

## Article

# Integration of Climate Change and Ecosystem Services into Spatial Plans: A New Approach in the Province of Rimini

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**Abstract:** This study presents a spatial methodology for integrating climate change (CC) risks and ecosystem service (ES) assessments into strategic spatial planning, applied to the Metropolitan Plan of the Province of Rimini (Emilia-Romagna, Italy). The proposed approach combines IPCC-aligned climate vulnerability analysis with ecosystem service mapping based on the methodology developed by CREN. Climate risks, including urban heat islands, droughts, and urban floods, were assessed using satellite-derived indices such as Land Surface Temperature (LST), Vegetation Health Index (VHI), and hydraulic modeling. For ESs, nine key services were evaluated and mapped by integrating land use, forest cover, and habitat data with biophysical modulation factors (e.g., slope, carbon stock, infiltration capacity). The results highlight priority areas where climate adaptation and ecological functions converge, enabling targeted interventions. This integrated workflow offers a replicable and scalable planning tool to support evidence-based decision-making at the metropolitan level. Its adoption is recommended by other local and regional authorities to strengthen the climate and ecological responsiveness of spatial planning instruments.

**Keywords:** climate change; ecosystem services; urban planning; climate adaptation; urban adaptation; remote sensing; earth observation



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## 1. Introduction

Growing attention has been devoted to climate change (CC) due to its significant impacts on urban systems, ecosystems, and public health—collectively referred to as climate impacts (CIs) [1,2]. Climate projections for urban areas highlight the need for integrated planning activities to reduce greenhouse gas emissions and enhance urban resilience to future climate impacts [3,4]. Therefore, it is important to prioritize CC mitigation and adaptation in urban agendas and revise conventional urban planning approaches. Local governments play a vital role in this transformation, as they can define strategies and measures to reduce climate-altering gas emissions and adapt their territories through local planning tools, as outlined in the Paris Agreement (2015). Besides climate issues, it is essential to consider ecosystem properties to ensure quality of life and environmental well-being. Evaluating ecosystem services (ESs) is gaining consensus, especially in urban and regional planning, as a tool for assessing ecosystem supply and biodiversity [5,6]. By mapping ESs at various scales, it is possible to increase awareness of the role ecosystems play in supporting human well-being and reinforce the interconnection between urban and natural systems. However, this evaluation approach presents several limitations, primarily due to the scarcity of high-quality spatial data [7,8]. The connection between

CC adaptation and ESs has become increasingly significant. Nature-based solutions and green infrastructure are now widely recognized as essential components of planning strategies. This marks a significant shift, particularly in Italy, where green spaces have traditionally been evaluated based solely on their size rather than on their contribution to ecological integrity and socio-economic resilience [9–11]. To effectively address climate impacts through ecosystem services, planning must adopt an integrated, cross-sectoral, and multiscale perspective. Incorporating ecosystem services into planning instruments and initiatives is essential at all levels, from regional to local. Regional and metropolitan strategies should be defined to enable local implementation, following guidelines that endorse the principle of subsidiarity [12].

