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Special Issue 1.2024

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Scientific debate, research, approaches and good practices

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Analysis of territorial fragilities through GIScience

A method tested in the Life+ A_GreeNet project to implement urban green infrastructures

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Abstract

This paper presents the results of applied research on the Adriatic linear city (Marche, Abruzzo) aimed at building an innovative cognitive framework through GIScience methods/techniques (geodata processing, remote sensing, and scientific indexes) to support the first analytical phase of the A_GreeNet Life+ project and its aims. In particular, the paper shows the different methodological steps necessary to produce a risk map and multi-thematic geodatabase in a GIS (Geographic Information Systems) environment based on open data. The research results lay the foundations for new ways and different perspectives of investigating the urban landscape in line with the process of renewing cognitive tools for urban planning. Starting with the cognitive framework developed, the project partnership network will be scaled down for the second analysis phase aimed at prefiguring a new scenario for forestation and redeveloping the landscape-vegetation system with the support of the related administrations and in accordance with the current planning framework.

Keywords

GIScience; Urban Green Infrastructure; Risk Maps; Territorial Fragilities; Urban Planning.

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1. The A_GreeNet Project within the Scientific-Cultural Debate

This contribution addresses emerging questions regarding challenges in cities in the 21st century from various directions. Such challenges include ecology and urban health, and most importantly, the climate crisis, which influences the public, academic, geopolitical, and social debate on both an international[1] (IPCC, 2022; EASAC, 2019) and national level[2] (CMCC, 2020). In this sense, the research, while not specifically addressing the two-fold digital and ecological transition, falls within both a process of renewing the cognitive tools of urban planning enabled by the digital geographical progress of GIS and the 'science of where' (GIScience) (Wright and Harder, 2020; van Maarseveen et al., 2019; Adelfio et al, 2019), along with geospatial techniques such as remote sensing (Liu, 2016; Anees et al, 2020; Partheepan, 2023). On the other hand, it reiterates the central role of the Urban green infrastructure (UGI) and nature-based solutions to respond to the social and spatial fragility of the territory (World Bank, 2021; Sturiale and Scuderi, 2019).

It is now well known that the urban climate is closely correlated with the form of urban settlements, building morphologies, and the materials present in the city (Maiullari et. al, 2021; Oke et al, 2017; Rosenzweig et al, 2018) as well as the arrangement/quantity/quality/size of green spaces in their multiple forms and botanical specifics (Salata, Yiannakou, 2016; Shirgir et al., 2019). Various studies have highlighted the benefits of green space for human health and mental-physical well-being, since such spaces provide places for socializing, recreation, and sharing, as well as direct and indirect ecosystem services (UN-Habitat, 2020; WHO, 2020). Other scientific reports and research highlight how natural habitats contribute to protecting the territory, and especially urban areas, from both endogenous (e.g. soil and morphology) and exogenous fragilities (e.g. anthropic and climate impacts). These are aggravated by global weather imbalances due to the climate change currently seen in Italy,[3] with greater severity in duration, intensity, and recursion (torrential rain, storm surges, heat waves, etc.) (Osservatorio Nazionale città-clima, 2022; Brownlee et al., 2021).

This framework is inevitably reflected in the case study, that is, the mid-Adriatic city in Italy, where the mutual relationships — humans/nature, urban form/climate aspects — also interact with i) local socioeconomic dynamics tied to the ageing population (ISTAT, 2020a; ISTAT, 2020b), ii) the intrinsic territorial fragility of the Adriatic side and Italy as a whole (Trigila et al, 2021; Lastoria et al, 2021), as well as iii) the substantial increase in tourist flows on the Adriatic coast of Marche/Abruzzo in summer (Regione Marche, 2023; Regione Abruzzo, 2022).

In this scientific/cultural frame of reference, A_GreeNet Life+[4] investigates the quantity/quality of the UGI of the mid-Adriatic city[5] to increase the availability of green areas through territorial agreements (i.e. 'Intra-Regional Urban Afforestation Agreement for the Middle Adriatic City'[6]) and especially by activating

[1] The international level includes the European Green Deal, a guide to achieve the objectives tied to the transitions and changes in today's society for sustainable development and climate neutrality in Europe: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

[2] In Italy, the direction is dictated by the National Recovery and Resilience Plan, in which Italy is committed to the dual transition, orienting future design towards securing the territory, the climate sustainability of the changes, the socioeconomic recovery of the country and disadvantaged populations, and even more: https://www.italiadomani.gov.it/content/sogei-ng/it/it/home.html

[3] ISPRA report of 17 May 2023 on the 16-17 May 2023 flood in Emilia-Romagna: https://www.isprambiente.gov.it/files2023/notizie/pdf24_merged.pdf. Other infographics on the impacts of extreme events in Italy can be found at: https://cittaclima.it/2022/12/29/bilancio-2022-dellosservatorio-cittaclima/

[4] Project data: budget: €3,631,776, duration: 01/10/2021 (expected start date) – 30/09/2025 (expected end date), partnership: Abruzzo Region (lead partner), Municipalities of Silvi, Ancona, Pescara, San Benedetto del Tronto, Legambiente onlus, Res Agraria srl, University of Camerino – School of Architecture and Design (SAAD/UNICAM); Unicam Team: Rosalba D'Onofrio (scientific coordinator), Elio Trusiani, Roberta Cocci Grifoni, Federica Ottone, Chiara Camaioni, Timothy Daniel Brownlee, Graziano Enzo Marchesani, Giorgio Caprari, Simone Malavolta. Funding: The Life+ AgreeNet Project is funded by LIFE EU Programme, grant number LIFE 20 CCA/IT/001752. More information at: https://www.lifeagreenet.eu/site/.

[5] Urban areas covered by the project fall within the municipalities of Ancona and San Benedetto del Tronto (Marche Region), Martinsicuro, Alba Adriatica, Tortoreto, Giulianova, Roseto, Pineto, Silvi, Pescara (Abruzzo Region).

[6] Contratto Interregionale di Forestazione urbana della città del Medio Adriatico – Abruzzo e Marche (CIdFU)

environmental forecasts internal to current urban plans (D'Onofrio et al, 2023). The project aims to implement coastal UGIs, along with the multiple ecological/functional and aesthetic/recreational services that it provides and which make the infrastructure capable of climate adaptation to protect the health of the urban habitat and people (EC, 2016; Forest Research, 2010).

Within the broader framework of the project, this paper presents a GIScience method applied to the area of study to construct a map of territorial risk and a multi-thematic GeoDataBase (GeoDB) using GIS (Geographic Information Systems) relating to three categories of fragility. The method, which is fully open source, was tested within the project as support for the first analytical phase on the large scale, which is useful for guiding subsequent steps[7] and the specific design solutions to enhance the coastal UGIs that are currently being organized.

As anticipated above, the research is organized around three conditions of territorial fragility/vulnerability that are particularly important today: i) ageing and fragile swaths of the population; ii) land coverage (permeable/impermeable) and the quantity/quality of vegetation; and iii) thermal stress tied to the increase in temperature, heat waves, and the urban heat island (UHI).

These indicators, investigated with scientific indices or aggregates of summary data, fall in line with national research involving similar studies in recent years with respect to area of application, scale, and goals. To cite a few of interest related to this contribution, Gabriele et al. (2023) developed an Environmental Sensitive Area Index (ESAI) to analyse the sensitivity of land to degradation (erosion, loss of biodiversity, etc.), a factor that increases the risk of landslides. Other researchers (Pozzer et al., 2021; Beltramino et al., 2022) have examined spatial correlations among the different risk variables (i.e. sensitivities, pressures, hazards) that contribute to territorial vulnerability. Maragno et al. (2021) proposed a multi-risk climate atlas (thermal stress, risk of flooding) to support local climate-proof planning. In addition, with respect to UHIs, D'Ambrosio et al. (2022) and Todeschi et al. (2023) assessed the territorial vulnerability to heat waves by simulating the impact today and in the future according to scenarios of global warming prepared by the IPCC (2022). These further expanded the area of application, calculating thermal anomalies among urban and periurban areas and considering discomfort for elderly people (Heat-Related Elderly Risks, HERI).

The common thread between this contribution and the research above relates, first, to the technical/operational ambition of the results, i.e. providing decision support systems (DSSs) and innovative analytical frameworks for decision makers and planners with regard to new territorial governance practices, where the climate and green areas are two central issues. On the other hand, it refers to the GIScience approach and the use of GIS-based techniques and methods (e.g. geoprocessing, remote sensing), open geographical data, and a wide range of scientific indices and social and morphological/climate indicators calibrated using case studies.

This state of the art, albeit partial, shows the liveliness of the scientific debate on data-science and GIS used to analyse the various geographies of risk and vulnerabilities in the Italian territory.

