pilot sites follows the simplified guidelines provided in this Annex. The analysis is carried out at criteria (or sub-criteria) level of the requirement tree, avoiding the use of indicators for the sake of widening the accessibility of the method to a larger user group. Weights for requirements, criteria and sub-criteria are outlined together with the values used for their evaluation. Weights and values are determined using the Analytic Hierarchy Process method and are further adjusted by experts' opinion and literature review including capitalised project results. Aggregation of values into a vulnerability index is based on the additive method. In case a more detailed vulnerability assessment is required, please refer to the methodology outlined in the deliverable D. T1.2.2. In the same deliverable, definitions of terms used in these guidelines (requirements, criteria and sub-criteria) are provided.

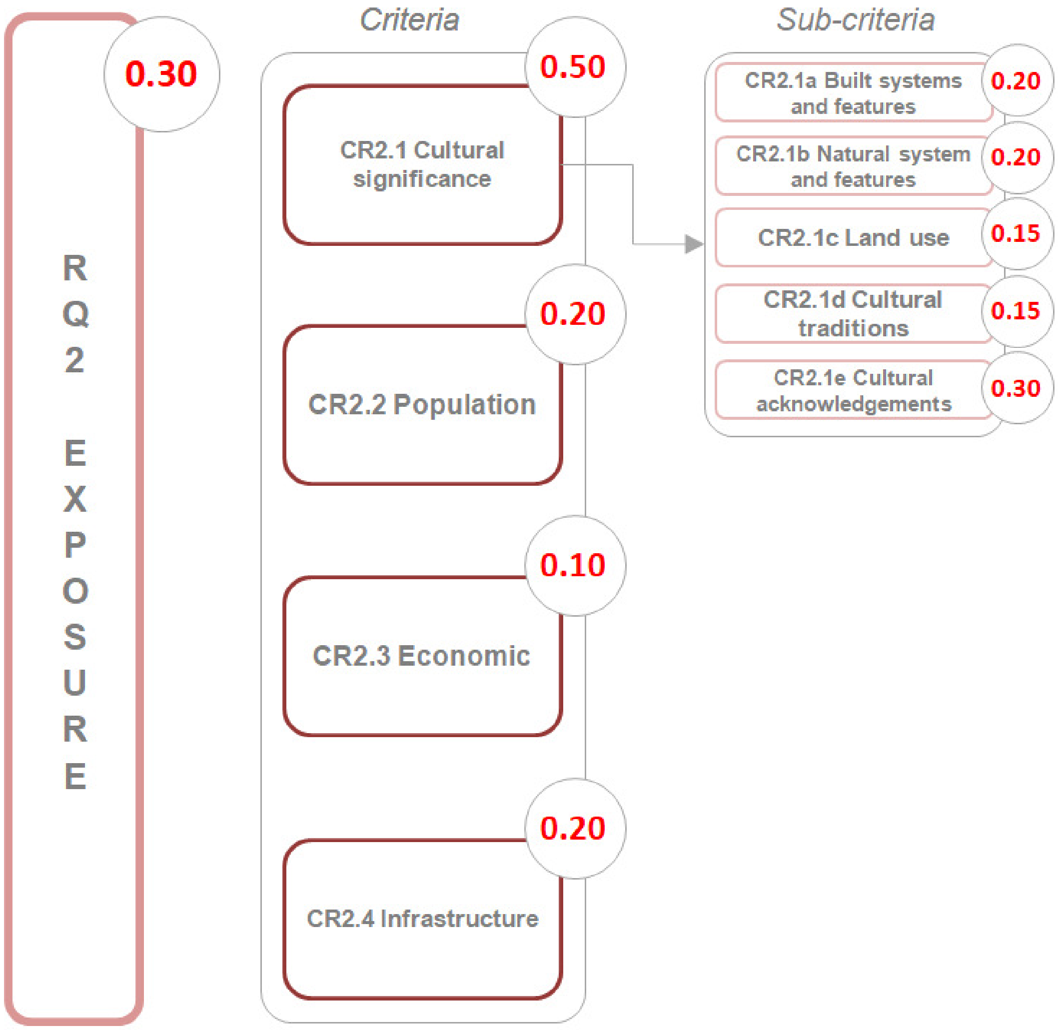
**Please note that the weighting proposed in this document may vary according to site-specific requirements (e.g. hazard type, CH typology etc.). Therefore, the presented values and weights should be considered for reference only and valid for an idealised flood scenario, which may require adjustments in real life applications. Multi-risk situations and synergetic effects of concurring climate-related actions are also not taken into account and should require an in-depth analysis.**

