Environmental Impact Assessment Review 100 (2023) 107097

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Supporting metropolitan Venice coastline climate adaptation. A multi-vulnerability and exposure assessment approach

Denis Maragno [a,b,*], Gianfranco Pozzer [a,b], Carlo Federico dall'Omo [a,b]

[a] EPiC Earth and Polis Research Centre, Department of Architecture and Arts, Unierisità Iuav di Venezia & Fondazione Eni Enrico Mattei, Italy
[b] Università Iuav di Venezia, Department of Architecture and Arts, Italy

ARTICLE INFO

Keywords:
Climate adaptation planning
Climate change vulnerability
Multi-criteria analysis
Sustainable urban planning
GIS technique

ABSTRACT

Urban planning for adaptation to climate change privileges the construction of cognitive frameworks developed through the use of new spatial technologies and open-source databases. The significant and most highly innovative aspect concerns how resilience to CC under conditions of vulnerability and risk is defined, monitored and assessed.

Based on these premises, this paper aims to explore a new methodology of climate vulnerability, exposure and risk analysis through multicriteria assessment techniques by activating a case study in the coastal municipality of Jesolo (Italy).

Taking into consideration three main weather-climate impacts (Urban Flooding, Coastal Flooding and Urban Heat Island) the methodology searches for the best geo-referenced data that can best describe the recognizing impact of the cumulative impact condition through testing a GIS-based multi-attribute exploratory procedure. Intersectoral and multilevel vulnerability conditions at different spatial scales are configured.

The analysis methodology continues using open source data (from Open Street Map) to construct local exposure information layers. Exposure combined with spatial vulnerability conditions allows the generation of multi-hazard mapping.

Experimentation with multi-hazard climate-oriented spatial assessment can guide planning and public decision-making in new policy domains and target mitigation and adaptation actions in land planning, management and regulation practices.

Finally, the proposed methodology can activate stakeholder engagement processes within municipalities to discuss the actual perceived risk and begin a collaborative journey with citizens to identify best practices and solutions to adopt in the areas indicated by the risk mapping.

1. Introduction

The current conditions of cities and territories, adversely affected by the synergistic effect of climate-environmental change and physical space transformation (IPCC, 2007, 2019), call for a reorganization of local policies and an updating of land assessment and governance techniques(Busayo and Kalumba, 2021; Hurlimann et al., 2021).

Climate change (CC)-induced hazards, in particular, are the phenomena that most clearly need innovative tools capable of directing spatial development towards a new design and public decision-making perspective (Malczewski and Rinner, 2015).

Considering the need to adapt the territory as opportunities, that is, occasions to rethink urban spaces, redevelop or redesign territories, the cognitive dimension in planning assumes a strategic role (Gandini et al., 2021). The functions of the cognitive apparatus (understood as synthesis, geographic readings, produced through the capitalization of spatial data) must also be sufficiently adequate (effective) to support new urban urgencies until recently not present (Marin and Modica, 2017; Sharifi, 2021).

The recognition of the influence of CCs on urban landforms fosters and nurturing an informed use of new spatial information (Maragno et al., 2020, 2021; Rosentreter et al., 2020). The primary purpose supports the decision-making (and monitoring) phases of planning to consider unprecedented declinations of the concept of spatial adaptation

* Corresponding author at: EPiC Earth and Polis Research Centre, Department of Architecture and Arts, Unierisità Iuav di Venezia & Fondazione Eni Enrico Mattei, Italy.
E-mail address: dmaragno@iuav.it (D. Maragno).

https://doi.org/10.1016/j.eiar.2023.107097
Received 28 June 2022; Received in revised form 20 March 2023; Accepted 22 March 2023
Available online 29 March 2023

(Perminova et al., 2016; Rus et al., 2018; Islam et al., 2020).

In fact, for some years now, several national and international research experiences have been experimenting with new routes in the direction of adaptation, exploiting the potential of learning in information and technology (Ronchi et al., 2020). The IPCC (IPCC, 2012) defines vulnerability as the predisposition of a territory to experience climate impacts. Reading the territory through information layers, thematizing the predisposition of a territory to be impacted, allows the planner two essential things:

1. focus on the most vulnerable areas;
2. to consider adaptation solutions concerning the morphological vocation and architectural, cultural and functional characterization of vulnerable spaces.

This allows the study of solutions (Nature-Based Solutions, Green Infrastructures, etc.) and the redesign of spaces and areas through win-win approaches designed to reduce the effects of possible climate impacts, taking advantage of the opportunity to revise, rethink, and redesign cities, valuing their differences and peculiarities (Heinzlef et al., 2022).

Studies and research show how, by assuming vulnerability reduction as an intermediate goal to achieving spatial adaptation, it is possible to activate heterogeneous experiments useful to increase the resilience of different urban settings (Lerer et al., 2015; Morabito et al., 2015; Musco et al., 2016).

To do so, the urban planning discipline must be able to design new approaches of analysis, capable of returning spatial readings (Gis-based), answering the question "what if?", expanding in the planning evaluation stages, and understanding the relationship between climate change and land systems (Halla et al., 2022; Heinzlef et al., 2022; Liu, 2022; Limonta and Paris, 2017).

In a context where the impacts of CC on cities and territories are multiple, the need to assess conditions of territorial fragility related to converging climate stresses (multi-impact) is nurtured (Schetke et al., 2012; Khan et al., 2020; Zhang et al., 2020). Based on these premises, the present research pathway reasons the appropriateness of studying vulnerability as a logical product of different morphological behaviors, recognizing the concept of territorial multi-vulnerability, hereafter referred to by the acronym MV.

MV can be defined as a morphological response characterized by a variety of spatial assets and sensitive targets potentially stressed by a climate multi-hazard condition (Liu, 2022), which in turn is anchored in an interpreted spatial, geographic and meteorological context.

The MV concept recommends using spatial evaluative practices conducted on the morphological characteristics of territories and their resilience performance (Grafakos et al., 2020). It is an analysis model that integrates multi-criteria survey techniques to transform and combine geographical data and value judgments to optimize spatial analysis in selecting complex decisions. In doing so, the planning process can manage adaptation choices in a more informed and integrated way (Rus et al., 2018; Halla et al., 2022).

To support this reinterpretation, this paper seeks to answer four research questions (RQ 1-RQ 4) adhering to specific thematic categories: CC and multi-impact assessment; new planning paradigms; new opportunities for spatial assessment; new policies and strategic decisions for CC adaptation (Fistola et al., 2020).

In brief, the research questions guiding the survey are as follows:

RQ 1. Is it possible to recognize, classify, and compare morphological patterns predisposed to stresses generated by multi-impact climate?

RQ 2. Can spatial criteria be used to simulate the geographic behavior of climate impacts concerning the morphological and functional characteristics of the territory?

RQ 3. Can the exposure levels of an area subject to a potential multi-impact climate be assessed?

RQ 4. How can a spatial analysis on spatial multi-vulnerability improve CC adaptation policies and guide public decision-making in new policy domains?

In this direction, the hypothesis formulated here, which we seek to test with an exploratory multi-attribute survey, is that CCs configure intersectoral and multilevel conditions at different spatial scales. In these terms, a multi-system assessment of them facilitates the ability to read the problem by fueling the opportunity to guide the plan into new domains of research and transformation (Schetke et al., 2012; Padulano et al., 2021; Pietrapertosa et al., 2021).

To test the validity of the hypothesis, this paper tests a procedure for multi-vulnerability analysis in a sample municipality of the Upper Adriatic Sea (Municipality of Jesolo - Province of Venice). The procedure (hereafter referred to by the acronym P_{MV}) recognizes an exploratory potential to return a mapping of MV anchored to a definition of multi-vulnerability characterized by three types of climate impacts. Specifically, urban heat islands (UHI), urban flooding from extreme weather events (Urban Flooding - UF) and coastal flooding from intense storm surges (Sea storm - Ss).

MV mapping allows for map classification of land characterized by multi-vulnerability and assessing urban functions exposed to possible climate impact. Exposure is estimated on sensitive urban activities (infrastructural, settlement, commercial, financial, social or cultural), collected by data mining from Open Street Map (OSM) databases.

This analytical procedure helps to investigate a multi-risk approach to climate change. The risk characterization derives from the combination of three variables: vulnerability, hazard, and exposure (IPCC, 2019). In this study, the multi-risk assessment is based on different degrees of vulnerability mapping linked to the spatial analysis of urban activities (exposure). Multi-risk is therefore calculated as the propensity of a society or territory to suffer the adverse effects of climate change. The multi-risk is implementable with estimates based on the impact of the extreme events expected in future climate scenarios (hazards).

The study conducted on the Municipality of Jesolo responds to the technical-scientific content of the AdriaClim research program (Interreg Italy-Croatia Territorial Cooperation Program 2014–2020), whose objective is to consider MV assessment as a driver to support shared and multifunctional urban adaptation strategies.

2. Case study

The study area is the Municipality of Jesolo (Venice), a pilot territory of the AdriaClim research project (Fig. 1). The municipality is a typological-representative unit of the metropolitan system of Venice (CMVE) and the Regione Veneto territorial system. Overall, the Veneto coast is subdivided into 5 administrative units, and 3 are part of the research developed on AdriaClim. These municipalities play a central role in the Regione Veneto economic and social system. At the same time these are the more exposed coastal areas of the Adriatic basin. The presented research assumes the Municipality of Jesolo as it is the more representative context for overlapping climate impacts linking to socio-economic activities.

The territory of Jesolo covers about 96.4 km^2 and is inhabited by 26,503 inhabitants (source: ISTAT, August 31, 2022). It is an environment with particular geographical and climatic features.

The geographical shreds of places create a combination of natural and artificial, and complex forms of urbanization characterized by territorial fragilities linked to the geomorphology (Jesolo, 2016). Its proximity to Venice makes it one of the main tourist destinations, attracting millions of visitors every year. Jesolo is a well-established Venetian seaside resort in the national and international tourist landscape, with an average annual number of tourist visits of 5,438,519 visits/year (ISTAT, 2022).