This paper outlines the methodological approach to developing the Plan for the Metropolitan Territory of the Province of Rimini (PTAV)<sup>1</sup>, in accordance with Regional Urban Planning Law No. 24/2017<sup>2</sup> [13–15], with scientific support provided by Iuav University of Venice during the development phase. The PTAV provides the knowledge and strategies that municipalities are required to adopt and implement in the drafting of local-scale plans, with the aim of promoting community well-being and addressing environmental and climate emergencies<sup>3</sup>. It aims to define a long-term, resilient vision for territorial development, aligning public interest with urban and environmental planning decisions. This shared approach enhances governance capacity and supports more informed and effective decision-making. It emphasizes the importance of assessing the territory and its evolutionary processes (Regional Law 24/17, Art. 22). By incorporating the Climate Adaptation Planning Methodology [16], the PTAV aims to reduce climate vulnerabilities and develop local resources, focusing on ecosystem services (ESs). The plan provides a strategic opportunity for the province and its municipalities to collaborate around a shared vision, pooling their respective strengths and resources to pursue common objectives. Integrating climate change adaptation and ecosystem services into planning strategies makes the plan both innovative and dynamic, transforming the urban knowledge framework into a diagnostic tool for evaluating planning effectiveness over time. Moreover, the spatial knowledge derived from assessments of climate vulnerability<sup>4</sup> and ecosystem services offers essential support to metropolitan and local authorities in advancing socio-economic and environmental goals, particularly through ecological transition and enhanced climate resilience. The paper outlines the response to the legal requirement to assess and consider climate impacts at the provincial scale for the territory of Rimini, integrating them into strategic planning processes. It also reflects on the added value of incorporating both climate risks and ecosystem services into spatial planning as a means to support sustainable development and climate adaptation strategies.

This contribution, therefore, aims to answer the following research questions:

- RQ1: How do we consider climate impacts within planning processes?
- RQ2: How should ESs be assessed in relation to the competencies of planning instruments? What are the implications for database structure and knowledge frameworks?
- RQ3: How can ESs be considered within strategic planning processes? What are the benefits? What does it imply in monitoring?

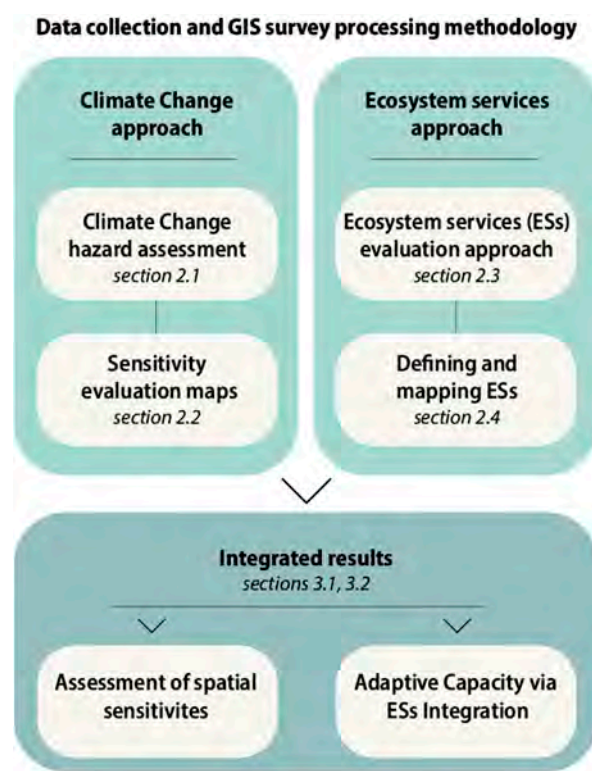
## 2. Materials and Methods

The methodological approach adopted is strongly related to the methodology suggested by the IPCC [2]. From this methodology, the operational steps involved in developing climate vulnerability assessments are, in fact, defined.

This study produced sensitivity maps for each climate impact and adaptive capacity maps for each ecosystem service (ES) to guide the PTAV planning process, incorporating adaptation and ES issues. Sensitivities and adaptive capacities were assessed separately to

better define strategic plans. This approach enriched the planning process with new spatial information, enhancing and improving existing adaptive capacities where needed.

Hazard characterizes an event potentially impacting a specific territory. The authors integrated climate change (CC) and ecosystem services (ESs) into the spatial planning process. For CC, they first defined future climate hazards specific to the Province of Rimini, then identified potential impacts, focusing on heat waves and intense rainfall events. As for ESs, the Emilia-Romagna Region, in line with the European Directive on environmental sustainability and Italian Law No. 221/2015, enacted Regional Law 24/2017 to promote green economy measures and reduce the overexploitation of natural resources. This legal framework established the basis for surveying and assessing ESs provided by environmental systems. Nevertheless, an integrated workflow was needed to combine climate impact and ecosystem service assessments in a coherent framework to inform PTAV decision-making. This section outlines the methodological approach adopted for assessing climate impacts and ecosystem values within the Province of Rimini's planning process. The workflow structure is illustrated in Figure 1.