## 7.2. Weights for requirements, criteria and sub-criteria

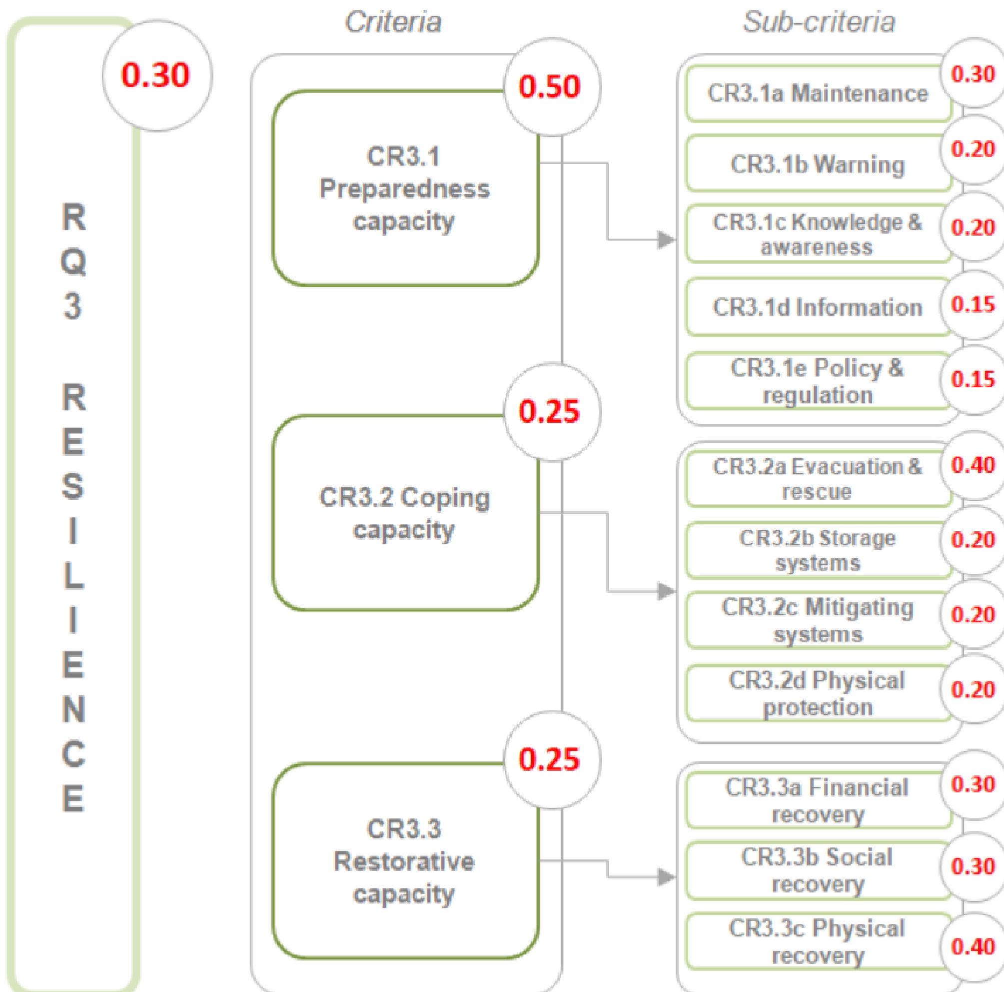



| **Requirement:** | **SUSCEPTIBILITY (RQ1)** | **$\gamma_R$=0.70** | |
|---|---|---|---|
| ***Criterion*** | ***Sub-criterion*** | $\gamma_c$ | $\gamma_{sc}$ |
| **CR1.1 Building and structures** | CR1.1a Constructions & materials | 0.20 | 0.30 |
| | CR1.1b Envelope | | 0.50 |
| | CR1.1c Basement & foundations | | 0.20 |
| **CR1.2 Topography** | - | 0.10 | - |
| **CR1.3 Geosphere** | CR1.3a Bedrock | 0.10 | 0.30 |
| | CR1.3b Soil | | 0.50 |
| | CR1.3c Geomorphology | | 0.20 |