The climatic evidence, on the other hand, refers to a temperate and

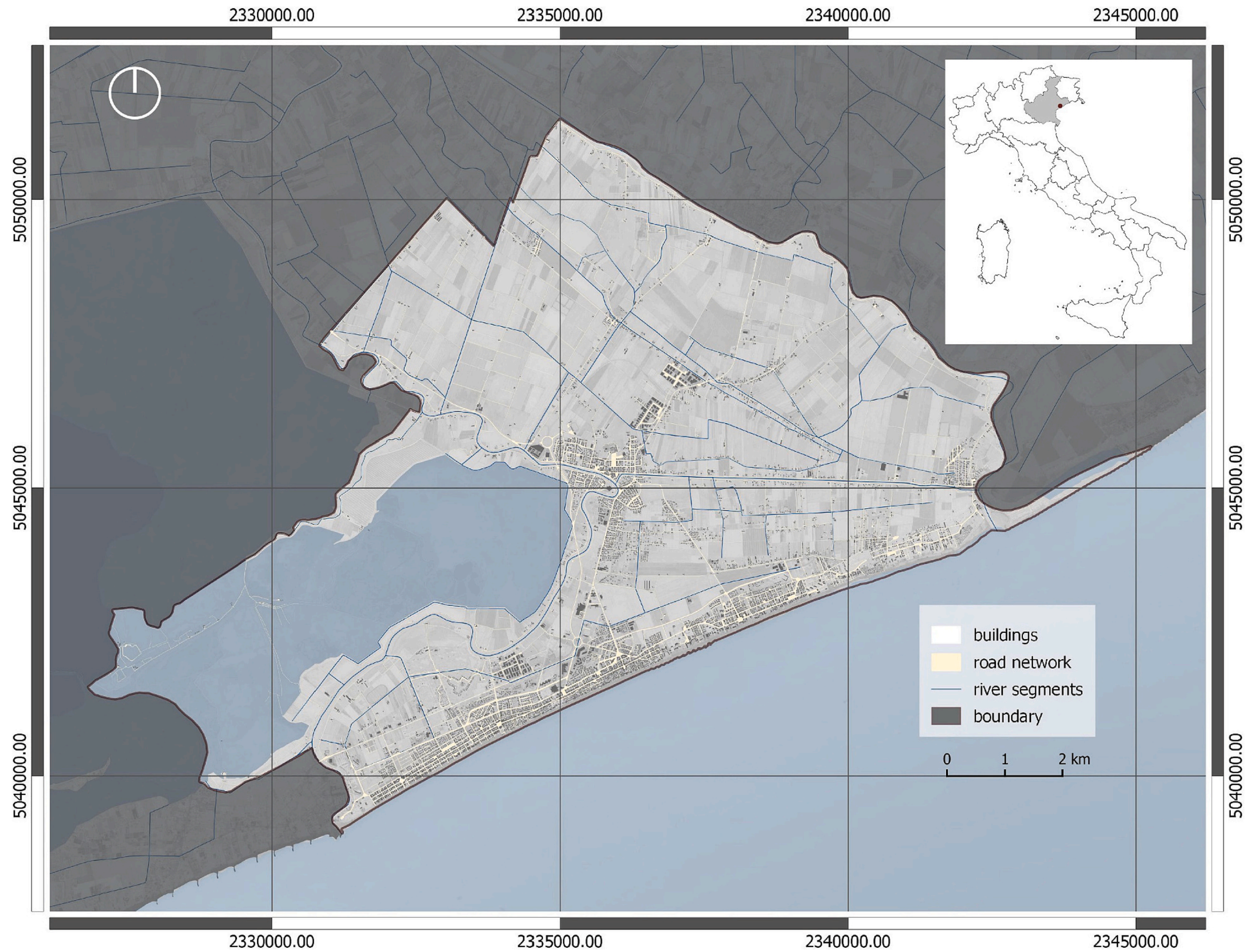

Fig. 1. Study area.

breezy climate, which is affected by the mitigating influence of the sea. Rainfall is variable: the seasonal average is similar in winter and summer and tends to decrease from the inland towards the coastal area. Rainfall is typically intense, concentrated in time, thunderstorms and accompanied by strong winds (ARPAV, 2021). During the summer, winds mitigate the high temperatures due to the sea breeze regime. However, the high building density of some municipal areas in summer often reveals urban forms that generate heat traps.

The choice to activate a multi-vulnerability analysis in this territory is, in particular, motivated by:

- presence of intense coastal urbanization;
- presence of urban and coastal flood-prone areas;
- presence of urban heat island formation;
- presence of coastal erosion phenomena.

3. Methodology

The methodology aims to assist and aid climate change adaptation policies. The workflow aims to meet the multiple expectations of each analytical and instrumental activity to answer the research questions. This process constitutes the heart of the research, guaranteeing its replicability, multiscalar, and multidisciplinarity. This approach aims to provide spatial planning with a practical and operational evaluation method to support and facilitate climate change adaptation strategies (Patassini, 2020; Siqueira et al., 2017). A greater awareness of the possible multi-impact conditions elaborated with multi-criteria investigation techniques favors the definition of procedures and adaptation choices more oriented towards the multi-actor decision-making process.

The methodology consists of two major phases.The first helps prepare the second step according to the local climate characteristics (own climate hazard and impact), while the second is helpful to assess the vulnerabilities and risk combining each impact defined in the first step. The new spatial information obtained has the function of leading adaptation planning and monitoring by showing (according to weight) the geography of the most vulnerable areas.

In a nutshell, the contents of the two phases are (Fig. 2):

- The first phase, based on the concept of multivulnerability (MV, as a condition defining the propensity of a territorial system to suffer damage induced by multiple climate stresses), aims to study the relationship between climate stresses and the territory, identifying climate impacts. The list of climate impacts will guide data collection and evaluation criteria in the second phase.
- The second phase defines the assessment techniques for processing multivulnerability using multi-criteria assessment and produces the exposure assessment to define local risk. The second phase produces three spatial outputs (multivulnerability, exposure and risk) whose task is to numerically synthesize the local vulnerability and risk propensity into two raster files. These raster files are advanced analytical tools, designed to be overlaid on the city within a GIS environment. They provide an in-depth understanding of the local geography of climate risk, by leveraging advanced data analysis and visualization techniques. They can be considered as "cognitive devices" as they enable decision-makers to acquire, process, and utilize information in order to identify patterns, make predictions, and take

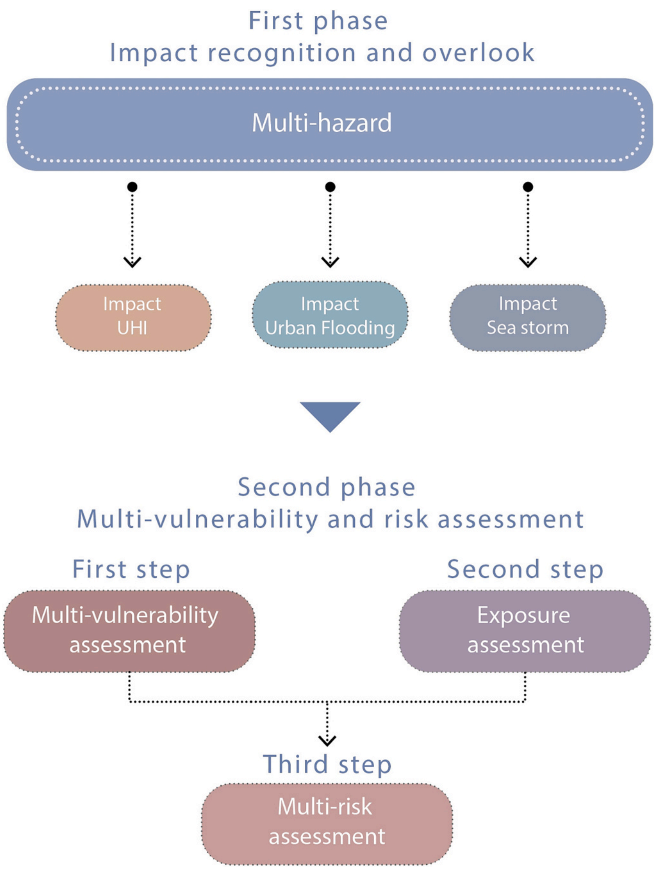

Fig. 2. Design methodology.

appropriate actions.

In the thesis, the planning uses assessment results as knowledge drivers to realign governance and local adaptation actions to the new challenges imposed by climate change.

3.1. *First phase - impact recognition and overlook*

The first assessment step requires an impact recognition providing a general knowledge framework to the MV assessment. In this sense, MV concept can be represented basing on the following theoretical-interpretive function:

$$A_{MV} = (I_1, I_2, \dots, I_n)_{mh} \tag{1}$$

where,

A_{MV} = "subject area", which describes the concept of multi-vulnerability (density, ecological values, infrastructure endowment, morpho-types, etc.) as a function of impacts I_i (UHI, UF, Ss).

mh = *multi-hazard.*

The concept of MV guides the work in this direction: mh is the result of observing climate data and its changes. Climate changes considered dangerous for infrastructure, the environment, society, and the economy define the local impacts (I_i).

MV is not understood as mere 'damage orientation' but as a concept that defines its conditions for generating a spatial context potentially exposed to a multi-hazard climate. MV is an extension of the concept of 'damage propensity,' with operational implications on the specific and differentiated critical issues related to climate change to which the AdriaClim project and the Jesolo case study attempt to respond.

As detailed in the introduction, the multi-hazard of the case study feeds three types of impacts: UHI, UF, and Ss. The choice to analyze multiple impacts pushes the present research and the AdriaClim project to go beyond approaches oriented to the analysis of single impacts, highlighting the need for evaluative models capable of defining the spatial interaction between urban morphologies and the risk equation (Pasi, 2020).