**Figure 1.** Workflow of the methodology.

Starting from the spatial knowledge framework, the methodological approach integrates climate and ecosystem analyses into a unified strategy that addresses two emerging themes in planning processes in an innovative and dynamic manner.

### 2.1. Geographical and Climatic Context: Current and Expected Hazard Scenarios

This section describes the climate change hazard assessment, considering past climate scenarios and trends regarding temperature and precipitation (Figure 2).



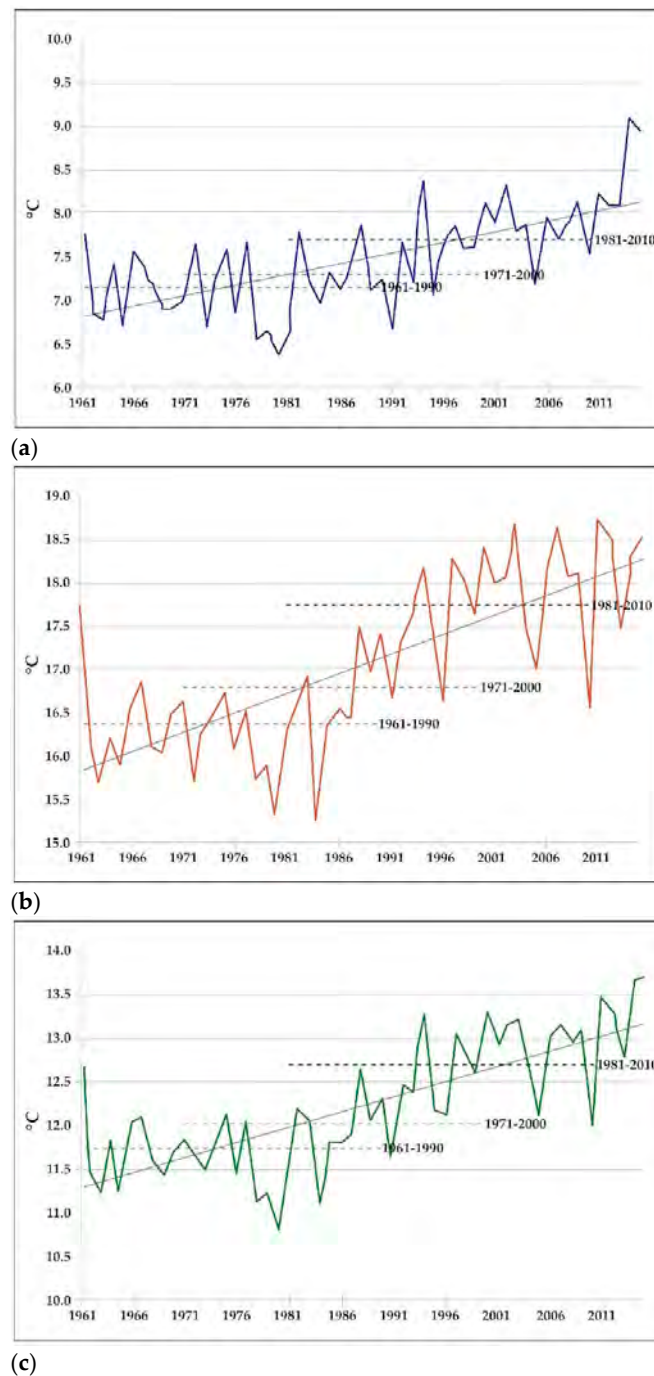
**Figure 2.** Workflow of the geographical and climatic context.