| | | | |
|---|---|---|---|
| **CR1.4 Vegetation** | - | 0.20 | - |
| **CR1.5 Hydrosphere** | CR1.5a Groundwater | 0.10 | 0.30 |
| | CR1.5b Surface water | | 0.40 |
| | CR1.5c Sea | | 0.30 |
| **CR1.6 Conditions** | CR1.6a Use | 0.30 | 0.30 |
| | CR1.6b State of conservation | | 0.40 |
| | CR1.6c Previous harming interventions | | 0.20 |
| | CR1.6d Utilities | | 0.10 |




| **Requirement:** | **EXPOSURE (RQ2)** | **$\gamma_R$=0.30** | |
|---|---|---|---|
| ***Criterion*** | ***Sub-criterion*** | $\gamma_c$ | $\gamma_{sc}$ |
| **CR2.1 Cultural significance** | CR2.1a Built systems and features | 0.50 | 0.20 |
| | CR2.1b Natural systems and features | | 0.20 |
| | CR2.1c Land use | | 0.15 |
| | CR2.1d Cultural traditions | | 0.15 |
| | CR2.1e Cultural acknowledgements | | 0.30 |
| **CR2.2 Population** | - | 0.20 | - |
| **CR2.3 Economic** | - | 0.10 | - |
| **CR2.4 Infrastructure** | - | 0.20 | - |




| **Requirement:** | **RESILIENCE (RQ3)** | **$\gamma_R$=0.30** | |
|---|---|---|---|
| ***Criterion*** | ***Sub-criterion*** | $\gamma_c$ | $\gamma_{sc}$ |
| **CR3.1 Preparedness capacity** | CR3.1a Maintenance | 0.50 | 0.30 |
| | CR3.1b Warning | | 0.20 |
| | CR3.1c Knowledge and awareness | | 0.20 |
| | CR3.1d Information | | 0.15 |
| | CR3.1e Policy and regulation | | 0.15 |
| **CR3.2 Coping capacity** | CR3.2a Evacuation and rescue | 0.25 | 0.40 |
| | CR3.2b Storage systems | | 0.25 |
| | CR3.2c Mitigating systems | | 0.25 |
| | CR3.2d Physical protection | | 0.20 |

| | | | |
|---|---|---|---|
| **CR3.3 Restorative capacity** | CR3.3a Financial recovery | 0.25 | 0.30 |
| | CR3.3b Social recovery | | 0.30 |
| | CR3.3c Physical recovery | | 0.40 |

## 7.3. Values for criteria and sub criteria

Values are assigned to the lowest level in the requirement tree, i.e. either criteria or sub-criteria, whichever is available for a specific criterion analysed.

| **Ref** | **Criterion/sub-criterion** | **Value meaning** | **Value** |
|---|---|---|---|
| | | *SUSCEPTIBILTY (RQ1)* | |
| CR1.1a | Constructions & materials | Stocky constructions made of resistant materials | 0.00 |
| | | Slender constructions made of resistant materials | 0.20 |
| | | Stocky constructions made of materials prone to degradation or impact damage | 0.50 |
| | | Slender constructions made of material prone to degradation or impact damage | 1.00 |
| CR1.1b | Envelope | No openings at ground floor | 0.00 |
| | | Small openings at ground floor | 0.49 |
| | | Large openings at ground floor | 1.00 |
| CR1.1c | Basement & foundations | No basement or protruding components on deep foundations | 0.00 |
| | | Basement and protruding components on deep foundations | 0.80 |
| | | Presence of basement and protruding components on shallow foundations | 1.00 |
| CR1.2 | Topography | No surrounding slopes | 0.00 |