3.2. *Second phase - multi-vulnerability and risk assessment*

This second phase is developed from a process of spatial multicriteria analysis of converging climate impacts (Malczewski, 2006). It is a multi-methodological procedure that can be traced to define a systemic and multidisciplinary framework for assessing vulnerability and risk to climate change (IPCC approach to climate risk). From an operational point of view, the second phase is articulated in three separate but interrelated steps (see Fig. 2).

The first step is based on exploring spatial data and aims to develop a multi-attribute evaluation framework. The result is input for the definition of alternative spatial multi-vulnerability scenarios (Carver, 1991; Eastman, 1999). The recognition of vulnerability condition is defined by the combination of five sub-criteria standardized and weighted using AHP (Analytic Hierarchy Process) decision-making technique (Wind and Saaty, 1980; Saaty, 1987; Sahoo et al., 2016; Adolphson, 2010; Jeong, 2018), and aggregated through a weighted sum. This procedure uses satellite-derived data (Landsat-8) and pre-processed morphological data from the Copernicus EU Earth observation and monitoring program (Colson et al., 2018; Oliveira et al., 2020; Rosentreter et al., 2020). The added value of these information models makes the spatial analysis open, continuously integrable, and directly comparable.[1]

The second step activates the exposure analysis. The objective is to recognize the local risk starting from the definition of multi-vulnerability and considering those economic assets and neighborhood services that characterize the urban context under examination as exposed factors.

Through a spatial convergence between multi-vulnerability and exposure (third step), it is possible to represent a multi-risk indicator to establish management and planning priorities for urban and territorial spaces.

3.2.1. *First step: multi-vulnerability assessment*

Following the recognition of MV (A_{MV} - First phase), the workflow continues with a data collection to select the morphological evaluation criteria used in the assessment methodology (P_{MV}).

P_{MV} uses information and data from heterogeneous sources. They allow to describe the profile of the urban-territorial system and to define A_{MV}, referable to the three reference impacts: UHI, UF, Ss. From an evaluation point of view, these three types of impact can be interpretative meta-criteria. Some data originate from remote sensing analysis algorithms, while others come from pre-packaged spatial information available in regional, provincial and European work/research settings (Table 1). (See Table 2.)

By combining the meta-criteria with the data in Table 1, it is possible to define a spatial multi-criteria approach, i.e. to recognize the spatial domain of MV.

Specifically, the use of the data in Table 1 has a threefold purpose:

[1] The increased potential for processing and elaborating data acquired from remote sensors favors the development of new and unprecedented investigation techniques that can be easily updated with new information deposits coming from the processes of digitalization of the territory. Using new investigation techniques in remote sensing solutions allows the integration of the information reservoirs with new multi-source data. It provides scientific research with exhaustiveness and completeness of data, indispensable also to orient better the choice of the information criterion concerning the investigation demand.

Table 1
Information layers and base maps used for multi-vulnerability analysis.

Information level	Type	Resolution	Source	Year
Vegetation Health Index (VHI)*	Raster	30 m × 30 m	Landsat 8 (United States Geological Survey-USGS)	2020
Map of runoff coefficients (MCD)**	Raster	30 m × 30 m	Università Iuav di Venezia	2018
Digital Terrain Model (DTM)	Raster	25 cm × 25 cm	City Subway of Venice	2014
Imperviousness Density (IMD).	Raster	10 m × 10 m	Copernicus Programme	2018
European Settlement Map (ESM)	Raster	2 m × 2 m	Copernicus Programme	2015
Soil cover and soil cover database	Shapefile		Wind Region	2018

* Elaboration *by the authors conducted on multispectral image "LC08_L1TP_191029_20200730_20200807_01_T1".*
** *Elaboration on Veneto Region Land Cover database (CCS 2018). See* Maragno et al., 2020.

carried out according to the fuzzy set theory (Charabi and Gastli, 2011; Khan et al., 2020) with 'ramp functions' (or sigmoidal). The application of fuzzy membership functions allows for defining the level of eligibility.[2] The criterion is expressed in a scale of values included in the interval [0,1] (0, null eligibility; 1, maximum eligibility).

With the AHP decision-making technique, P_{MV} organizes the evaluation in a hierarchical form.[3] Expressing a preference judgment through the pairwise comparisons of the criteria that contribute to the classification of the alternatives[4] and the construction of the final decision (Wind and Saaty, 1980; Estoque and Murayama, 2010). Pairwise comparisons are made using the scale of absolute numbers (Table 4), which summarizes the level of importance of the criteria (Saaty, 1987).

In the AHP approach, it is also necessary to verify the degree of consistency of the matrix. The degree of consistency can be verified by calculating the consistency index IC,[5] verifying that the values associated with each criterion do not correspond to a random association. The IC is less than 0.1; thus, the matrix is said to be of acceptable in the judgments' consistency of the judgments made. The use of raster models, together with a weighted linear combination with the preference

Table 2
Definition of the MV "subject area" and generation of evaluation criteria.

Subject area	Interpretive meta-criterion	Evaluation criterion	Criterion definition	Format and metrics of the criterion	Metrics	Value range	Notes
MV	UHI	Vegetation Healt Index (VHI)*	Vegetation health indicator	Raster image	%	0–100	High values identify water stress conditions
	UHI, UF, Ss	Imperviousness Density (IMD).	Level of sealed soil	Raster image	%	0–100	High values identify areas of high sealing and low vegetation
	UF, Ss	Runoff coefficient map (MCD)	Spatial association between runoff coefficients and land uses (CCS)	Raster image	%	20–90 (0,2 - 0,9)	High values identify urban *flooding* conditions
	UF, Ss	Digital Terrain Model (DTM)**	Digital map of land elevation distribution	Raster image	Altimetry expressed in cm	−100 - +200	High values identify areas most susceptible to storm surges and flooding
	UHI, UF, Ss	European Settlement Map (ESM).	Map of human settlements	Raster image	Dichotomous spatial information	[0,1]	The value 1 identifies a high concentration and compactness of constructions

* VHI is a satellite index that detects vegetative cycles and areas with good vegetative health. However, in this research, VHI is used as a criterion of environmental criticality, recognizing surface areas more susceptible to heat wave. In this case, values corresponding to the complement of 100 are utilized and must be reversed for proper analysis.
** DTM values are reversed. High values identify urban and coastal areas with relatively low elevations.

- Characterize the meta-criteria concerning the nature of the climate impact;
- Define the judgment criteria with which to evaluate the semantic domain;
- Evaluate and describe the relationship between urban morphologies and their susceptibility to climate impact.

The characterization of MV is defined by selecting a core set of morphological criteria suitable for recognizing vulnerability in a multi-impact key. The following Table, a logical association between MV "subject area", interpretative meta-criteria and evaluative criteria is reported.

P_{MV} (Fig. 3) allows us to build a multi-attribute spatial assessment model by exploiting morphological variables as decision criteria that can return the propensity of spatial systems to be negatively affected by a multi-impact climate (Luria and Aspinall, 2003; Perminova et al., 2016; Li et al., 2022).

Given the different metrics of each criterion, normalization is essential to limit the excursion of values within intervals, or ranges, that are irrelevant to weighting (Table 3). The normalization process is

[2] Suitability refers to the effectiveness of the criterion in recognizing a spatial vulnerability condition.

[3] The AHP technique is developed by applying a hierarchical analytical model, which allows the evaluation of a set of alternatives in the presence of multiple criteria. It is a model of reticular analysis that develops on multiple levels through a hierarchy of dominance. The evaluation problem is decomposed into sub-problems of easier size to solve. For further discussion see Saaty (1987) principle of hierarchical composition.

[4] The alternatives depend on the suitability of the evaluation criteria. The representation of the alternatives is returned through the final suitability map (MV). The alternative is associated with the pixel, the latter being an arbitrary spatial unit (Uribe et al., 2014).

[5] The consistency index (defined by Saaty) is determined as IC = (max-n)/(n-1), where λmax represents the maximum eigenvalue given by the average of the consistency measures Zi associated with the row values (eigenvalues). The symbol [n] represents the number of criteria. In the case of good or perfect consistency, the CI index ranges from 0 (perfect consistency) to 0.1 (good consistency). For values greater than 0.1, it is appropriate to reformulate the judgment matrices by redefining multiple pairwise comparisons. The judgment is sufficiently consistent if the consistency ratio (RC) is approximately equal to or less than 0.10. RC (RC=IC/RI) is obtained by comparing the CI index with the Random Index RI derived from Saaty (1987) random index scale. The RI index is chosen in relation, linking to the number of items used in the pairwise comparison.