The research falls within this disciplinary strand, infusing geo-ICT innovation applied to studies of the city and territory in the era of climate instability with value and scientific features, while highlighting its limits and potential. With regard to the techniques and technologies used, this contribution falls in line — with suitable differences — with the state of the art illustrated above. With respect to theory, the added value of the research consists in systematizing the innovative geospatial knowledge with urban planning techniques and

[7] To situate the contribution within the broader line of research, subsequent evaluations on the large/local scale were carried out as of today and for 2030, and 2050 using the GIS-based open-source 'UMEP – Urban Multi-scale Environmental Predictor' plug-in. The model estimated the mean radiant temperature (Tmrt), converted into the UTCI (Universal Thermal Climate Index). This index assesses thermal stress relative to the impact of climate variables on people. To this end, the meteorological data of the 'representative day' (2019) were projected to 2030 and 2050 according to emission scenarios RCP 10 4.5 (IPCC, 2022). At the end of the workflow, the interpolation of the UTCI with the risk map discussed here definitively highlights the system of the most sensitive areas with which simulations will be made of the state before/after the UGI project as of today, and at 2030 and 2050 (ENVI-Met software).

planning regulations that the research group is working on in synergy with local public administrations (PAs). That is, where areas of discomfort and risk are involved (where social fragility adds to morphological and climate fragilities), actions to mend and improve the environmental system will be planned on different scales, through the application of current regulations where they have not been implemented. According to D'Onofrio et al. (2023), this step is fundamental in situating the planning of nature-based solutions and strengthening UGIs within urban planning, which does not contain specific tools except for voluntary ones (e.g. Piano del Verde [Green Plan]). It is also essential in bridging the gap between the theoretical way in which UGIs are discussed and the practical world in which they are planned and managed (Ferreira et al. 2021; D'Onofrio et al., 2022). In doing so, virtuous practices are instituted to refine and truly enrich the research contributions, aligning them with activities proposed by public departments.

- The specific objectives of this work are summarized as follows:
- spatializing disadvantaged areas (population, housing density, large families) in the 10 municipalities in question, starting with the most up-to-date databases (2020–2021);
- creating a soil atlas using the Soil Adjusted Vegetation Index (SAVI) with respect to permeability and the presence of greenery;
- diachronic mapping of thermal stress through the calculation of Surface Temperature (ST) and Land Surface Temperature-LST;
- structuring a multi-thematic GeoDB for the creation of updatable risk maps.

2. Methodological Steps for Building the Knowledge Framework

Before discussing the technical details of the method, the case study, the reasons for its interest, and the limits of the area of study considered in the A_GreeNet are presented below.

2.1. The Case Study of the Mid-Adriatic City

On the physical/spatial level, the coastal municipalities in the Marche and Abruzzo regions constitute a linear city 355 km long, home to 39% (Marche) and 34% (Abruzzo) of the regional populations (ISTAT, 2020b). The urbanization process has led to a progressive reduction/fragmentation of the green/forested/agricultural lands in the area (Comitato Capitale Naturale, 2018) transforming what was a semi-natural coastal landscape in the second half of the 1900s into a very dense urban landscape. This is particularly evident if one assess the land consumed in the urban/coastal area of Pescara (51.3%8) and San Benedetto del Tronto (37.60%), in Abruzzo and Marche, respectively (Munafò, 2019, pp. 65).

Such extensive soil impermeability reduces water absorption, affecting the microclimate on different scales. This is primarily caused by i) the weakness of large-scale planning, ii) the expansive nature of local planning, and iii) the ineffectiveness of governance in activating policies, plans, and measures for multi-level adaptation that integrates UGIs.

The effects of such criticalities are reflected in studies on climate trends in the area. In the Marche region, there has been a significant increase in temperature, rising between 1.6°C and 2.6°C with respect to the 1990s, which is associated with an increase in summer days and tropical nights (Fioravanti et. al., 2016). Furthemore, a study conducted by the European Data Journalism Network9 (EDJNet) in 2020 highlighted that Pescara (Abruzzo) has witnessed a substantial rise in the average annual temperature over the past fifty years. In the 1960s, the estimated average temperature was +14.2°C, and by 2009–18, it had increased to +16.3°C, indicating a notable temperature increase of 2.1°C.

[8] Values with respect to the limits of the entire municipality.
[9] The infographic of the research for the City of Pescara is available at: https://climatechange.europeandatajournalism.eu/en/italy/abruzzo/pescara/pescara

Filling in this critical framework, the National Adaptation Plan, as yet lacking approval, defines the macro region of interest as an area with low adaptation capacity, a high risk of desertification by 2050, and a significant increase in summer days (PNACC, Annex 1, 2018). Other studies showed an increase in local mortality in Ancona during the heat wave in 2003 (Condemi et al., 2015) as well as in August 2017 (DEP[10], 2017, Fig. 9, p. 28) with specific reference to people over 65 years of age. Similar increases in mortality were also observed in Pescara in May–June 2022 in correlation with temperature increases (DEP, 2022, Fig. 3, p. 25).
For these reasons, the case study is significant and suitable for testing a methodology that tries to spatially relate social variables, physical-territorial aspects, and climatic dynamics.
In this perspective, three types of analysis were developed on the basis of municipal administrative limits and especially drawing up-to-date urban perimeters as the areas most affected by these dynamics.
The areas of study (Fig. 1) can be identified with the urban expansion of the coastal city characterized by i) the building continuum and ii) the constant presence of anthropic infrastructure (i.e. railway and motorway).
A difference can be seen between a 'restricted perimeter' and an 'expanded perimeter'. This specification relates to the two different purposes of the A_GreeNet project. While the project focuses on the urbanized coastal areas with the highest population density ('restricted'), other areas were identified by the public administration technicians based on trends due to i) ongoing transformations or ii) future transformations based on plans by the individual PAs.

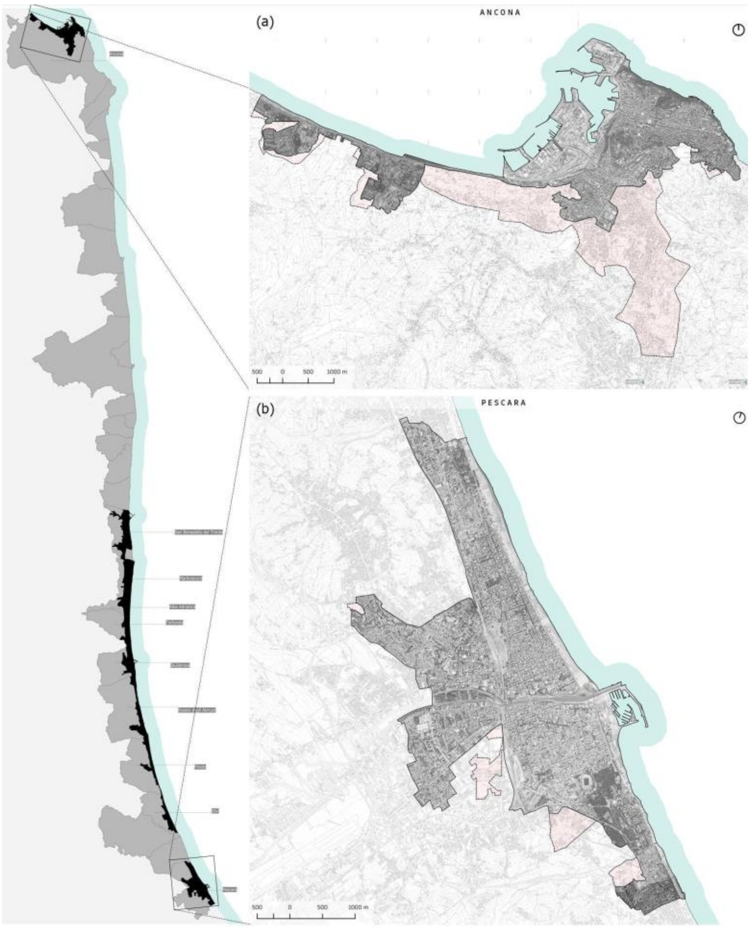

Fig. 1 Limits of internal studies made by municipalities involved in the project (black). The limits of the City of Ancona (a) and the City of Pescara (b), and the related differences between the 'restricted perimeter' (orthophoto) and 'expanded perimeter' (pink). Source: Prepared by the authors using Google Maps ©2022, Marche Regional Technical Map 1:10000 (2000), Abruzzo Regional Technical Map 1:10000 (2007)

[10] The observed data refer to the results of the Heat Health Watch Warning Systems (HHWWS), the Surveillance System of Daily Mortality (SISMG), and A&E admissions in the periods mentioned above. For more information, see: https://www.salute.gov.it/portale/caldo/dettaglioContenutiCaldo.jsp?lingua=italiano&id=408&area=emergenzaCaldo&menu=vuoto

Data and Methods

In line with the research objectives set out above, this section presents the data, methodological process, and geo-based techniques used to construct the map of territorial risk in the area of study (Fig. 2). This was developed using geoprocessing, remote sensing applications, and geospatial analysis tools in the GIS environment (i.e. QGIS software), which rely on open-source geo-spatial hardware/software and libraries (e.g. SAGA-GIS, GRASS ecc.).

The territorial fragilities were analysed with respect to three specific issues deemed important for the area of study, as highlighted above, and around which this section is organized:

- demographic aspects and resident registers;
- soil and green atlas;
- thermal stress.