| | | | |
|---|---|---|---|
| | | Stable slopes with inclination less than 15 degrees<br>Stable slopes with slope inclination higher than 30 degrees<br>Unstable slopes with inclination of 15-30 degrees | 0.15<br>0.30<br>1.00 |
| CR1.3a | Bedrock | presence of stable bedrock<br>presence of unstable bedrock | 0.00<br>1.00 |
| CR1.3b | Soil | coarse-grained soil (sand, gravel)<br>fine-grained soil (silt, clay)<br>highly organic soil (peat) | 0.00<br>0.30<br>1.00 |
| CR1.3c | Geomorphology | presence of stable geological formation<br>presence of unstable geological formation | 0.00<br>1.00 |
| CR1.4 | Vegetation | no vegetation/ vegetation cover on agricultural fields < 30 %<br>vegetation prone to low damage<br>vegetation prone to serious damage<br>vegetation prone to total destruction / vegetation cover on agricultural field ≥ 30% | 0.00<br>0.30<br>0.80<br>1.00 |
| CR1.5a | Groundwater | stable water table<br>water table prone to sudden fluctuations | 0.00<br>1.00 |
| CR1.5b | Surface water | far from permanent, seasonal and man-made water course<br>close to permanent, seasonal and man-made water course | 0.00<br>1.00 |
| CR1.5c | Sea | far from sea<br>close to sea | 0.00<br>1.00 |
| CR1.6a | Use | private | 0.10 |

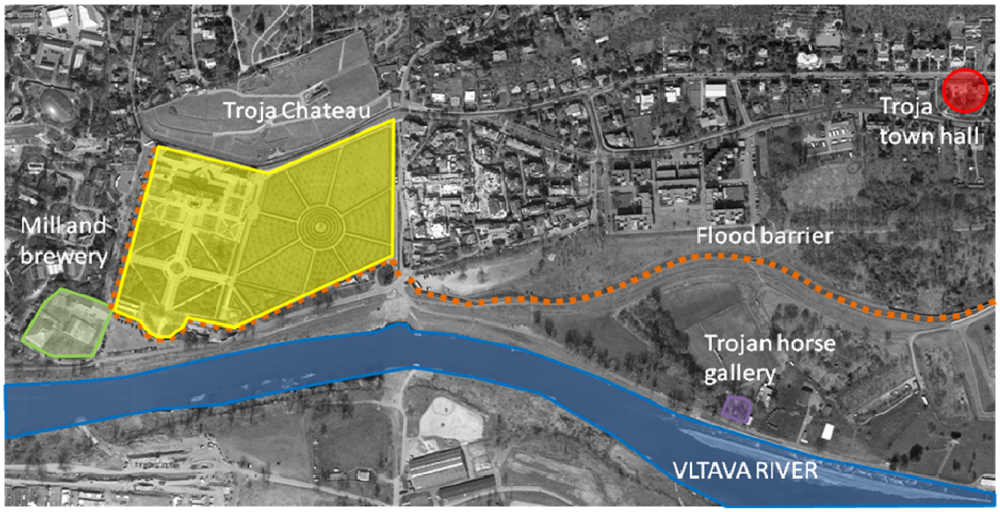
| | | | |
|---|---|---|---|
| | | public<br>touristic<br>abandoned | 0.20<br>0.80<br>1.00 |
| CR1.6b | State of conservation | Good<br>Fair<br>Poor<br>Very bad | 0.00<br>0.18<br>0.73<br>1.00 |
| CR1.6c | Previous harming interventions | Yes, previous interventions<br>No interventions made | 0.00<br>1.00 |
| CR1.6d | Utilities | located in the second floor or above<br>located in the first floor<br>located in the basement | 0.10<br>0.90<br>1.00 |
| | | *EXPOSURE (RQ2)* | |
| CR2.1a | Built systems and features | absence of built systems and features<br>presence of built systems and features | 0.00<br>1.00 |
| CR2.1b | Natural systems and features | absence of natural systems and features<br>presence of natural systems and features | 0.00<br>1.00 |
| CR2.1c | Land use | No historical activities influencing development and modification.<br>Historical activities influencing development and modification. | 0.00<br>1.00 |
| CR2.1d | Cultural traditions | absence of cultural traditions<br>presence of cultural traditions | 0.00<br>1.00 |
| CR2.1e | Cultural acknowledgements (according to the national adopted scale) | None<br>Grade IV<br>Grade III<br>Grade II | 0.00<br>0.27<br>0.61<br>0.86 |