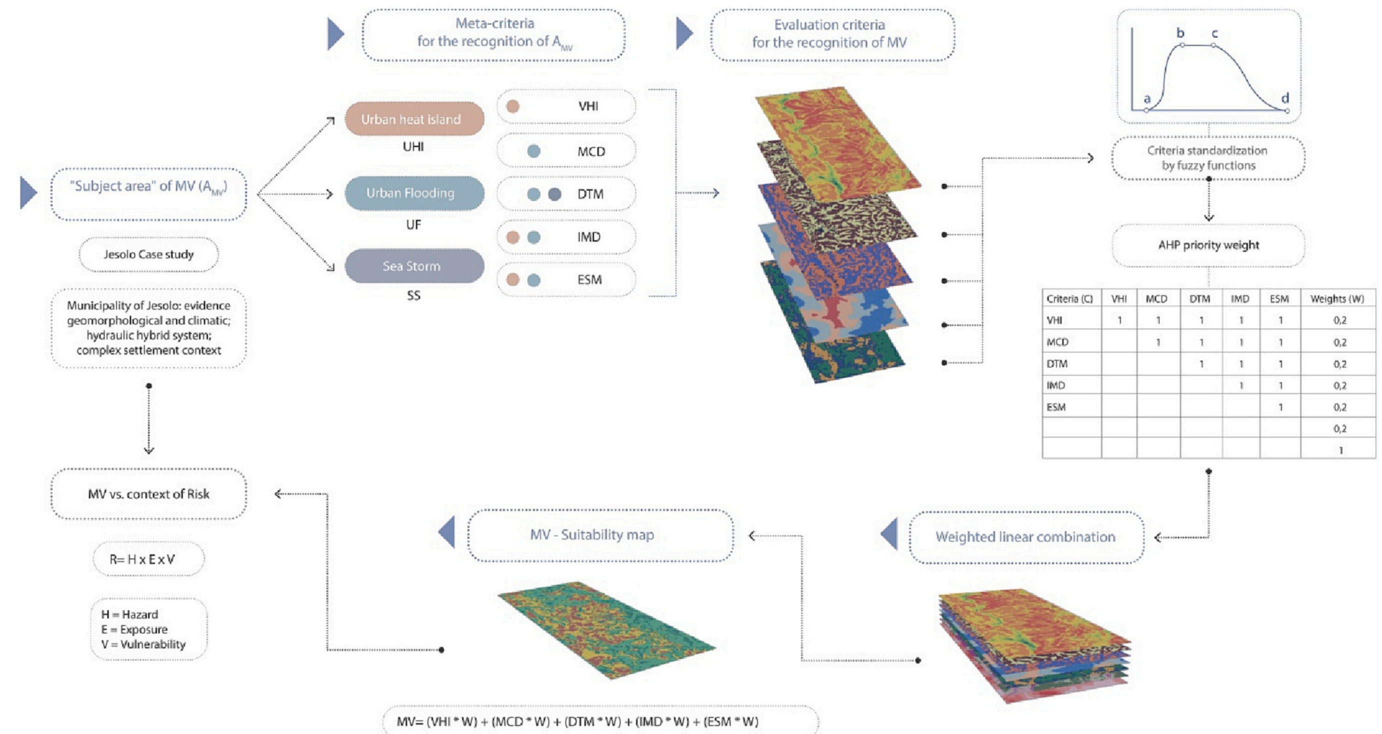

Fig. 3. Multi-attribute evaluation procedure P_{MV}.

Table 3
Fuzzy normalization of evaluation criteria.

Criterion	Metrics	Standardization	Function	*Suitability* value
VHI	%	[0, 1]	Fuzzy membership - large	Suitability values increase with increasing drought.
IMD	%	[0, 1]	Fuzzy membership - power	The suitability values increase with increasing waterproofing
MCD	%	[0, 1]	Fuzzy membership - power	The suitability values increase as the runoff coefficient increases
DTM	centimeters	[0, 1]	Fuzzy membership - linear	Suitability values increase near depressions.
ESM	Dichotomous variable (0,1)	[0, 1]	Fuzzy membership - linear	Suitability values increase near high settlement density

Table 4
Saaty's reference scale for pairwise comparisons (AHP method).

Definition (scale)	Rating (intensity of importance expressed in absolute numerical value)	Reciprocal
Equal importance	1	1
Moderate importance	3	1/3
Strong importance	5	1/5
Very strong importance	7	1/7
Extreme importance	9	1/9

judgments, finally allows the aggregation of the five evaluation criteria and the construction of the suitability map MV.

3.2.2. *Second step: exposure assessment*

The secondstep deals with the construction of the climate change exposure map. The exposure *layer* is recognized by structured detection of urban assets from OpenStreetMap (OSM) source. Infrastructural and economic assets, neighborhood functions and services necessary for the proper functioning of the urban fabric under consideration are considered exposed factors (Table 5).

The model uses the API (Application Programming Interface) protocols and the OSM tags (keywords). The OSM project tags are gastronomy; culture, entertainment and arts; historical objects; leisure, recreation and sports; waste management; tourism and accommodation; finance; healthcare; communication; transportation; administrative facilities; shops and services. These are twelve macro-categories that allow returning a certain homogeneity and consistency of spatial information directly related to the functional profile of the urban space under study[6]. The collection of data is done by specifying an export area (or mining), in the case of research data were downloaded for all the coastal

Table 5
Information layer used for exposure assessment.

Information level	Type	Resolution	Source	Year
Urban activities	Shapefile		OpenStreetMap (OSM)	2021

[6] User-generated 2.0 data have advantages related to continuous updating, the wide coverage, the concretization of information through a plurality and free accessibility of sources. Can encourage the presence of repeated or low-precision data (Hochmair et al., 2018; Yang et al., 2018). However, these data are often not subject to quality control. Another issue Yang et al. (2018) with respect to OSM-type data concerns their spatial distribution: often, only the most densely populated areas have a complete bouquet of information.

municipalities of the Veneto Region.

The exposure analysis then involves creating a density map using the Kernel Density Estimation (KDE) algorithm, which the team based on a 200-m radius. The team used this non-parametric density function in three dimensions that estimate the intensity of a distribution of points within a specified radius or threshold (τ) by weighting them according to their distance from the point of estimation (Gatrell et al., 1996). This method enables the research team to observe specific settlement patterns that are more vulnerable or exposed to risks due to climate change based on density, distribution, characteristics, and functions.

The team used this procedure to produce a raster image with concentration values, useful in the multi-risk estimation phase.

3.2.3. Third step: multi-risk assessment

Finally, the third and last step (of the second phase) involves associating MV information with the exposure component. The spatial convergence between multi-vulnerability and exposure represents a valid indicator of local multi-hazard, useful to establish management and planning priorities for urban and territorial spaces.

The multi-risk estimation is then derived through the spatial relationship between the MV variable and the exposure variable returned in the form of a density map (KDE).

This step analyzes the convergence of impact effects from a multi-risk perspective. It identifies which parts of the city are most vulnerable to adverse climatic-environmental conditions. The team uses the report (Table 6) to evaluate which activities are most impacted by multiple risks.

4. Results

4.1. Multi-vulnerability results

The hierarchical evaluation assumes that the problem under study is representable in this form. Although a limitation, the procedure allowed to recognize the level of importance of the criteria (preference or position)[7], estimating the eigenvector of global priorities. The assignment of preferences (or weights) depends on analytical-assessment choices accrued during the AdriaClim research project (Table 7).

The eigenvector, derived from the analytical evaluation of hierarchies, allows determining which criterion is more important in relation to the superordinate objective (MV) and what extent.[8]

The results show that the most important criteria for the spatial recognition of MV are morpho-typological criteria, followed by land use, the ecosystem component and population density.

The MV suitability (Fig. 4) returns the 'climate-territory' relationship, relating a climate multi-impact (UHI, UF, Ss) to urban ecosystem performance[9] as a filter. The values are presented on a scale of 0 to 1, where high values indicate a high degree of susceptibility to spatial multi-vulnerability, and low values to conditions of resistance and resilience. To effectively report the spatialization of the results, MV suitability is classified into 5 homogeneous classes: low MV (0–0.2); medium-low MV (0.2–0.4); medium-high MV (0.4–0.6); high MV (0.6–0.8); very high MV (0.8–1).

The assessment of MV returns different responses to the impact. The predisposition to multi-vulnerability results prominent in the land use classes "Dense Urban Fabric", "Dense Discontinuous Urban Fabric", and "Industry, commerce, infrastructures, public and private services", where an incidence of 82,82%, 40,43% and 34, 10% respectively has been calculated (Table 8). In these classes, it is evident how planning patterns and urban morphologies can contribute significantly to the reduction of the mitigation capacity of the spatial ecosystem.

Table 6
Multi-risk assessment model.

Territory of investigation	Exposure	Vulnerability	Risk	Reference statistical unit
Municipality of Jesolo	The density of urban point functions downloaded from OSM	MV calculated through a multi-criteria evaluation	Product between MV and display	Pixel

Table 7
Matrix of dominance coefficients.

Criteria	MCD	DTM	EMS	IMD	VHI	Derived weight (Autovector)
MCD	1					0,102
DTM	9	1				0,266
ESM	1	1/5	1			0,140
IMD	4	4	4	1		0,352
VHI	1	1	1	1/5	1	0,140

λ_{max} = 6,02; number of factors = 5; CI = 0,00, RI = 1,11; RC = 0.

4.2. Exposure results

The exposure is returned with semi-automatic detection of urban activities performed in August 2021, exploiting OSM Application Programming Interfaces (APIs). At the end of the survey, a single spatial layer of about 844 detections was produced (organized into 12 macro-classes: "Culture, entertainment and arts"; "Historical elements"; "Finance and communications"; "Gastronomy"; "Waste management"; "Health services"; "Mobility"; "Shops"; "Administrative services"; "Leisure and sports"; "Tourism and accommodation"; "Schools". Geolocation returns a characterization of urban places with specific integrated economic functions. In addition to the urban ecosystem phenomena of which it is an expression, about the social, tourist and cultural connective trends.

The second level of processing concerns the spatial properties assumed by urban activities. This is an analysis methodology conducted with a statistical density measure carried out based on the "exposure" layer. As can be deduced from the reading of Fig. 5, the density analysis improves the understanding of the distribution of the point data through a *cluster* representation.

Clustering allows us to observe the shape of the city and to identify functional areas with a certain regularity in the spatial distribution of urban activities. Most activities are concentrated in the urbanized districts (the central ones) and on the coastal strip.

4.3. Multi-risk results

The multi-risk assessment, derived from the relationship between MV and exposure density (KDE), yields a spatial reality in which the denser areas of the city are more susceptible to climate multi-impact. The results (largely predictable) are described in Fig. 6, where the indicator takes high values in correspondence with possible greater damage that the multi-impact can procure to urban activities, in relation

[7] AHP assumes that those involved in the evaluation process have judgment skills that are sufficiently analytical and consistent with the objective of the evaluation.

[8] At the end of the evaluation this process can be subjected to sensitivity analysis to verify the robustness and the stability.

[9] MV recognition is strongly oriented to urban context. The final MV suitability values are then clipped using the first level of the Veneto Region land cover and land use database (CCS, 2018).