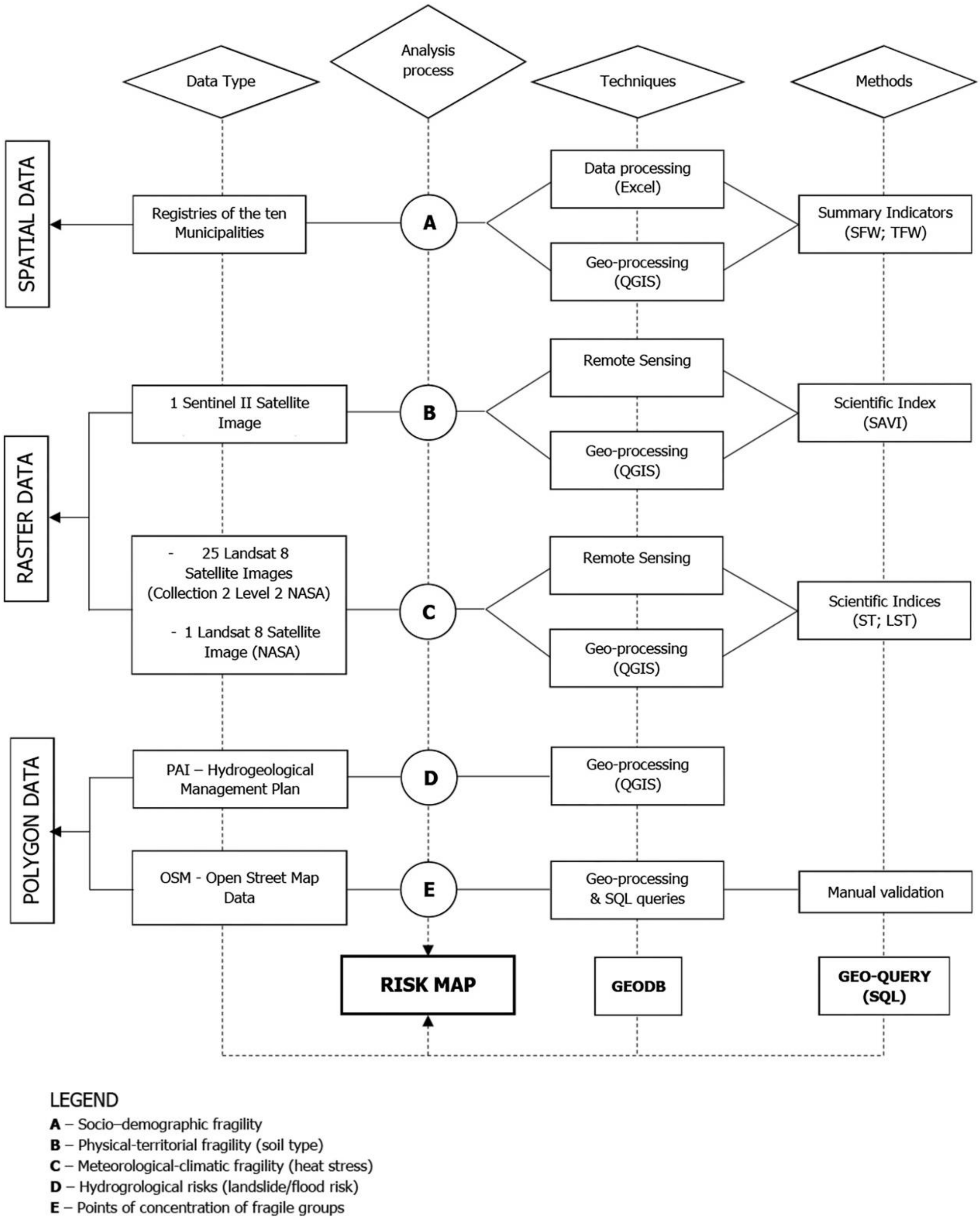

Fig. 2 Research workflow, from the data to the techniques and methods used to develop the risk map for the case study

The Socio-Demographic Analysis

The analysis conducted returns a georeferenced mapping of socio-demographic fragility in the area of study with respect to i) population density, ii) resident age, and iii) presence of large resident families. To this end, the registries of all the municipalities involved (updated to 2020 or 2021) were acquired from the PAs, processed with quantitative mixed methods (data-analysis in Excel and GIS environment) and georeferenced with respect to ISTAT census sections[11]. Given the data availability, the following criteria and data were examined:

- total number of residents;
- number of residents aged ≤ 14 years;
- number of residents aged ≥ 65 years;
- number of households with 4 or more members.

Considering the data acquired thus, two indicators were calculated on the basis of the parameters chosen:

- social fragility weight (SFW[12]);
- total fragility weight (TFW[13]).

The indicators represent both the incidence - i.e. the weight of socio-demographic fragility in relation to the size of the census section (SFW) - and the number - i.e. the quantity-concentration of children under 14, elderly people, families with 4 or more members present in each census section (TFW).

							Indicators	
		Socio-demographic variables						
Census section (no.)	**Square metres (m²)**	**Residents (no.)**	**Residents ≤ 14 years old (no.)**	**Residents ≥ 65 years old (no.)**	**4-5 member families (no.)**	**6+ member families (no.)**	**SFW[11] (0-1)**	**TFW[12] (no.)**
1	481,431.32	6	0	0	1	0	0	1
2	15,298.58	57	4	12	5	0	0.00137	21
3	12,491.04	2	0	0	0	0	0	0
4	9,992.15	1	0	0	0	0	0	0
5	15,453.10	23	2	4	0	0	0.00039	6
6	15,886.20	no data						
7	4,674.00	35	6	8	3	0	0.00364	17
8	6,690.22	95	7	26	4	0	0.00553	37
9	3,511.29	68	4	14	5	0	0.00655	23
10	2,538.91	51	4	19	1	0	0.00945	24
11	7,257.47	53	3	24	1	0	0.00386	28
12	7,255.46	50	4	15	5	0	0.00331	24
13	11,474.65	122	10	33	8	1	0.00453	52
14	4,577.93	93	7	23	2	0	0.00699	32
15	10,145.53	13	0	3	0	0	0.003	3
16	3,720.33	43	3	18	2	0	0.00618	23
17	5,325.89	no data						
18	6,008.53	214	22	44	7	1	0.01232	74
19	2,205.82	33	1	7	0	0	0.00363	8
20	5,980.24	161	15	30	8	0	0.00886	53
Tot.al		99,542	11,530	26,497	6670	533	-	45,230

Tab. 1 Extract from the database of the City of Ancona, processed for the purposes of the socio-demographic fragility assessment

[11] Census sections available for download at: https://www.istat.it/it/archivio/104317#accordions

[12] Social fragility weight is the incidence of demographic fragility aspects (elderly, minors, large families) in relation to census size (SFW/census section in square metres); see Table 1.

[13] Total fragility weight is the sum of the socio-demographic variables for each census section (Residents ≤ 14 + Residents ≥ 65 + 4-5 member families + 6+ member families); see Table 1.

For a better understanding of the indicators, a double graphical layout was chosen (Fig. 3), which enhances the potential of the geo-based representation and notes some limitations of the quantitative data (synthetic indicators) presented later (see Sect. 4). In any case, considering the macro-scalar approach and the large portion of territory investigated, the census section data are sufficiently accurate for the purposes of a general critical evaluation and for identification of the most critical residential areas.

The work as developed was carried out for all 10 A_GreeNet Partner Municipalities and constitutes the first piece and first vulnerability variable for the construction of a socio-morphological and climate risk map useful for pursuing the project objectives. Below is an excerpt of the socio-morphological fragility map and an excerpt of the database developed for the City of Ancona (Table 1).