| | | | |
|---|---|---|---|
| | | Grade I | 1.00 |
| CR2.2 | Population | no population<br>population but no fragility<br>presence of fragile population | 0.00<br>0.30<br>1.00 |
| CR2.3 | Economic | no economic value<br>livelihoods of local residents<br>presence of stable and ramified system with high economic value | 0.00<br>0.50<br>1.00 |
| CR2.4 | Infrastructure | absence of relevant infrastructure<br>presence of relevant infrastructure | 0.00<br>1.00 |
| | | *RESILIENCE (RQ3)* | |
| CR3.1a | Maintenance | no maintenance<br>irregular maintenance<br>regular maintenance | 0.00<br>0.50<br>1.00 |
| CR3.1b | Warning | absence of early warning systems<br>presence of early warning systems | 0.00<br>1.00 |
| CR3.1c | Knowledge and awareness | lack of technical knowledge<br>no knowledge sharing among stakeholders<br>lack of awareness<br>knowledge and awareness ensured | 0.00<br>0.50<br>0.80<br>1.00 |
| CR3.1d | Information | no info<br>partial, not up-to-date or incomplete information exist<br>partial or complete info exist but not available<br>complete info is available | 0.00<br>0.30<br>0.50<br>1.00 |
| CR3.1e | Policy and regulation | lack of regulations for CH<br>unclear responsibilities<br>ownership status issues | 0.00<br>0.30<br>0.50 |

| | | | |
|---|---|---|---|
| | | regulated CH protection | 1.00 |
| CR3.2a | Evacuation and rescue | Absence of evacuation and rescue plan<br>Existence of evacuation and rescue plan | 0.00<br>1.00 |
| CR3.2b | Storage systems | Absence of storage systems<br>Existence of storage system | 0.00<br>1.00 |
| CR3.2c | Mitigating systems | Absence of mitigating systems<br>Existence of mitigating system | 0.00<br>1.00 |
| CR3.2d | Physical protection | Absence of physical protection<br>Existence of physical protection | 0.00<br>1.00 |
| CR3.3a | Financial recovery | no funds available<br>funds available but not accessible<br>funds available but insufficient<br>funds available and accessible | 0.00<br>0.10<br>0.30<br>1.00 |
| CR3.3b | Social recovery | Absence of social recovery plan<br>Existence of social recovery plan | 0.00<br>1.00 |
| CR3.3c | Physical recovery | no risk management plan<br>risk management plan without specific emergency measures<br>risk management plan exists and up to date | 0.00<br>0.30<br>1.00 |

## 7.4. Example of vulnerability evaluation

PRAHA TROJA CHÂTEAU




1) ***Evaluation of susceptibility (sub-)criteria:***

| **Ref** | **Criterion/sub-criterion** | **Value meaning** | **Value** |
|---|---|---|---|
| | | *SUSCEPTIBILTY (RQ1)* | |
| CR1.1a | Construction & materials | Stocky constructions made of materials prone to degradation or impact damage | 0.50 |

| | | | |
|---|---|---|---|
| CR1.1b | Envelope | Large openings at ground floor | 1.00 |
| CR1.1c | Basement & foundations | Basement and protruding components on shallow foundations | 1.00 |
| CR1.2 | Topography | Stable slopes with inclination less than 15 degrees | 0.15 |
| CR1.3a | Bedrock | presence of stable bedrock | 0.00 |
| CR1.3b | Soil | coarse-grained soil (sand, gravel) | 0.00 |
| CR1.3c | Geomorphology | presence of stable geological formation | 0.00 |
| CR1.4 | Vegetation | vegetation prone to low damage | 0.30 |
| CR1.5a | Groundwater | water table prone to sudden fluctuations | 1.00 |
| CR1.5b | Surface water | close to permanent, seasonal and man-made water course | 1.00 |
| CR1.5c | Sea | far from sea | 0.00 |
| CR1.6a | Use | public | 0.20 |
| CR1.6b | State of conservation | Good | 0.00 |
| CR1.6c | Previous harming interventions | Yes, previous interventions | 0.00 |
| CR1.6d | Utilities | located in the second floor or above | 0.10 |

From the weight assignment in section 7.1, it is known that:

***Susceptibility= (0.20xBuilding and structures) + (0.10x Topography) + (0.10x Geosphere) + (0.20 x Vegetation) + (0.10 x Hydrosphere) + (0.30x Conditions)***