The Province of Rimini is located along the southernmost stretch of Emilia-Romagna's coastline, with a hinterland consisting of a flat area in the north that extends to the sea to the east in the areas of Rimini and Riccione. To the west, a hilly and mountainous Apennine belt makes up the area (Figure 3). The Province of Rimini has a warm temperate climate that is stably humid, with hot summers and a reduced diurnal temperature range, thanks to the influence of the Adriatic Sea.



**Figure 3.** Localization of Rimini Province: study area.

The studies carried out by ARPAE<sup>5</sup>, comparing the recent climate (1991–2015) with that of the 30-year reference period 1961–1990, show evident changes attributable to CC [17]. According to the "IdroMeteoClima Emilia-Romagna Report" [18], carried out by the Arpa Emilia-Romagna Climate Observatory, in 2020, there was a temperature deviation of about +0.5 °C on the recent climate (1991–2015) and +1.5 °C on the 1961–1990 climate (Figure 4a–c).

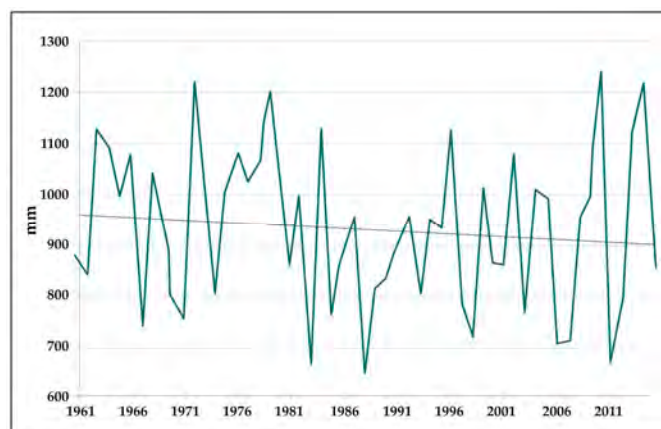


**Figure 4.** (a–c) Graph of historical trends and temperature (°C) minimum (a), maximum (b), and average (c) between 1961 and 2015 in Emilia-Romagna (Atlante climatico dell’Emilia-Romagna 1961–2015).

Overall, 2020 was, on average, the fifth warmest year after 2014, 2015, 2018, and 2019. It was also the mildest year ever since 1961 for average winter temperatures, with few days of frost and anomalous late spring frosts, which caused severe damage to fruit crops in advanced phenological development. As far as rainfall is concerned, no significant changes in annual precipitation patterns have been observed. However, shifts in the regime are evident, with prolonged droughts and more frequent extreme events (Figure 5).

In recent years, significant rainfall deficits have characterized the phenomenon over almost the entire region compared to 1961–1990. The negative anomalies have also been very intense, with values as low as  $-300$  mm in Emilia-Romagna in 2020. November

2020, usually the wettest month, presented the lowest level of rainfall in the last 60 years, with deviations of about 70% less than the climatic reference values (1961–1990). The year 2021 was a drought year:  $-235$  mm of precipitation compared to the reference climate (1991–2020), with negative anomalies over much of the regional territory [19].



**Figure 5.** Graph of historical trends and trends in annual precipitation (mm) between 1961 and 2015 in Emilia-Romagna (Atlante climatico dell’Emilia-Romagna 1961–2015).

Rainfall events become more polarized, tending toward the extremes precisely with more intense and concentrated events occurring than in the past [20–22].

The analysis of climate trends made it possible to identify hazards for the territory, from which it was possible to identify possible climate impacts. Data were collected and processed for each climate impact in a (Geographic Information System) environment to assess the territory’s sensitivities and vulnerabilities (considering E.S.s as adaptive capacity) [2]. From the analyses performed, the authors decided to consider urban heat islands, droughts, and urban flooding as climate impacts in the PTAV.

## 2.2. Sensitivity Assessment Maps in GIS: Heat, Drought, and Floods

The following steps outline the main components of the climate impact stress assessment. The climate impacts considered are urban heat island, water stress conditions, and floods (Figure 6).