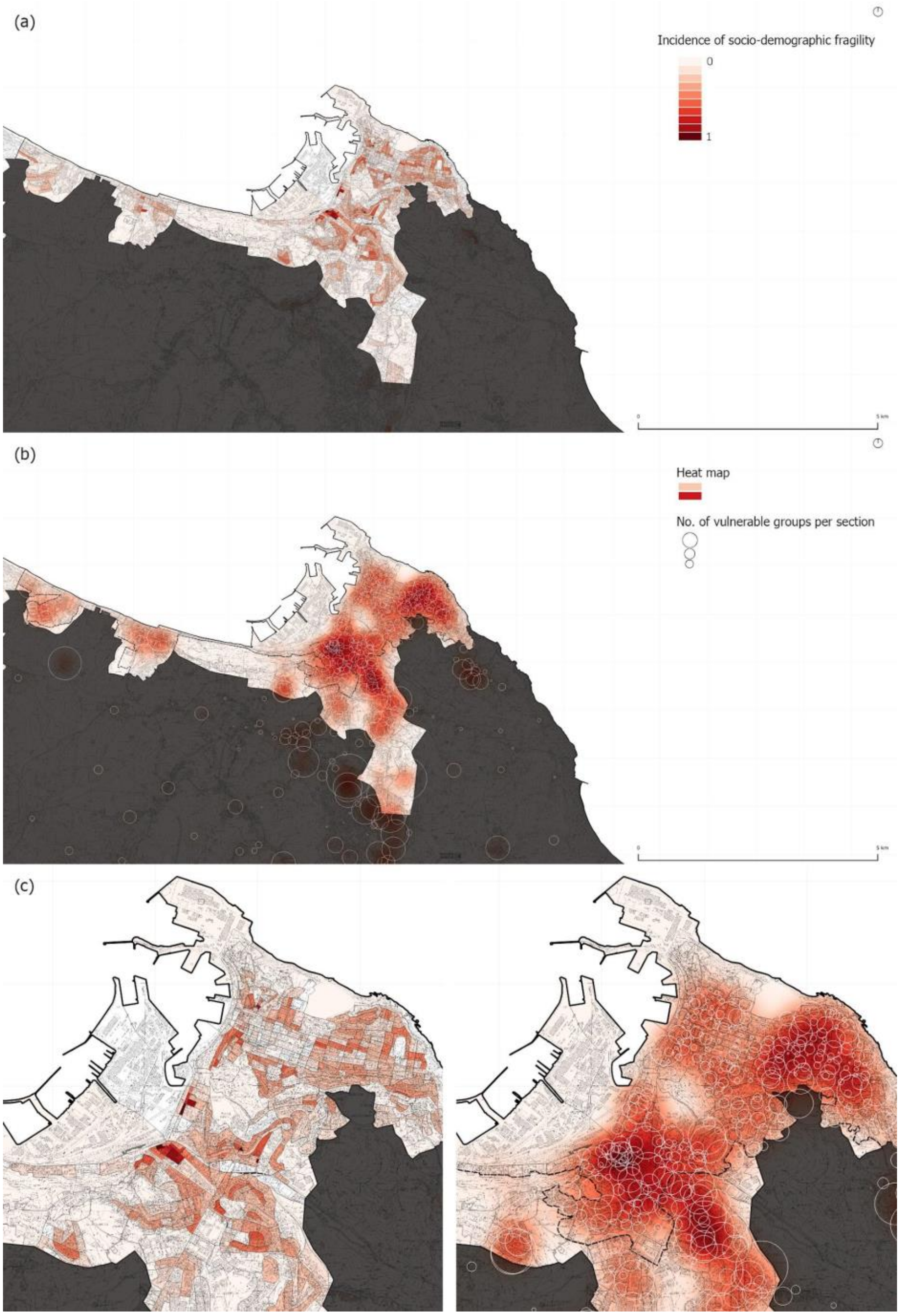

Fig. 3 Incidence of socio-demographic fragility (a) and quantity-concentration of the vulnerable population (b) with respect to individual census sections. Panel (c) shows a detail of the City of Ancona for a comparison of the two graphical representations. Source: Prepared by the authors using the Marche Regional Technical Map 1:10000 (2000)

Morphological Analysis: A Qualitative/Quantitative Survey of Soil and Greenery

Within the scope of research activities aimed at evaluating the condition and health of the UGI in the linear city of the mid-Adriatic region, the analysis of the macro-scale context concentrated on the semi-automated sampling of natural and semi-natural green areas.

This process was developed using remote sensing applications starting with i) open-access multispectral satellite images, ii) the use/calculation of a particularly efficient vegetation index in an urban environment (SAVI), and iii) its critical manual interpretation in order to distinguish artificial and natural surfaces.

This study yielded a spatial mosaic reflecting the degree of vegetation vigour of the land cover based on photosynthesis activity and the presence of chlorophyll in the plants at the time of the satellite shot.

This, in fact, is particularly visible in the red and near-infrared bands, which are two electromagnetic bands in the satellite shots made available by the Sentinel-2 mission of the European 'Copernicus' programme (European Spatial Agency, ESA[14]).

The process involved an initial scan of the satellite images available online covering a recent time period (May–July 2021[15]) that photographed the territory in its current state[16].

Excluding images with high cloud cover, two images[17] were selected from 10 May 2021, taken from the satellite at 10 a.m.

The images, with a square spatial resolution of 10 metres per pixel (10 m/px), were processed geographically in a GIS environment. The raw pixel data in the red (RED, band number 4) and near-infrared (NIR-Near Infrared, band number 8) electromagnetic bands were converted using the following formula (Huete, 1988):

$$SAVI \quad = \frac{(NIR-R)}{(NIR+R+L)} * (1 + L)$$

where:

NIR = Near Infrared;

R = Red

L = soil correction/adjustment factor (low vegetation = 0 and high vegetation = 1), which was given an intermediate value of 0.5 by scientific literature (Huete, 1988; Sedlák et al, 2018).

The index defined thus represents an initial qualitative-quantitative survey with respect to the entire survey area, capable of visually and spatially rendering the level of artificial objects/nature in the context. Based on the graphical results, it is easy to identify both the forest cover and/or areas with vegetation and the system of infrastructure, the built area, and vast waterproofed surfaces (Fig. 4).

The individual pixels in the images express a continuous value from less than zero (< 0) to greater than or equal to 1.5 (≥ 1.5), returning the areas with impermeable coverage (built areas, impermeable areas, areas without vegetation, etc.; in red, Fig. 4) and the permeable-natural and semi-natural areas (coastal pine forests, areas with trees, crop vegetation, parks, etc.; in green, Fig. 4).

Finally, in order to sample, capture, and quantify the size of the different areas, a threshold value (0.5) - verified by geoprocessing tests and analogically validated through critical photo interpretation - was identified, with which the permeable and impermeable areas were divided into two classes for the purposes of the risk map.

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[14] Data downloaded from the portal https://scihub.copernicus.eu/dhus/

[15] The effectiveness of semi-automatic processing in surveying the greenery depends on the months in which photosynthesis in the vegetation is most active

[16] This step of the research was conducted in early 2022.

[17] Selected images: S2A_MSIL2A_20210510T100031_N0300_R122_T33TUJ_20210510T115157, Sentinel-2, Level-2A, USGS; S2A_MSIL2A_20210510T100031_N0300_R122_T33TVH_20210510T115157, Sentinel-2, Level-2A - USGS

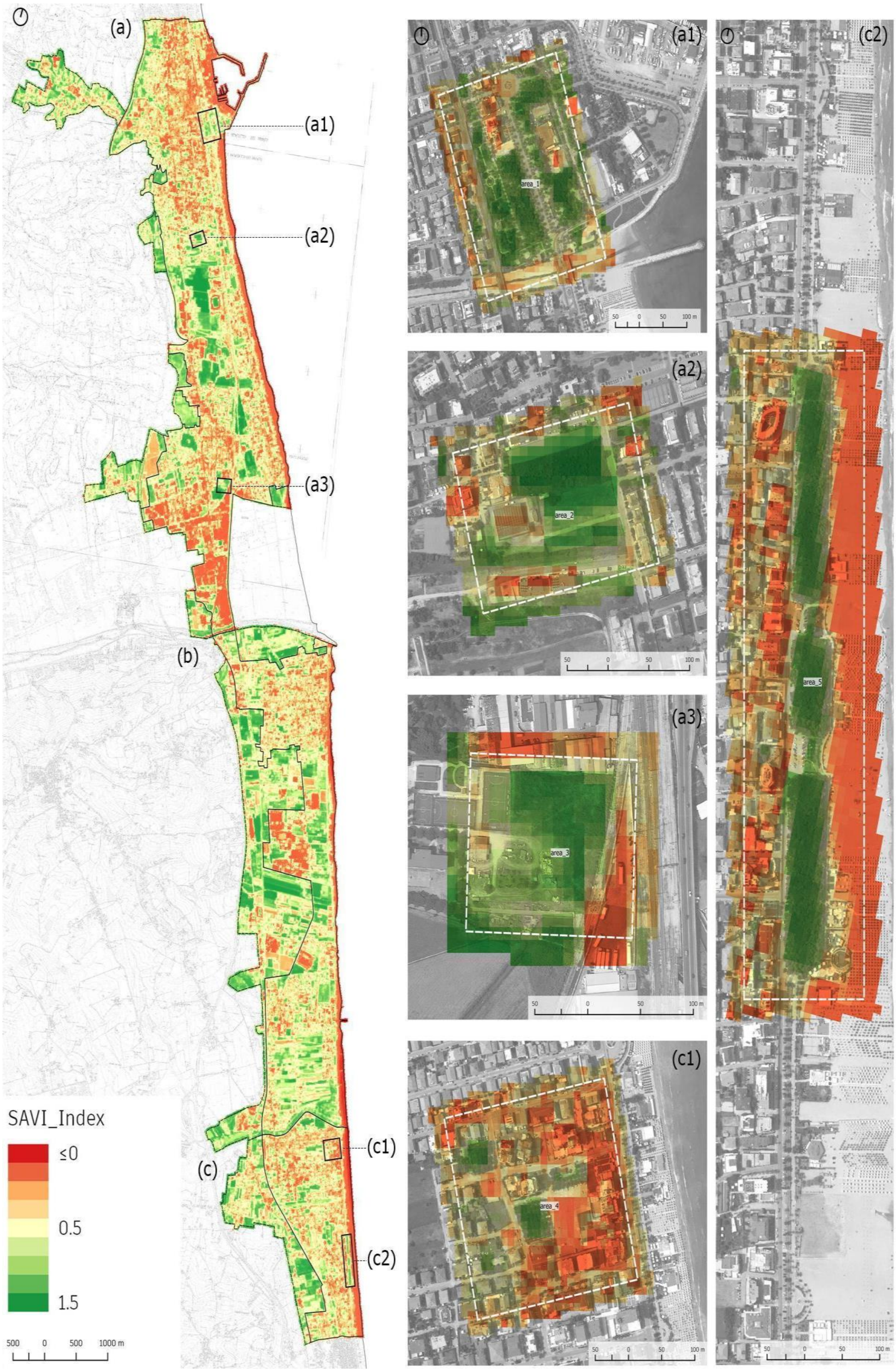

Fig. 4 SAVI Index calculated within the study area of the Municipalities of (a) San Benedetto del Tronto, (b) Martinsicuro, (c) Alba Adriatica, based on the Sentinel II image (Copernicus, ESA) from 10.05.2021. Panels (a1, a2, a3, c1, c2) show details of project pilot areas. Source: Prepared by the authors using Google Maps ©2022, Marche Regional Technical Map 1:10000 (2000), Abruzzo Regional Technical Map 1:10000 (2007)