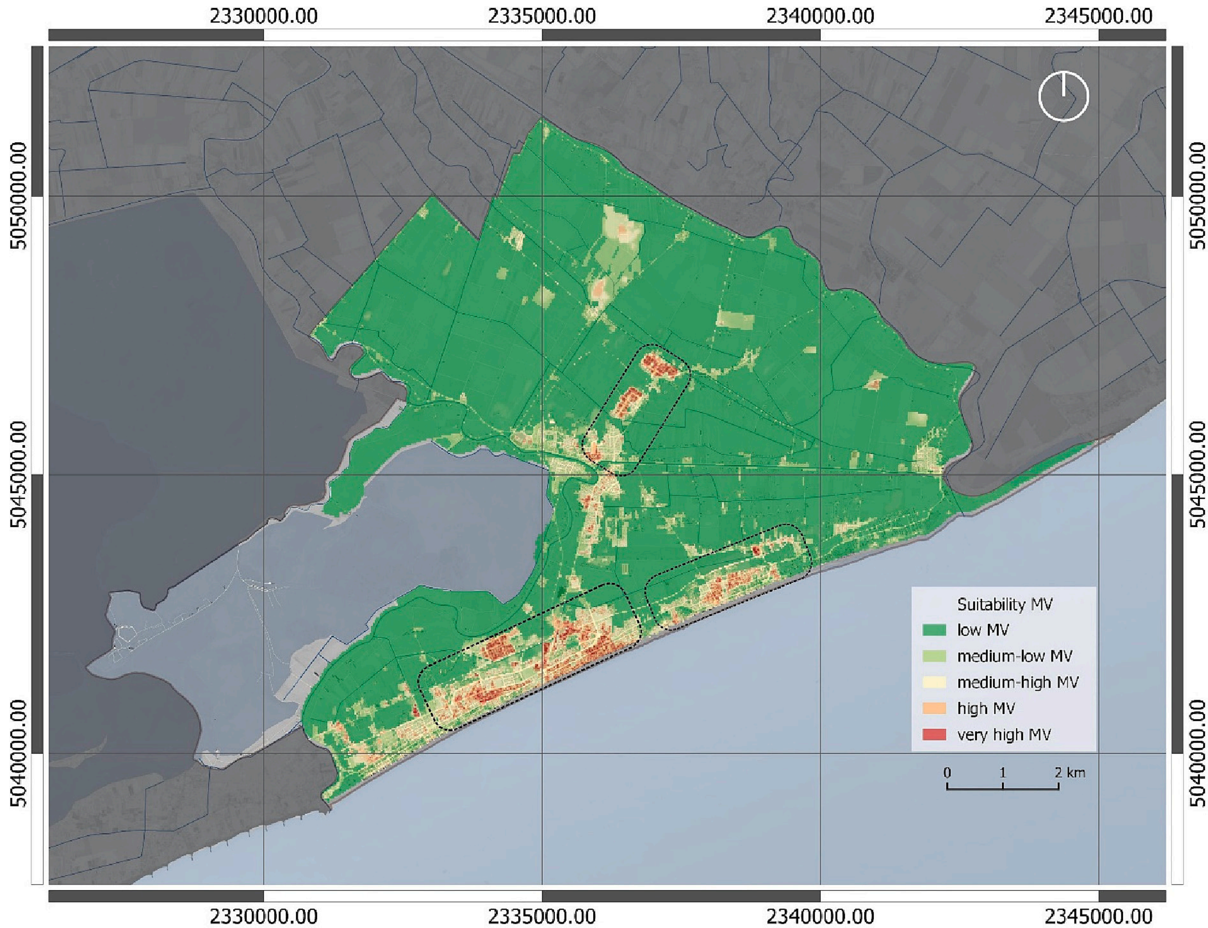

Fig. 4. Multi-vulnerability (MV) suitability map.

Table 8
Percentage incidences of high and very high MV in the land use classes of the CCS 2018 database (Veneto Region).

Land uses	Total area in hectares	Surface subject to high and very high MV	
		hectares	%*
Dense urban fabric	34,42	28,51	82,82
Dense discontinuous urban fabric	259,5	104,91	40,43
Medium/severe discontinuous urban fabric	653,96	47,61	7,28
Industry, commerce, infrastructure, public and private services	318	102,11	32,11
Road network	195,51	49,17	25,15
Mining areas, landfills areas under construction	198,17	21,71	10,96
Urban green areas	85,74	2,09	2,43
Sports and recreational areas	125,32	4,18	3,34
Total	1870,62	360,28	19,26

* Percentages of high and very high MV of each land-use class made a hundred its total area.

to their continuity and distribution in the MV domain.

The precise analysis of the data also allows us to obtain information on the urban activities most exposed to climatic multi-risk. In particular, Table 9 shows significant percentages of high and very high multi-risk for the most central urban fabric of the city and the commercial and craft sectors. Not negligible incidences are also found in the finance and communications sector, health services and tourism activities (referring to accommodation and associated services).

5. Discussion

The methodology outlined in this paper is a comprehensive tool for knowledge and awareness acquisition. The tool guides users through multi-vulnerability, exposures, and multi-risk, encouraging integrated and systemic perspectives in planning. Innovatively, the research methodology assists in developing strategic reflections and decision-making processes tailored to multiple climate risks. Experimentation with a multi-system spatial assessment enables planning to raise awareness of the use of multi-objective information and to support public decisions defining 'anti-vulnerability' strategies that can be matured in a multi-actor working domain (Ameen et al., 2015; Gandini et al., 2021; Rudge, 2021). In this case, the AdriaClim project proves to be a valuable planning process in recognizing this new operational relevance concerning three operational characteristics:

- returning a spatial response to climate change based on a systemic reading of the morphological characters of places;
- reading exposure in a context interpreted according to multi-impact climate logic and creating risk priorities according to specific urban and socio-economic profiles and interests;
- facilitating urban adaptation procedures based on thoughtful and shared choices.

Considering the results of the applied methodology and the shared experience gained from collaborating in the Adriaclim Project, the discussion focuses on the objectivity of the work, its limitations, and potential in order to answer the research questions set out in the introduction to this paper.

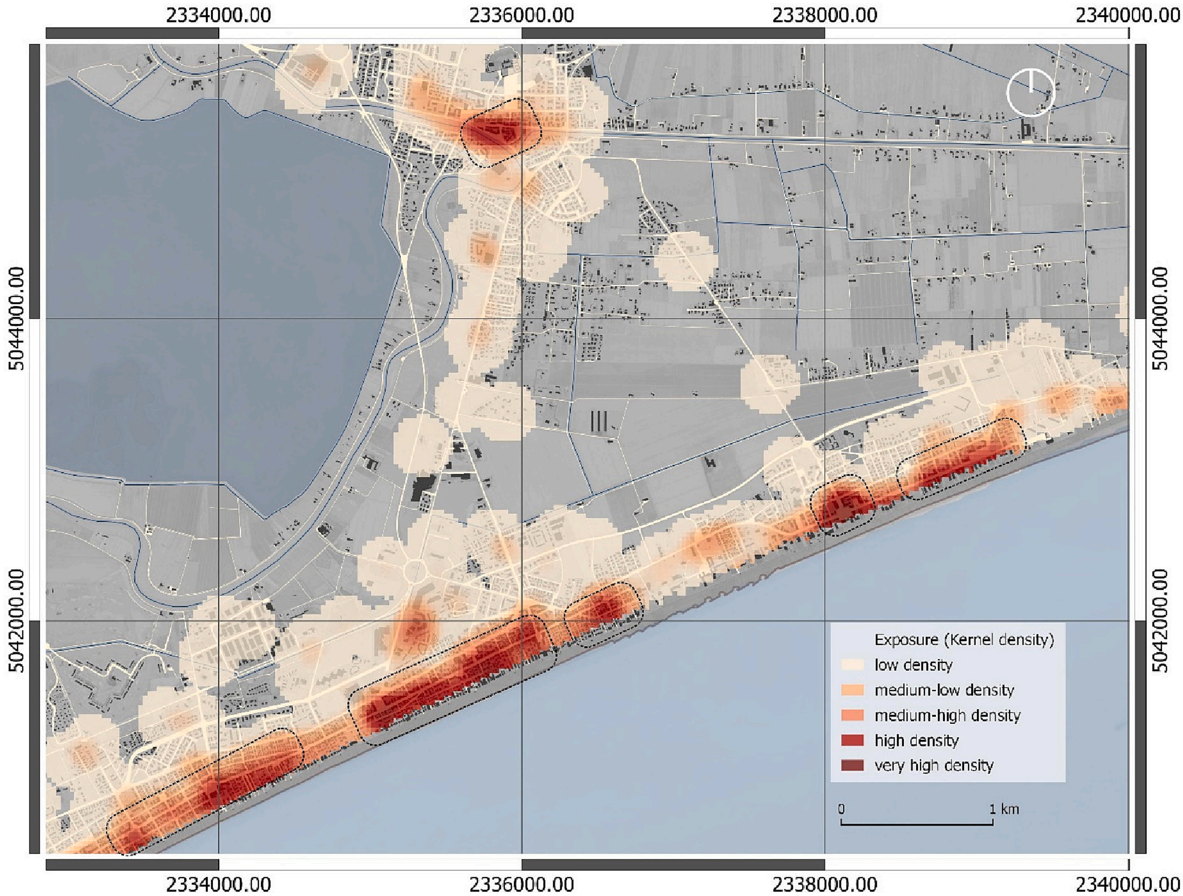

Fig. 5. Urban activity density broke down into five classes using the natural breaks method.

RQ 1 - The spatial multi-vulnerability assessment tested in the previous sections represents an essential part of the definition of new planning paradigms aimed at addressing the most significant emergencies concerning climate change (CC). Placing CC at the center of a multi-attribute spatial assessment fosters the creation of an acquisition tooluseful for recognizing urban forms and morphologies of places most sensitive to expected impact scenarios (Fig. 4).

The methodology presented here stimulates the fusion of spatial functions typical of GIS with multi-criteria analysis (AMC) techniques typical of Spatial Decision Support Systems.[10] The main innovations introduced by the procedure result:

- Improving the spatial geodatabase oriented to drive and monitor the climate mitigation and adaptation process;
- Testing of a spatial multi-vulnerability estimation procedure to support the spatial recognition of urban multi-risk (with *Risk = {Vulnerability, exposure, hazard});*
- To feed a tailor-made spatial assessment and establish diagnostic monitoring proper to verify climate-proof planning more frequently by exploiting today's dynamic data from new information technologies.