Building structures: (0.50x0.30) + (1.00x0.50) + (1.00x0.20) = 0.85

Topography: 0.15

Geosphere: (0.00x0.30) + (0.00x0.50) + (0.00x0.20) = 0.00

Vegetation: 0.30

Hydrosphere: (1.00x0.30) + (1.00x0.40) + (0.00x0.30) = 0.70

Conditions: (0.20x0.30) + (0.00x0.40) + (0.00x0.20) + (0.10x0.10) = 0.07

For the case study analysed:

**Susceptibility** = (0.20x0.85) + (0.10x0.15) + (0.10x0.00) + (0.20x0.30) + (0.10x0.70) + (0.30x 0.07) **= 0.336**

→ **Susceptibility = 0.34**

***2) Evaluation of exposure (sub-)criteria:***

| **Ref** | **Criterion/sub-criterion** | **Value meaning** | **Value** |
|---|---|---|---|
| | | *EXPOSURE (RQ2)* | |
| CR2.1a | Built systems and features | presence of built systems and features | 1.00 |
| CR2.1b | Natural systems and features | presence of natural systems and features | 1.00 |
| CR2.1c | Land use | Historical activities influencing development and modification. | 1.00 |
| CR2.1d | Cultural traditions | presence of cultural traditions | 1.00 |
| CR2.1e | Cultural acknowledgements | Grade II | 0.86 |
| CR2.2 | Population | population but no fragility | 0.30 |
| CR2.3 | Economic | livelihoods of local residents | 0.50 |
| CR2.4 | Infrastructure | Presence of relevant infrastructure | 1.00 |

From the weight assignment in section 7.1, it is known that:

***Exposure= (0.50xCultural significance) + (0.20x Population) + (0.10x Economic) + (0.20x Infrastructure)***

Cultural significance: (1.00x0.20) + (1.00x0.20) + (1.00x0.15) + (1.00x0.15) + (0.86x0.30) = 0.958

Population: 0.30

Economic: 0.50

Infrastructure: 1.00

For the case study analysed:

**Exposure =** (0.50x0.958) + (0.20x0.30) + (0.10x0.50) + (0.20x1.00) = **0.789**

→ **Exposure = 0.79**

### 3) *Evaluation of resilience (sub-)criteria:*

| **Ref** | **Criterion/sub-criterion** | **Value meaning** | **Value** |
|---|---|---|---|
| | | *RESILIENCE (RQ3)* | |
| CR3.1a | Maintenance | irregular maintenance | 0.50 |
| CR3.1b | Warning | presence of early warning systems | 1.00 |
| CR3.1c | Knowledge and awareness | knowledge and awareness ensured | 1.00 |
| CR3.1d | Information | partial or complete info exist but not available | 0.50 |
| CR3.1e | Policy and regulation | regulated CH protection | 1.00 |
| CR3.2a | Evacuation and rescue | Presence of evacuation and rescue plan | 1.00 |
| CR3.2b | Storage systems | Existence of storage system | 1.00 |
| CR3.2c | Mitigating systems | Existence of mitigating system | 1.00 |
| CR3.2d | Physical protection | Existence of (temporary) physical protection | 1.00 |
| CR3.3a | Financial recovery | funds available but insufficient | 0.30 |
| CR3.3b | Social recovery | Absence of social recovery plan | 0.00 |
| CR3.3c | Physical recovery | risk management plan exists and up to date | 1.00 |

From the weight assignment in section 7.1, it is known that:

***Resilience= (0.50xPreparedness capacity) + (0.25xCoping capacity) + (0.25xRestorative capacity)***

Preparedness capacity: (0.50x0.30) + (1.00x0.20) + (1.00x0.20) + (0.50x0.15) + (1.00x0.15) = 0.78

Coping capacity: (1.00x0.40) + (1.00x0.20) + (1.00x0.20) + (1.00x0.20) = 1.00

Restorative capacity: (0.30x0.30) + (0.00x0.30) + (1.00x0.40) = 0.49

For the case study analysed:

**Resilience** = (0.50x0.78) + (0.25x1.00) + (0.25x0.49) **= 0.7625**

→ **Resilience = 0.76**

***4) Vulnerability evaluation:***

**Vulnerability= 0.70xSusceptibility + 0.30xExposure -0.30xResilience**

V = (0.70x0.34) + (0.30x0.79) - (0.30x0.76) = 0.247

For the case study analysed:

**Vulnerability = 0.25**

With 0≤V≤1 (low to high vulnerability).