Thermal Stress: A Diachronic Analysis of Surface Heat

The third vulnerability variable is the analysis of thermal stress using GIScience and remote sensing techniques in a GIS environment. The analysis was carried out through the use of i) multispectral images available via open-access,[18] ii) freely available semi-processed products (NASA – USGS[19]), and iii) the development of indices and mathematical formulas to calculate land surface temperature (LST) based on established methods in the scientific literature.

This analysis, like the others, was conducted on the large scale by photographing the current overheating dynamics in Italy (Spano et al., 2020; Munafò, 2022; Nanni, Minutolo, 2022), with particular reference to temperature trends over the last five years in the project areas obtained by studying regional weather bulletins.[20] As anticipated, the process was carried out on two fronts. On the one hand, various semi-processed images were acquired from the United States Geological Survey (USGS) with regard to provisional surface temperature (ST). On the other hand, the LST index was calculated on an extreme heat day identified using the 'representative day' method[21] (Tirabassi and Nassetti, 1999; Cocci Grifoni et al, 2022).

The huge number of products provided by the USGS — such as ST — are fundamental for the multi-criteria and diachronic monitoring of the Earth's surface temperature (Cook, Monica J., 2014; Cook et al, 2014) through thermal infrared spectral channels placed on geostationary satellites. These scientific indices measure the surface temperature related to the urban boundary layer (Oke, 2006), i.e. the coverage of the urban area above the average height of buildings. The estimate of surface temperature depends on i) the energy-emissivity of individual elements on the ground and systemic factors of an anthropogenic nature (albedo/reflectance of materials, etc.), ii) the degree of artificiality of materials and their intrinsic properties (e.g. light resistance), iii) the level of artificialization/impermeability of soils, iv) the coverage/presence of trees and the type/extent of green areas, and v) humidity, etc. (Caprari, 2021).

With this in mind, the results, which are presented below, were processed in several steps. They provide a large-scale and spatial/temporal overview of the thermal criticality of the study area, i.e. with respect to surface temperature and urban, natural and agricultural habitat elements.

The first step of the method returned a time series of 25 multispectral (pre-processed) images[22] acquired between 2017 and 2022 by the Landsat 8 mission (NASA). The images thus acquired were processed in a GIS environment to obtain the optimized data using the following formula:[23]

$$ST \quad = \left(\left(img_{B10} * 0.00341802 \right) + 149.0 \right) - 273.15$$

where:

B10 = BAND 10 thermal infrared satellite image (TIRS);

0.00341802 + 149.0 = pixel scaling and calibration factor;

–273.15 = conversion unit from degrees Kelvin (°K) to degrees Celsius (°C).

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[18] https://earthexplorer.usgs.gov/

[19] Specifically, the images are part of the Collection 2 Level 2 'Science Product', containing information pre-processed by an algorithm developed by the Rochester Institute of Technology (RIT) and the National Aeronautics and Space Administration (NASA). More information at: https://www.usgs.gov/landsat-missions/landsat-provisional-surface-temperature

[20] Report acquired from the "'Agenzia per i Servizi nel Settore Agroalimentare della Regione Marche-ASSAM, Centro Funzionale Multirischi della Regione Marche'" http://www.meteo.marche.it/blog/post/2022/07/01/Regione-Marche-Analisi-clima-giugno-2022.aspx) and from "'Centro Funzionale d'Abruzzo, AllarMeteo service'."

[21] This paper does not present the specifics of the process used in the research as it would require a special in-depth study beyond the scope of this contribution.

[22] Images within the summer period (May–August) were selected, with cloud cover between 0-40% and/or taking care that the clouds did not affect the study areas.

[23] Formula suggested in product use guidelines: https://www.usgs.gov/media/files/landsat-8-9-collection-2-level-2-science-product-guide

Once the satellite images had been processed, seven of the most critical temperature images were identified through photo-interpretation, analysis of the image histogram, and mostly using the criterion of frequency, i.e. the number of pixels per thermal degree. This method is useful because the maximum temperature as a selection value might not be representative of the frequency/presence of a given temperature value but rather be limited to a few pixels (areas) in the entire image. In relation to the frequency, the threshold value of 40°C was chosen, which returned the set of images suitable for representing the thermal-critical scenario for the five-year period 2017–2022. An extract is given below (Fig. 5).

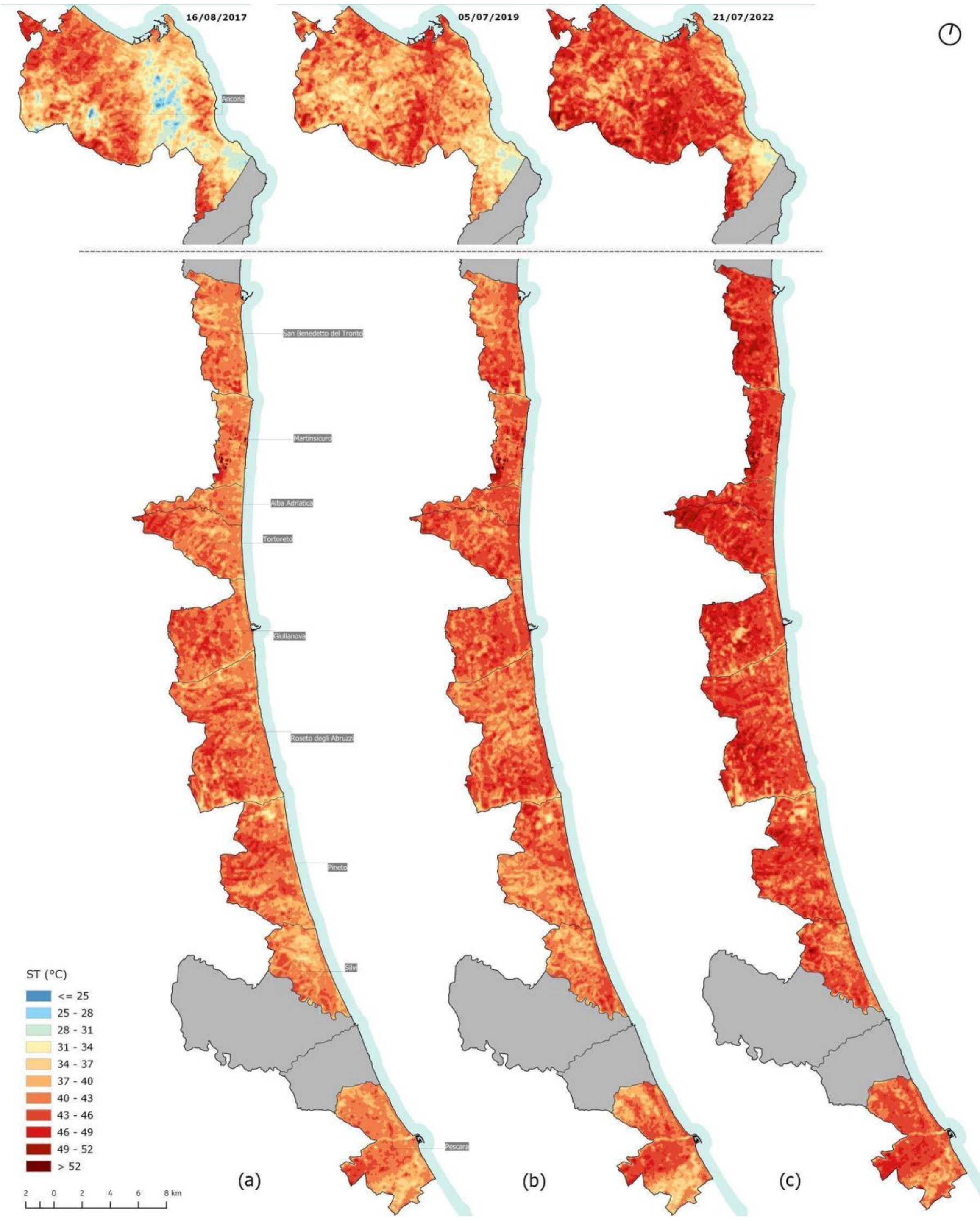

Fig. 5 ST Index developed for 3 days (a) 16.08.2017, (b) 05.07.2019, (c) 21.07.2022 out of the 7 calculated for each partner municipality (additional dates: 03.08.2018, 10.07.2021, 05.07.2022, 29.07.2022). Source: Prepared by the authors using Landsat 8 satellite images, NASA – USGS

Once this first diachronic analysis was completed, a satellite image[24] (Landsat 8 mission) was selected from 21 July 2019[25] (09:46 am) to calculate the LST index. This in-depth study is necessary for several reasons related to the higher spatial resolution of this data (60 m/px, ST; 30 m/px, LST) and the quality of the computation process, which is more detailed, used regularly, and better represented in the literature (Avdan, Jovanovska, 2016; Anandababu et al., 2018; Sandra et al., 2012; Wesley & Brunsell, 2019; Ejiagha et al., 2020). Multiple mathematical formulas were applied to the image to i) calculate the index and convert the raw data to temperature using the relevant electromagnetic bands (in particular B10, B4, B5), as suggested by Avdan & Jovanovska (2016), and ii) calibrate the data with geoprocessing operations to create the graphical output.