RQ2 - This study examines the concept of multi-impact and spatial multi-vulnerability analysis to identify a design that can reveal ecosystemic relationships, illustrate their connections, and demonstrate methodological rigor. The analytical-exploratory approach of spatial inquiry serves as both a means of learning and a design element. The design approach is rooted in the spatial recognition of the association between morphological fragilities and strategic spatial values, specifically, the relationship between multi-vulnerability and exposure.

This relationship enables the identification of multi-risk or the search for urban contexts that are functionally and formally connected to settlement emergencies caused by the harmful effects of a multi-climate impact. The identification of multi-risk takes into account the interests of various stakeholders, as revealed through a structural analysis of different exposure profiles (Fig. 5). The tolerance of different stakeholders to multi-risk depends on social, economic, and structural factors.

The spatial association between vulnerability and exposure allows for an initial understanding of the multi-hazard climate on the morphological-functional profiles of urban space. The relationship between these variables improves the survey model as a driver of innovation, enabling the testing of the dynamics of settlement contexts' response to climate change by category, size, and spatial location (Fig. 6). In areas most vulnerable to multi-impact, testing exposure against levels of multi-vulnerability returns degrees of risk in highly infrastructured contexts, with a focus on local climate response in coastal settings (Fig. 6).

In summary, coupled with exposure, the multi-vulnerability model can be used to define re-planning strategies and to implement and manage local adaptation works that are significant in terms of economic and social value in areas most prone to multi-impact.

RQ 3 - To perform analyses of territorial fragility, it is essential to identify climate adaptation measures appropriate for the physical and functional context of the urban fabric in which they are to be implemented. These can be evaluated and compared through the study of exposure and the relevance of stakeholders (local actors subject to specific territorial fragilities). The spatial correlation between multi-vulnerability and density of services and functions guides a dialogic

[10] Evaluative-decisional practices have the purpose of developing and solving problems inherent in environmental and land management.

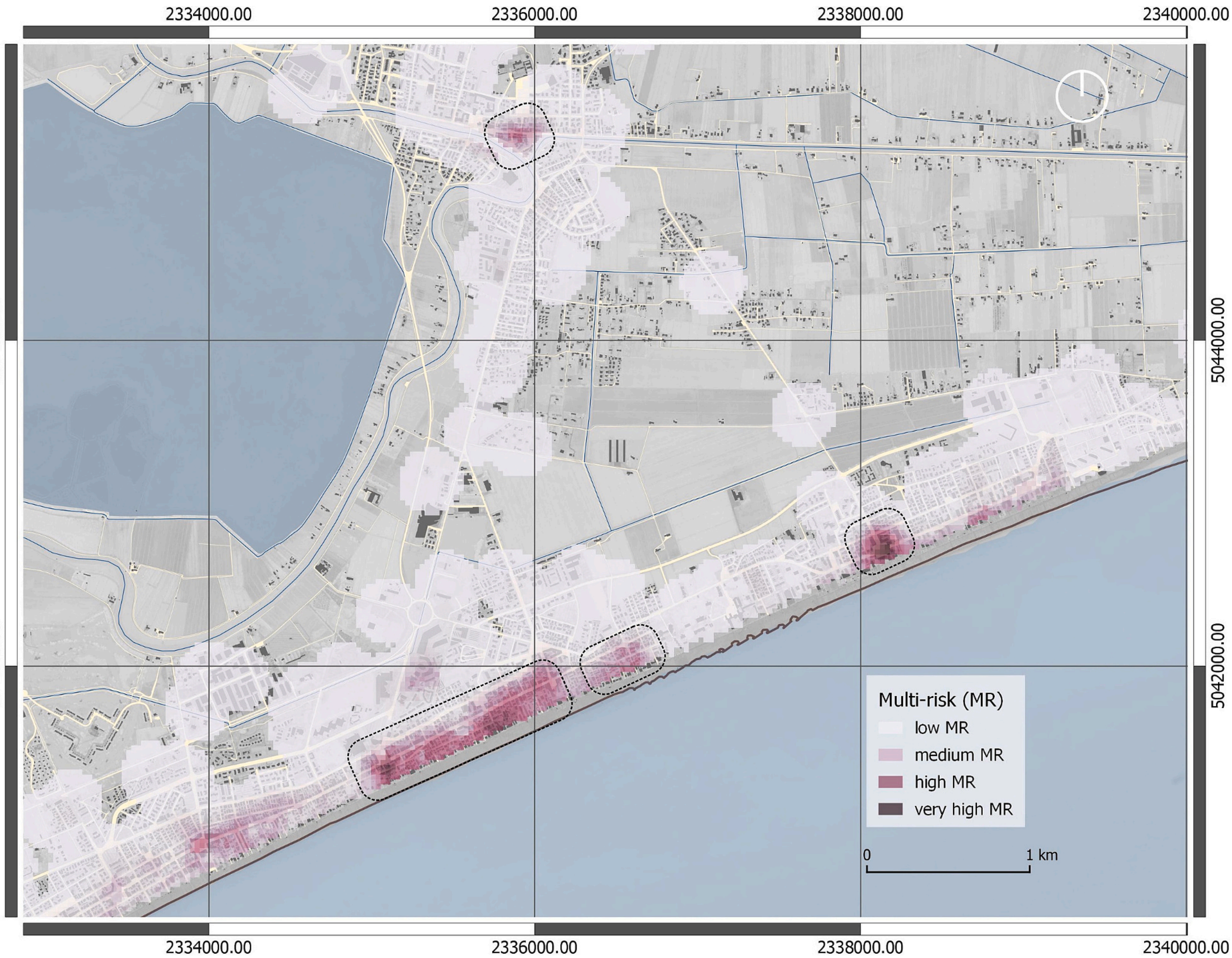

Fig. 6. Multi-risk (MR) map.
Index with values ranging from 0 to 1, where 0 indicates zero MR and 1 maximum MR. The classification uses a quantitative comparison criterion: evaluated and weighted according to the characteristics of the statistical distribution of the variable (MR).

Table 9
Percentage incidences of high and very high multi-risk in the 12 macro-categories related to urban activities.

Macro-categories of activity	Number of activities in the macro-category	Activities subject to high and very high multi-risk	
		n.	%*
1- Culture, entertainment and arts	10	5	50,00
2- Historical elements	3	0	0,00
3- Finance and Communications	22	11	50,00
4- Gastronomy	172	33	19,19
5- Waste management	128	21	16,41
6- Health services	23	3	13,04
7- Mobility	174	19	10,92
8- Shops	78	23	29,49
9- Administrative services	4	2	50,00
10- Leisure and sport	22	0	0,00
11- Tourism and accommodation	205	74	36,10
12- Schools	3	0	0,00
Total	844	191	22,63

* Percentages of high and very high multi-risk of each macro-category, made up of 100 % of the total assets that compose it.

exploration of the territory, which enables the development of adaptation processes that can be matured in the context of criteria and alternatives. The exposure analysis leads to a decision hierarchy, where multi-impact characterization is essential. The analysis of the results reveals that the tourism-accommodation sector is one of the urban functions most affected by multiple climate risks (as seen in Table 9). The level of risk is primarily influenced by geographical contextualization, and this percentage decreases as one moves away from the coast. Other factors such as culture, entertainment, finance, and communications also come into play. The risk analysis highlights the need for a local government to adopt a diversified approach in designing, implementing, and managing urban regeneration and adaptation interventions. The multi-risk tool is primarily used to activate adaptation initiatives of the existing heritage through the significant involvement of private parties as partners.

Identifying and assessing exposure to hazards is well-established for known hazards such as earthquakes, eruptions, and cyclones. However, the exposure level needs to be better defined for climate hazards such as the sea-level rise and extreme heat. This raises the question of whether we should establish a systematic approach to defining exposure to climate hazards.

Local governments must adopt a diversified approach to manage and design urban regeneration and adaptation interventions effectively. Geographical contextualization primarily determines the level of risk, and as we move away from the coast, the risk decreases. Other factors such as culture, entertainment, finance, and communications also come into play. The multi-risk tool primarily activates adaptation initiatives of existing heritage through the significant involvement of private parties as partners. This approach confirms the usefulness of the multi-risk tool in activating adaptation initiatives. However, assessing and addressing potential risks becomes challenging with a clear understanding of exposure to climate hazards. This is an open question that deserves further research and consideration.

RQ4 - GIS functions are essential in integrating data and interpreting spatially-referenced phenomena. However, the multi-attribute exploratory analysis also plays a significant role in using comparative techniques and procedures to structure a learning process that makes the spatial dimension of decisions precise. For example, the spatial correlation between multi-vulnerability and density of services and functions guides a dialogic exploration of a territory. This enables the development of adaptive processes that can be matured in a context of criteria and alternatives that can be evaluated and compared through the study of exposure and the relevance of stakeholders (local actors subject to specific territorial fragilities).

Climate change is becoming an increasingly complex problem affecting different levels and areas. The climate change issue is increasingly a multilevel and cross-sectoral condition. One way to better understand this problem is to use different methods to study how different things are related in space. By doing this, we can understand better how to make decisions that can help protect people and places from the effects of climate change. This can help government and other organizations work together to create plans to make our communities more resilient to climate change. Decision Support Systems (SDSS) are correctly integrated with the multi-vulnerability and multi-risk assessment steps. The concepts of multi-attribute and multiple impact analysis facilitate the role of Spatial Decision Support Systems (SDSS) when adequately integrated with the multi-vulnerability and multi-risk assessment steps. Experimentation with multi-system spatial assessment could sensitize spatial governance practices to use multi-objective information that can support public decisions about the definition of anti-vulnerability strategies that can be matured within a multi-actor working domain.