The steps for the LST can be summarized as follows:

- Calculation of atmospheric spectral radiance;
- Conversion of radiance to temperature at the sensor;
- Calculation of the NDVI vegetation index for the soil emissivity correction;
- Development of NDVI index;
- Calculation of vegetation ratio;
- Calculation of land surface emissivity;
- Calculation of LST index.

Without detailing the individual calculations for each variable, which have already been presented in the literature, here we highlight some aspects of this process. Like the ST above, this large-scale graphical result (Fig. 6) like the previous ST, does not return the temperature perceived by people at street level (0–2 m), which is left to subsequent micro-scalar simulations, but it does highlight the system of areas most exposed to solar radiation and susceptible to overheating in the urban-territorial area.

In fact, these areas absorb most of the direct radiation during the day and then release heat during the night, thus contributing to the UHI, which is exacerbated locally by the urban form and the rise in heat waves and, globally, by tropicalization of the climate.

Pursuing the aims of the contribution, the last section (Sect. 3) specifically investigates the process of creating a multidimensional GeoDB and risk map capable of highlighting the fragility/healthiness of the territory, depending on the interest — here with respect to the heat stress, UGI quality/quantity, and population vulnerability.

3. Results: An Updatable Geodatabase for Generating Risk Maps

The result of the cognitive framework is a qualitative-quantitative risk map developed through i) spatial correlation of the processed data and ii) querying the GeoDB.

The following are the variables produced, which are combined with other indicators and spatial data of interest. Together, make up the GeoDB dataset:

- socio-demographic fragility;
- soil quality: morphological-spatial vulnerability (SAVI Index);
- multi-temporal thermal stress (ST Index, LST Index);
- hydrogeological Management Plan (PAI[26]), i.e. risk areas;
- educational institutions and health centers.

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[24] Selected image: LC08_L1TP_190030_20190721_20200827_02_T1, Landsat 8, Collection 2 Level 1, USGS.

[25] The image selected from among the 7 extremely hot days, was identified through the above-mentioned method of the 'representative day', which returns the recurring thermal condition most representative of the specific area in question.

[26] Piano di Assetto Idrogeologico

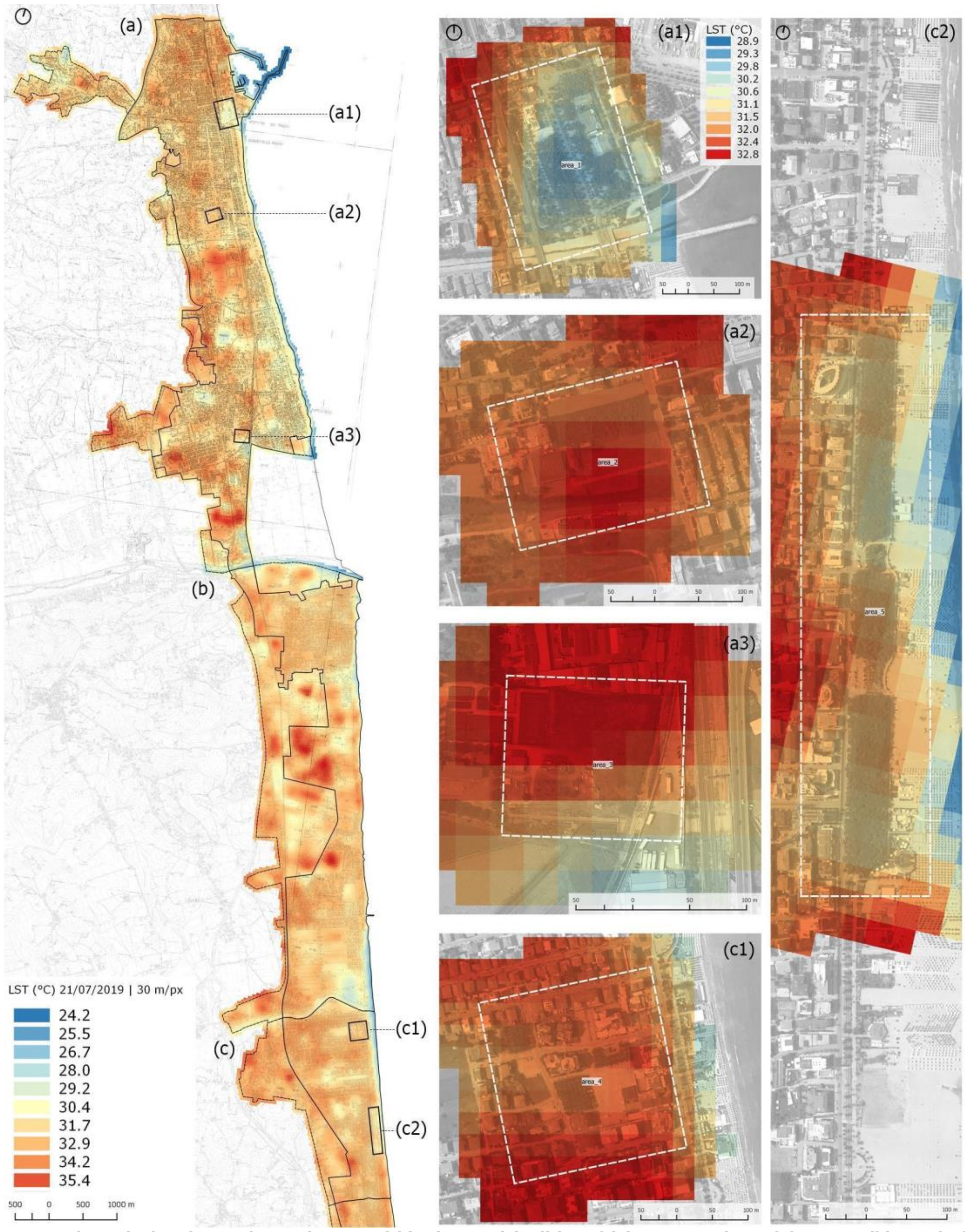

Fig. 6 LST Index calculated over the study area within the municipalities of (a) San Benedetto del Tronto, (b) Martinsicuro, and (c) Alba Adriatica, based on the Landsat 8 image (NASA – USGS) from 21.07.2019. Panels (a1, a2, a3, c1, c2) show details of project pilot areas. Source: Prepared by the authors using Google Maps ©2022, Marche Regional Technical Map 1:10000 (2000), Abruzzo Regional Technical Map 1:10000 (2007)

Points of interest (POIs) and/or places where vulnerable groups aggregate, including schools, nursing homes, hospitals, etc., as well as areas at risk of landslides/flooding, etc., were integrated. The latter are particularly important considering the hydrogeological instability of the central Apennines, which is aggravated by land consumption trends in the coastal area, poor territorial maintenance and care, sealing/artificialization of many areas along rivers, ditches, and streams, etc., as highlighted by thematic studies (Munafò, 2022). In this sense, data on the POIs were acquired from unofficial public databases such as OpenStreetMap[27] (OSM), which relies on contributions from the geographical community and international users on a voluntary basis (Voluntary

[27] Specifically, the 'overpass turbo' search engine was used as a web-based tool to extract OpenStreetMap data by spatial query with SQL (Structured Query Language), e.g. amenity = hospital; amenity = school; etc. Site available at: https://overpass-turbo.eu/.

Geographic Information – VGI). On the other hand, sector planning data (PAI) were downloaded directly from the geoportals of local authorities[28] and official GIS-based open data.

All acquired/produced/measured data were manually validated and integrated into the GeoDB via geospatial processing in the GIS environment. The data were homogenized[29] and spatialized on a uniform polygonal grid (hexagons) - with horizontal and vertical spacing of 30 m and a surface area of 749.42 m^2 - that covers the entire area of study. Each hexagon returns the informational and semantic attributes of the GeoDB, i.e. the geometric base on which the risk map is visualized and spatialized. The aggregation of data into regular shaped grids with uniquely named cells/areas (via IDs) is extremely useful for i) 'normalizing' data from multiple sources, ii) mitigating problems associated with the use of irregularly shaped polygons created for other purposes and with other criteria (i.e. administrative census sections), and iii) having a 'key' to implement the GeoDB over time. As the last step in the whole research process, the GeoDB was spatially interrogated using 'logical operators'[30] in SQL computer language and the discretionary use of quantitative 'threshold limits', between an analogue approach and digital tool. The expression relates the three fragility variables and the added vulnerability data with respect to their presence in and/or level of criticality for each hexagon. As can be seen from the highlighted hexagons (Fig. 7), there are multiple dimensions of risk, since there are several variables that affect their severity, including age, soil morphology, and thermal stress. Red borders are used for areas with socio-demographic fragility, i.e. areas subject to a high concentration of weak population groups with respect to census size or areas with a high number of fragile residents. Orange is used for morphological-climate fragility (soil and heat). Blue and brown, respectively, are the landslide and flooding risk. In order to understand the contents of the resulting risk map, two tabular excerpts of the GeoDB are reported (Table 2[31]) concerning only hexagons subject to risk, i.e. those highlighted in the municipalities of Ancona and Pescara.

	Indicators									
	Socio-demographic				Soil type		Heat		Hydro-geol.	
Hexagon ID (no.)	**Residents (no.)**	**TFW (no.)**	**NFW (0-1)**	**Frag/Res (%)**	**Imp (%)**	**Perm (%)**	**LST mean (°C)**	**ST mean (°C)**	**PAI land-slide**	**PAI flood**
3,305	186	89	0.01231	47.85	100	0	33.47	44.17	no data	
3,341	339	167	0.10654	49.26	100	0	32.81	43.11	no data	
3,342	339	167	0.10654	49.26	100	0	32.84	43.27	no data	
3,343	591	287	0.21538	48.56	100	0	33.02	43.68	no data	
3,344	323	154	0.21538	47.68	100	0	33.46	44.16	no data	
110,739	242	125	0.97512	51.65	100	0	33.17	42.26	no data	
110,740	242	125	0.97512	51.65	100	0	33.45	42.63	no data	
110,745	398	173	0.24337	43.48	100	0	34.64	44.29	no data	
110,746	650	274	0.24337	42.15	100	0	34.63	43.94	no data	
110,747	343	147	0.24337	42.86	100	0	34.41	43.36	no data	

Table 2 Extract of the Risk GeoDB for the Cities of Ancona (above) and Pescara (below)

[28] Specifically, the Flood Risk Management Plan PGRAAC (Directive 2007/60/EC, Article 6 of Italian Legislative Decree 49/2019) prepared by the Central Apennine District Basin Authority of the Marche and Abruzzo Regions and the Hydrogeological Management Plan (PAI) was acquired. Data is available at: http://www.pcn.minambiente.it/mattm/servizio-di-scaricamento-wfs/; https://webgis.abdac.it/portal/home/.

[29] The individual processes for calculating the three fragility variables returned the data in different geographical formats (polygonal, e.g. .shp; raster, e.g. geotiff; etc.). For the purposes of the GeoDB, these were converted into and/or associated with the polygonal data (hexagons).

[30] https://docs.qgis.org/3.28/it/docs/pyqgis_developer_cookbook/expressions.html

[31] Acronyms used in the tables: Hexagon ID: unique hexagon number; Residents: number of residents; TFW: Total fragility weight (see Table 1); NFW: Normalized fragility weight (from 0 to 1); Frag/Res: ratio of vulnerable groups to number of residents; Imp: Impermeable surfaces ; Perm: Permeable surfaces ; LST mean: Land surface temperature, average; ST mean: Surface temperature, average; PAI landslide: hexagons subject to landslide (PAI source); PAI flood: hexagons subject to flood events (PAI source)

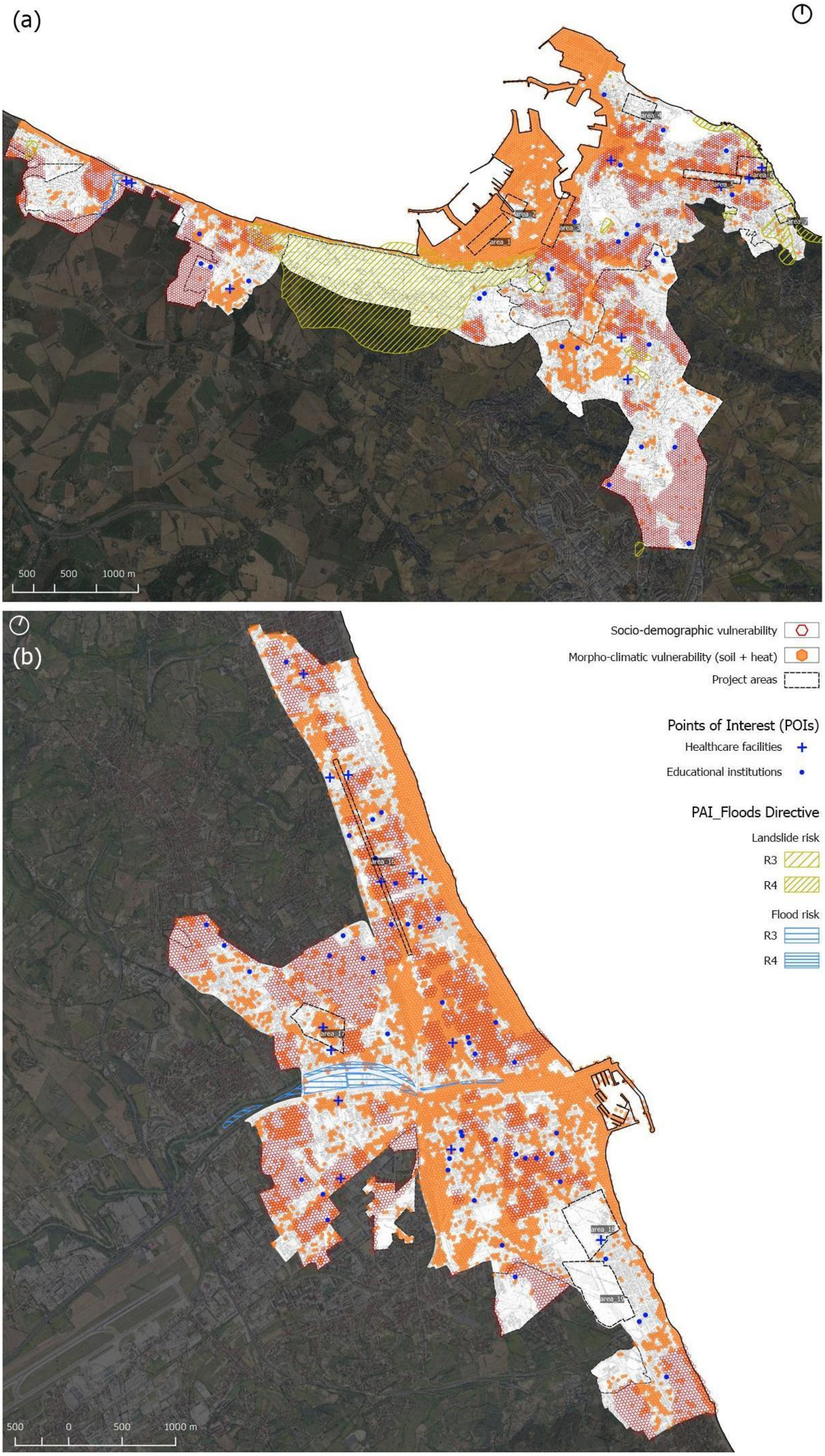

Fig. 7 Risk map of the study area within the Cities of Ancona (a) and Pescara (b). The risk areas/hexagons resulting from the spatial query of the Geo-DB are highlighted. Source: Prepared by the authors using Google Maps ©2022, Marche Regional Technical Map 1:10000 (2000), Abruzzo Regional Technical Map 1:10000 (2007)