6. Limitations and recomandation

Reflecting on the limitations of this research highlights the need for further improvement. Despite the limitations of available data, which hinder the production of more precise indicators, technological advancements can enhance the efficiency of the survey and decision support protocol. The methodological matrix employed in this research remains relevant and adaptive to innovation, serving as the foundation for future improvements.

However, it is essential to acknowledge that simply relying on technological advancements may not be enough to overcome these limitations (Klutho, 2013). A comprehensive approach encompassing a range of interrelated factors, including data collection and analysis, is necessary to fully address the challenges posed by limited indicators.

The methodology employs a multi-attribute spatial assessment to pinpoint areas most susceptible to climate change impacts and advise strategies for reducing vulnerability. Using GIS and multi-criteria analysis techniques allows for a more nuanced and detailed understanding of the complex interplay between various vulnerability factors.

One of the methodology's key strengths is its ability to synthesize multiple perspectives and consider the interests of various stakeholders, resulting in a comprehensive and integrated approach to climate change adaptation and mitigation. Furthermore, the integration of GIS and multi-criteria analysis enhances the precision and accuracy of the results obtained.

The spatial recognition process relies on the quality and availability of data and the ability to interpret and analyze it meaningfully. This can pose a significant challenge, particularly in dynamic urban environments.

This study presents a novel and promising methodology for addressing the complex and multifaceted nature of climate change in urban planning. Although still in its experimental phase, this methodology offers a comprehensive and integrated approach by synthesizing multiple perspectives and considering the interests of various stakeholders.

Additionally, the methodology's innovative approach to assessing the vulnerability of urban areas to climate change can inform urban planning and policy decisions at multiple scales, from individual buildings and neighborhoods to entire cities. This can result in more effective and targeted strategies for reducing vulnerability, improving resilience, and mitigating significant impacts.

It is important to note that the methodology presented in this study can also be adapted and applied in other urban contexts, providing a valuable tool for addressing the global challenge of climate change. Moreover, this approach can be extended to other environmental and social issues, such as air quality, water scarcity, and social equity.

To further optimize the methodology and ensure its effective implementation, it is necessary to collaborate with stakeholders from various fields, including urban planners, policymakers, environmental scientists, and community representatives. This interdisciplinary collaboration can support the development of strategies for addressing climate change and its impacts on urban areas.

This paper aims to acknowledge these limitations and serve as a call to action for continued development and refinement of the methodology. By continuously seeking ways to improve the efficiency and effectiveness of the approach, we can ensure that it remains a valuable tool in addressing the complex challenges of our time.

7. Conclusions

This paper presented a methodology that combines multi-criteria assessment with spatial data acquired through remote sensing processes in a GIS environment (Liu, 2022). The method evaluates the impact of climate change by considering spatial variables such as density, morphology, and uses. This allows the identification of vulnerable areas that are more prone to the impacts of climate change. The approach also identifies possible scenarios of spatial multi-vulnerability, which can be managed by a deliberative component fueled by multi-actor assessments and decision paths.

The research findings suggest that the methodology is innovative to support monitoring and evaluating urban areas in exposure and risk conditions (Moghadas et al., 2019). The analysis considers using data and information from open-source spatial infrastructure to verify utilities by leveraging digital mapping embedded in shared communication platforms open to social control. This approach allows the implementation of a methodological procedure that is flexible, integrable, and replicable, becoming a valuable support tool for territorial governance. The model can guide spatial policies by mapping exposure concerning the possible risks of multi-impact climate.

The study also highlights the importance of having reliable estimates of weather-climate trends and the intensity of extreme events for defining vulnerability, hazard, and risk (Khan et al., 2020). The research suggests that considering the impact of climate change by formulating multiple morpho-climatic scenarios could make an essential contribution to urban risk management. Observing climate trends is useful when appropriately cross-referenced with local morphological factors. It is essential to consider land use forms and characterizations that exacerbate the problem of morphological impact.

The vulnerability of the settlement system is mainly related to urban morpho-types, analyzed concerning population density and their spatial coexistence. Although hazard scenarios can be an important factor in contextualizing vulnerability and risk, they hardly allow the interpretation of spatial behavior at the local level. Thus, assessing how climate prediction models can anchor themselves to morphological analysis exercises is crucial.

In conclusion, the study emphasizes the importance of using new technologies and their integration with different techniques and forms of spatial assessment. Constructing a multi-criteria cognitive apparatus facilitates the interpretation of climate impacts at the urban scale(Zhang et al., 2020). The research findings advise local governments to work through participatory working tables, involving different stakeholders in constructing a shared and multi-purpose adaptation process (Xiahou et al., 2022). Overall, the methodology developed in this paper could provides a valuable tool for territorial governance and urban risk management, contributing to a more sustainable and resilient future.

Funding

The paper publication is funded by ADRIACLIM project (Climate change information, monitoring and management tools for adaptation strategies in Adriatic coastal areas). European Commission – Interreg Italy - Croatia Territorial Cooperation Program 2014–2020, scientific coordinator Denis Maragno.

CRediT authorship contribution statement

Denis Maragno: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Gianfranco Pozzer:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization, Project administration. **Carlo Federico dall'Omo:** Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – original draft, Visualization.

Declaration of Competing Interest

Declare conflicts of interest or state "The authors declare no conflict of interest." Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. Any role of the funders in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript, or in the decision to publish the results must be declared in this section. If there is no role, please state "The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results".

Data availability

Data will be made available on request.

Acknowledgments

Authors thanks the collaboartors of project ADRIACLIM for their support, and mr. Matteo Faccin for his contribution. The conceptualization of the research bases also on the experience of project Venezia 2021, developed between 2019–2022, funded by Provveditorato Opere Pubblice Triveneto.

References

Adolphson, M., 2010. Kernel densities and mixed functionality in a multicentred urban region. Environ. Plann. B Plann. Des. 37 (3), 550–566. https://doi.org/10.1068/b35061. Pion Limited.

Ameen, R.F.M., Mourshed, M., Li, H., 2015. A critical review of environmental assessment tools for sustainable urban design. Environ. Impact Assess. Rev. 110–125. https://doi.org/10.1016/j.eiar.2015.07.006. Elsevier Inc.

ARPAV, 2021. Bollettini. Dati Meteorologici Ultimi Anni. Available at: https://www.arpa.veneto.it/bollettini/storico/Mappa_2022_TEMP.htm?t=RG (Accessed: 6 April 2022).

Busayo, E.T., Kalumba, A.M., 2021. Recommendations for linking climate change adaptation and disaster risk reduction in urban coastal zones: lessons from East London, South Africa. Ocean Coast. Manag. 203, 105454. https://doi.org/10.1016/j.ocecoaman.2020.105454. Elsevier Ltd.

Carver, S.J., 1991. Integrating multi-criteria evaluation with geographical information systems. Int. J. Geogr. Inf. Syst. 5 (3), 321–339. https://doi.org/10.1080/02693799108927858.

Charabi, Y., Gastli, A., 2011. PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. Renew. Energy 36 (9), 2554–2561. https://doi.org/10.1016/j.renene.2010.10.037.

Colson, D., Petropoulos, G.P., Ferentinos, K.P., 2018. Exploring the potential of sentinels-1 & 2 of the Copernicus mission in support of rapid and cost-effective wildfire assessment. Int. J. Appl. Earth Obs. Geoinf. 73, 262–276. https://doi.org/10.1016/j.jag.2018.06.011. Elsevier B.V.

Eastman, J., 1999. Multi-criteria evaluation and GIS. Geogr. Inf. Syst. 1 (1), 493–502. Available at: https://www.geos.ed.ac.uk/~gisteac/gis_book_abridged/files/ch35.pdf (Accessed: 18 November 2021).

Estoque, R.C., Murayama, R.C.E., 2010. Suitability analysis for beekeeping sites in La Union, Philippines, using GIS and multi-criteria evaluation techniques. Res. J. Appl. Sci. 5 (3), 242–253. https://doi.org/10.3923/rjasci.2010.242.253.

Fistola, R., Gargiulo, C., La Rocca, R.A., 2020. Rethinking vulnerability in city-systems: a methodological proposal to assess "urban entropy". Environ. Impact Assess. Rev. 85, 106464. https://doi.org/10.1016/j.eiar.2020.106464. Elsevier Inc.

Gandini, A., et al., 2021. Climate change risk assessment: a holistic multi-stakeholder methodology for the sustainable development of cities. Sustain. Cities Soc. 65, 102641. https://doi.org/10.1016/j.scs.2020.102641. Elsevier Ltd.

Gatrell, A.C., et al., 1996. Spatial point pattern analysis and its application in geographical epidemiology. Trans. Inst. Br. Geogr. 21 (1), 256. https://doi.org/10.2307/622936. JSTOR.

Grafakos, S., et al., 2020. Integration of mitigation and adaptation in urban climate change action plans in Europe: a systematic assessment. Renew. Sust. Energ. Rev. 121, 109623. https://doi.org/10.1016/j.rser.2019.109623. Elsevier Ltd.

Halla, P., Merino-Saum, A., Binder, C.R., 2022. How to link sustainability assessments with local governance? – connecting indicators to institutions and controversies. Environ. Impact Assess. Rev. 93, 106741. https://doi.org/10.1016/j.eiar.2022.106741. Elsevier Inc.

Heinzlef, C., et al., 2022. Urban resilience operationalization issues in climate risk management: a review. Int. J. Disaster Risk Reduct. https://doi.org/10.1016/j.ijdrr.2022.102974. Elsevier Ltd.

Hochmair, H.H., Juhász, L., Cvetojevic, S., 2018. Data quality of points of interest in selected mapping and social media platforms. In: Lecture Notes in Geoinformation and Cartography. Springer, Berlin Heidelberg, pp. 293–313. https://doi.org/10.1007/978-3-319-71470-7_15.

Hurlimann, A., Moosavi, S., Browne, G.R., 2021. Urban planning policy must do more to integrate climate change adaptation and mitigation actions. Land Use Policy 101, 105188. https://doi.org/10.1016/j.landusepol.2020.105188. Elsevier Ltd.