4. Discussion: Limitations and Potential of the Method

This work inevitably has some limitations with regard to the quality/quantity of the data acquired and variables developed, but it has outlined an interdisciplinary working method that aims to renew the cognitive framework of the large area of the mid-Adriatic coastal city, supporting the aims of the A_GreeNet project.
Here we briefly discuss the limits and potential of the three data processing steps.
With regard to the first topic (i.e. socio-demographic fragilities), the census sections do not follow the project perimeters but rather the administrative ones. It is possible that a census section may be cut off and/or include only a small extent of the area of study, which would consequently and erroneously receive all the data for the census section. This situation, even if it is small compared to the scale of the survey, could influence the spatial queries of the GeoDB (i.e. hexagons) and the resulting risk map. In this perspective, it is important to emphasize that all the data acquired by the municipalities are affected by the different size of the census (see Fig. 3 a; b) since the data are geo-localized with respect to the limits of the respective sections. The main municipalities and higher-density built areas include a greater number of smaller sections, for which the numerical data are smaller but concentrated with respect to the data for larger, sometimes 'peripheral' sections, which have a considerable number of fragile persons and target-users (see Fig. 3, c). In this sense, knowledge of the places and quality of the source data play a fundamental role in correctly interpreting the data. To partially overcome this problem, demographic and other data were georeferenced onto a uniform hexagonal grid and normalized. Moreover, for a complete overview of social vulnerability, multiple variables should be taken into account, such as per capita income, number of persons suffering from chronic and disabling diseases, hospital admissions, etc., which are currently not available. Anyway, the research made use of the most up-to-date registry data by working in synergy with technicians from the municipalities involved, going beyond open data that is publicly available (i.e. ISTAT census of 2011).
With regard to the second topic of interest (i.e. physical-territorial fragilities), the SAVI index provides fundamental cognitive support for quickly mapping greenery on the urban-territorial scale, but it returns mostly quantitative information. This index was preferred to the other common vegetation index used for a similar aim (NDVI), as it is particularly suitable for reducing the light/reflection effects of the different soil types, especially in areas with lower vegetation density such as the urban areas of the Adriatic city. Further qualitative/quantitative aspects could be provided from i) more detailed multispectral images (not available in open-source), ii) green censuses on a municipal basis (not always present or updated within the municipalities), and iii) a multi-temporal comparison between SAVI and other indexes such us the Normalized Difference Moisture Index (NDMI) and the Vegetation Health Index (VHI) proposed, for instance, in the literature (Maragno et al., 2021; Todeschi et al., 2023).
In our case, it must be emphasized that some permeable and semi-natural areas (i.e. agricultural crops), albeit few in number, appear as artificialized land such as buildings or asphalt surfaces if the soil is bare (i.e. agricultural crops subject to rotation) when the satellite shot was taken. In this perspective, a multi-temporal analysis of satellite images through SAVI would have been appropriate. Finally, for a cross-cutting analysis of the landscape-vegetation component, it would be useful to consider aspects such as the quality/function of the green areas (i.e. types of species present and their environmental/aesthetic value), accessibility, etc., which are difficult to investigate on the large scale and/or summarize as a numerical indicator. These considerations cannot all be addressed due to space/time issues, but will be treated on another scale using other methods during the next phase of A_GreeNet.
With regard to the third topic (i.e. meteorological-climate fragility), the limitations relate to i) the quality of data input (30–60 m/px), ii) the type of information (based on thermal exchanges between materials/elements on the ground and the satellite sensor), and iii) time (satellite image acquired only in the early morning). For a more inclusive critical overview, the data measured using a certain day/time set will be integrated with simulations capable of better understanding the relationship between urban form and climate variables, going

beyond the temperature parameter (wind, humidity, etc.), as established in the next phase of the project. Nevertheless, the LST index is widely used in the current literature for the same purposes, especially on the large scale. Even considering certain limitations, the results obtained from the cognitive framework highlight the areas most subject to thermal discomfort (i.e. Fig. 7) and show a trend of persistent thermal stress in the mid-Adriatic area (i.e. ST, Fig. 5) as also reported in the local meteorological reports.

An assessment of the potential of green infrastructure to investigate hydrogeological risk (Lai et al., 2021) as well as an analysis of the aerobiological risk of trees (i.e. allergenicity) using different GIS techniques and data (Pecero-Casimiro et al., 2019) would be interesting in order to complete such a cognitive framework.

The analysis of flash floods is needed in future research and GIScience can also support researchers in this case (Lin et al., 2019). In this specific case, it was preferable to acquire official, recently updated (2021) hydrogeological data, considering that i) the topic is secondary with respect to A_GreeNet, albeit fundamental with respect to strategy, and ii) the data processing would probably not have implemented the knowledge already developed by the relevant bodies. In this sense, Digital Terrain Models (DTMs), Digital Surface Models (DSMs), and specific tools to identify areas of catchment/flooding should be used, especially where multiple fragilities have been identified. In this specific case, this type of data cannot easily be acquired for all the areas involved in the project due to the time required to request the data and/or differentiate them geometrically.

Finally, from these reflections, it is evident that beyond the quantity of data, the quality of the data (spatially and semantically) and technological tools (algorithm, geoprocess etc.) determine the quality of the geoDB and related maps. This type of map (Fig. 7) is one of 'n' possible geo-spatial queries[32] on the specific dataset. In this sense, data interrogation presupposes i) discretionary validation if scientific thresholds are missing, and ii) a critical interpretation of the data and results associated with an in-depth understanding of site-specific dynamics. This framework gives rise to the need for an integrated dialogue between geo-based instrumental innovation and traditional techniques/approaches used in urban and landscape studies that are not uniquely related to alphanumeric attributes and processes involved in exact sciences. Even with such intrinsic limitations, the benefits of geo-technological progress in developing multi-temporal analyses on different scales, managing and promptly implementing public databases, and understanding of landscape dynamics from a different perspective is unquestionable.

5. Conclusion

This research presents a scientific methodology to critically assess territorial fragilities on the large scale with respect to three important topics. The process was tested in line with the A_GreeNet aims in order to: i) semi-automatically identify urban green areas and the limits/margins of coastal UGI; ii) highlight urban areas subject to social fragility and thermal discomfort; iii) test and improve a current method (Cocci Grifoni et al, 2022; Caprari, 2022) for downscaling such analysis from the macro to micro scale in order to focus on risk areas/subareas to prioritize actions for UGI improvements; iv) disseminate the value of open data to support territorial monitoring; and v) draw the attention of local planning authorities involved in the project to the need for site-specific UGI interventions and their role as a 'health device' for local communities.

The last point especially, i.e. the technical-operational impacts of the project, is still in progress and constitutes the greatest value and ambition of A_GreeNet.

The research presented here and the climate forecasts being developed (UMEP, ENVI-met) are designed to support PAs practitioners in deciding how/where to focus improvements of the UGI (e.g. reforestation, diversifying the agricultural/natural landscape, regenerating green areas, plant health restoration, etc.).

[32] For example, to display the map as shown in Fig. 7, all areas that are completely artificialized and impermeable or those with a high thermal stress were highlighted (see Tables 2, 3) and linked to those with a large number of fragile residents. In this case, the two macro risk categories were highlighted individually with two separate spatial queries for greater clarity considering synergies with the various stakeholders.

Such actions are not general but have considered the local urban plans and the specific legal status of the territory (i.e. prescription), especially where greening has not been implemented as planned and where several risks and critical factors are present (i.e. risk map).

In this context, the purpose of the project is to establish the groundwork for a governance structure that operates across multiple levels and involves various stakeholders. This means enhancing capacities in both administrative-management and technical-operational aspects related to climate adaptation.

It also encompasses the revitalization of knowledge frameworks (i.e. GIScience) and the enhancement of design capabilities for green infrastructure on various scales. This is achieved by contributing to the existing urban planning instruments and building regulations that have already gained approval (D'Onofrio et al, 2023; D'Onofrio et al, 2022). The innovation of the research lies in the generation of a contemporary, adaptable, and incremental evidence-based geo-database that combines the quantitative approach of synthetic data with analogue supervision throughout all stages of the process and a thorough examination of municipal planning regulations. This outcome contributes to the scientific debate on renovating cognitive processes for understanding territorial fragilities, transformations caused by climate change, and socio-demographic dynamics. The initial findings of the on-going research reaffirm the contribution of new technologies, geographical methods, and data that need to be integrated with traditional approaches to urban and landscape analysis. This integration is particularly crucial on larger scales, where geospatial observation reduces time requirements and unveils relationships that are less discernible with analogue instruments. It also enables the activation of a cyclical process of qualitative and quantitative monitoring and verification of the results of UGI policies/interventions. The potential research advancements encompass the inclusion of additional input data pertaining to the variables that have been developed. This may involve integrating data from municipal green censuses, municipal tree health reports, surveys of abandoned buildings or unused public heritage areas, per-capita income, data on individuals with chronic or disabling illnesses, and hospital admissions during specific periods (such as heat waves or the entire summer), along with high-resolution multispectral images. Moreover, the study stands to gain from the use of additional scientific indices, as mentioned earlier, or methods for semi-automatic serial data analysis.

This approach would enable the integration of a more extensive dataset or satellite images. Additionally, the scope of the research could be expanded by incorporating an analysis of urban accessibility to green areas (e.g. network analysis) and/or an assessment of the morphology of open spaces (e.g. slopes and outflows) to identify the areas most susceptible to flooding. Here, we also emphasize that the development of the GeoDB, scientific indexes and cartographies was made possible by Open Data and Open Science (GIS-based tools). In this perspective, the method promotes the spread of transferable open-access methods based on free-access data and portals and an updatable geoDB data that can be downloaded from the official project website. Disparities in public datasets related to both individual geometries and information quality is certainly not uncommon. This shortfall can be ascribed to limitations in the national/local digital transformation process, digital/technological skills, administrative and governmental challenges related to data transparency, the failure to update datasets, or the absence of certain datasets. The transferability of the method is contingent to a significant extent on these factors.

In conclusion, the forthcoming stages of research will consider interconnections between urban planning and the role of green spaces in enhancing the quality of life, supported by a refined understanding and capabilities offered by GIScience. UGI emerges as a structural constant, providing fertile ground for collaborative experimental research between academia and practice, aimed at fostering a more resilient living environment.

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