IPCC, 2007. IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. — European Environment Agency.

IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. https://doi.org/10.1017/cbo9781139177245.

IPCC, 2019. IPCC Special Report on Climate Change and Land — Climate-ADAPT.

Islam, S., Chu, C., Smart, J.C.R., 2020. Challenges in integrating disaster risk reduction and climate change adaptation: exploring the Bangladesh case. Int. J. Disaster Risk Reduct. 47 https://doi.org/10.1016/j.ijdrr.2020.101540. Elsevier Ltd.

ISTAT, Report on National Tourism 2019 - https://www.istat.it/it/archivio/252091.

Jeong, J.S., 2018. Design of spatial PGIS-MCDA-based land assessment planning for identifying sustainable land-use adaptation priorities for climate change impacts. Agric. Syst. 167, 61–71. https://doi.org/10.1016/j.agsy.2018.09.001. Elsevier Ltd.

Jesolo, 2016. Valutazione Ambientale Strategica (VAS) del PAT di Jesolo – Rapporto Ambientale.

Khan, A., Gupta, S., Gupta, S.K., 2020. Multi-hazard disaster studies: monitoring, detection, recovery, and management, based on emerging technologies and optimal techniques. Int. J. Disaster Risk Reduct. https://doi.org/10.1016/j.ijdrr.2020.101642. Elsevier Ltd.

Klutho, S., 2013. Mathematical decision making - an overview of the analytic hierarchy process and its applications. Eur. J. Oper. Res. 48 (1), 2–8.

Lerer, S., Arnbjerg-Nielsen, K., Mikkelsen, P., 2015. A mapping of tools for informing water sensitive urban design planning decisions—questions, aspects and context sensitivity. Water 7 (12), 993–1012. https://doi.org/10.3390/w7030993.

Li, P., Xiao, X., Seekamp, E., 2022. Climate adaptation planning for cultural heritages in coastal tourism destinations: a multi-objective optimization approach. Tour. Manag. 88, 104380. https://doi.org/10.1016/j.tourman.2021.104380. Elsevier Ltd.

Limonta, G., Paris, M., 2017. Riconoscere e monitorare la potenziale fragilità dei sistemi commerciali urbani: una proposta per la Regione Lombardia. In: Atti della XIX Conferenza Nazionale SIU. 'Cambiamenti. Responsabilità e strumenti per l'urbanistica al servizio del paese'. Available at: https://re.public.polimi.it/handle/11311/1015926 (Accessed: 19 June 2022).

Liu, K., 2022. GIS-based MCDM framework combined with coupled multi-hazard assessment for site selection of post-earthquake emergency medical service facilities in Wenchuan, China. Int. J. Disaster Risk Reduct. 73 https://doi.org/10.1016/j.ijdrr.2022.102873. Elsevier Ltd.

Luria, P., Aspinall, P.A., 2003. Evaluating a multi-criteria model for hazard assessment in urban design. The Porto Marghera case study. Environ. Impact Assess. Rev. 23 (5), 625–653. https://doi.org/10.1016/S0195-9255(03)00091-X. Elsevier Inc.

Malczewski, J., 2006. GIS-based multicriteria decision analysis: a survey of the literature. Int. J. Geogr. Inf. Sci. 20 (7), 703–726. https://doi.org/10.1080/13658810600661508. Taylor & Francis.

Malczewski, J., Rinner, C., 2015. Multicriteria Decision Analysis in Geographic Information Science. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-74757-4 (Advances in Geographic Information Science).

Maragno, D., et al., 2020. Land–sea interaction: integrating climate adaptation planning and maritime spatial planning in the north Adriatic Basin. Sustainability 12 (13), 5319. https://doi.org/10.3390/su12135319. MDPI.

Maragno, D., et al., 2021. Multi-risk climate mapping for the adaptation of the Venice metropolitan area. Sustainability 13 (3), 1334. https://doi.org/10.3390/su13031334. MDPI.

Marin, G., Modica, M., 2017. Socio-economic exposure to natural disasters. Environ. Impact Assess. Rev. 64, 57–66. https://doi.org/10.1016/j.eiar.2017.03.002. Elsevier Inc.

Moghadas, M., et al., 2019. A multi-criteria approach for assessing urban flood resilience in Tehran, Iran. Int. J. Disaster Risk Reduct. 35 https://doi.org/10.1016/j.ijdrr.2019.101069. Elsevier Ltd.

Morabito, M., et al., 2015. Urban-hazard risk analysis: mapping of heat-related risks in the elderly in major Italian cities. PLoS One 10 (5), 1–18. https://doi.org/10.1371/journal.pone.0127277.

Musco, F., et al., 2016. Mitigation of and adaptation to UHI phenomena: the Padua case study. In: Counteracting Urban Heat Island Effects in a Global Climate Change Scenario. Springer International Publishing, pp. 221–256. https://doi.org/10.1007/978-3-319-10425-6_8.

Oliveira, A., Lopes, A., Niza, S., 2020. Local climate zones in five southern European cities: an improved GIS-based classification method based on Copernicus data. Urban Clim. 33, 100631. https://doi.org/10.1016/j.uclim.2020.100631. Elsevier B.V.

Padulano, R., et al., 2021. Propagation of variability in climate projections within urban flood modelling: a multi-purpose impact analysis. J. Hydrol. 602, 126756. https://doi.org/10.1016/j.jhydrol.2021.126756. Elsevier B.V.

Pasi, A., 2020. In: Edizioni, Codice (Ed.), L' equazione dei disastri. Cambiamenti climatici su territori fragili - Antonello Pasini - Libro - Codice - | IBS. Torino. Available at: https://www.ibs.it/equazione-dei-disastri-cambiamenti-climatici-libro-antonello-pasini/e/9788875788650 (Accessed: 19 June 2022).

Patassini, D., 2020. Appunti sulla valutazione come filosofia pratica e ricerca di evidenza. Iuav University, Venezia. Available at: https://www.geos.ed.ac.uk/~gisteac/gis_book_abridged/files/ch35.pdf.

Perminova, T., et al., 2016. Methods for land use impact assessment: a review. Environ. Impact Assess. Rev. 64–74. https://doi.org/10.1016/j.eiar.2016.02.002. Elsevier Inc.

Pietrapertosa, F., et al., 2021. Multi-level climate change planning: an analysis of the Italian case. J. Environ. Manag. 289, 112469. https://doi.org/10.1016/j.jenvman.2021.112469. Academic Press.

Ronchi, S., Salata, S., Arcidiacono, A., 2020. Which urban design parameters provide climate-proof cities? An application of the urban cooling InVEST model in the city of Milan comparing historical planning morphologies. Sustain. Cities Soc. 63, 102459. https://doi.org/10.1016/j.scs.2020.102459. Elsevier Ltd.

Rosentreter, J., Hagensieker, R., Waske, B., 2020. Towards large-scale mapping of local climate zones using multitemporal sentinel 2 data and convolutional neural networks. Remote Sens. Environ. 237, 111472. https://doi.org/10.1016/j.rse.2019.111472. Elsevier Inc.

Rudge, K., 2021. Participatory climate adaptation planning in New York City: analyzing the role of community-based organizations. Urban Clim. 40, 101018. https://doi.org/10.1016/j.uclim.2021.101018. Elsevier.

Rus, K., Kilar, V., Koren, D., 2018. Resilience assessment of complex urban systems to natural disasters: a new literature review. Int. J. Disaster Risk Reduct. 311–330. https://doi.org/10.1016/j.ijdrr.2018.05.015. Elsevier Ltd.

Saaty, R.W., 1987. The analytic hierarchy process-what it is and how it is used. Math. Model. 9 (3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8. Pergamon.

Sahoo, S., Dhar, A., Kar, A., 2016. Environmental vulnerability assessment using Grey analytic hierarchy process based model. Environ. Impact Assess. Rev. 56, 145–154. https://doi.org/10.1016/j.eiar.2015.10.002. Elsevier Inc.

Schetke, S., Haase, D., Kötter, T., 2012. Towards sustainable settlement growth: a new multi-criteria assessment for implementing environmental targets into strategic urban planning. Environ. Impact Assess. Rev. 32 (1), 195–210. https://doi.org/10.1016/j.eiar.2011.08.008. Elsevier.

Sharifi, A., 2021. Co-benefits and synergies between urban climate change mitigation and adaptation measures: a literature review. Sci. Total Environ. 141642. https://doi.org/10.1016/j.scitotenv.2020.141642. Elsevier B.V.

Siqueira, H.E., et al., 2017. A multi criteria analog model for assessing the vulnerability of rural catchments to road spills of hazardous substances. Environ. Impact Assess. Rev. 64, 26–36. https://doi.org/10.1016/j.eiar.2017.02.002. Elsevier Inc.

Uribe, D., et al., 2014. Integrating stakeholder preferences and GIS-based multicriteria analysis to identify forest landscape restoration priorities. Sustainability 6 (2), 935–951. https://doi.org/10.3390/su6020935. MDPI.

Wind, Y., Saaty, T.L., 1980. Marketing applications of the analytic hierarchy process. Manag. Sci. 26 (7), 641–658. https://doi.org/10.1287/mnsc.26.7.641. INFORMS.

Xiahou, X., et al., 2022. Exploring social impacts of urban rail transit PPP projects: towards dynamic social change from the stakeholder perspective. Environ. Impact Assess. Rev. 93, 106700. https://doi.org/10.1016/j.eiar.2021.106700. Elsevier Inc.

Yang, S., et al., 2018. Study on the spatial heterogeneity of the poi quality in openstreetmap. In: Proceedings, 7th International Conference on Cartography and GIS, 18–23 June 2018, Sozopol, Bulgaria. Available at: http://www.resdc.cn (Accessed: 18 November 2021).

Zhang, D., et al., 2020. A GIS-based spatial multi-index model for flood risk assessment in the Yangtze River Basin, China. Environ. Impact Assess. Rev. 83, 106397. https://doi.org/10.1016/j.eiar.2020.106397. Elsevier Inc.