The phenomenon of the urban heat island describes elevated temperatures in urban areas relative to their rural surroundings [23–25]. During the day, artificial surfaces store more thermal energy (heat) than the surrounding agricultural and forest areas [26]; thus, during the night, the temperature difference amplifies. While the rural system cools rapidly, the urban fabric takes much longer, resulting in a slow and gradual release of heat due to the thermal inertia that characterizes the materials of the built space.

Ongoing CC requires planning processes to be supported by spatial survey tools that can identify and localize urban areas particularly vulnerable to such phenomena [27]. The present contribution develops its assessment and mapping of phenomena related to excessive heat on the Land Surface Temperature (LST) calculation. This term is used to describe a method that measures the temperature of surfaces. The LST thus emerges as a significant parameter as it provides insight into the thermal impact caused by climate variations [28].

The operation behind the LST is developed in a GIS environment, starting with the emissivity of the Earth’s surface and the brightness temperature of the Earth’s surface. The authors calculate the brightness temperature and land surface emissivity by processing data from the Landsat 8 mission<sup>6</sup> [29].

The survey produced raster images where each pixel expresses the surface temperature for every 30 m of land area. The processed images were identified based on the climate survey carried out in the previous phase, processing data from warmer days subject to heat waves. At the provincial level, the analysis of the LST allowed the distribution of ground temperatures greater than 30 degrees to be identified (Figure 7).

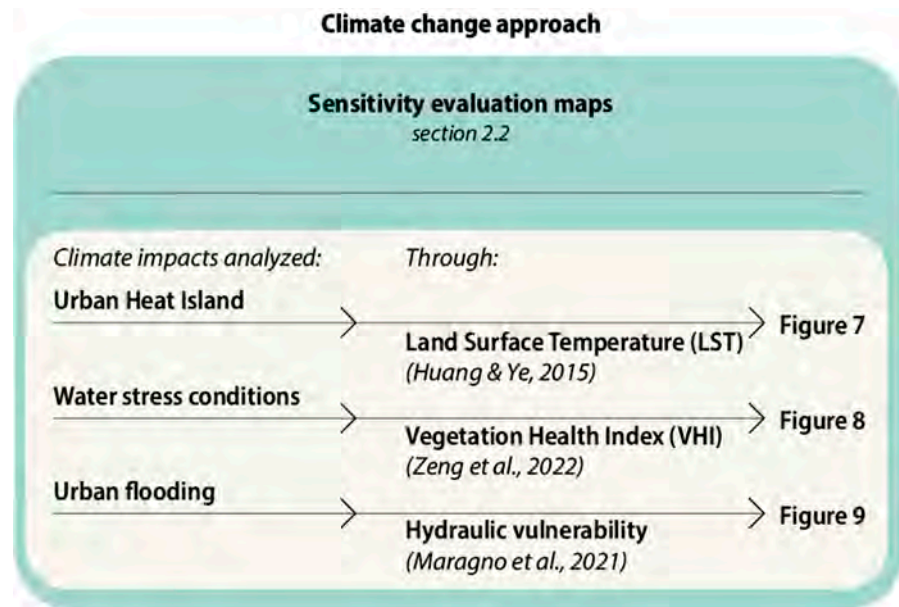
Determining water stress conditions at the provincial level requires adequate spatial information. To this end, the authors employed remote sensing techniques and calculated the VHI (Vegetation Health Index)<sup>7</sup>. Assuming that a constant and intense increase in soil temperature, combined with a prolonged period of no rainfall, harms vegetation vigor and causes significant vegetation stress, the VHI bases itself on the inverse correlation between LST (reflected soil temperature) and NDVI (presence of chlorophyll in the leaf).

The VHI is derived from the relationship between the Temperature Condition Index (TCI) and the Vegetation Condition Index (VCI). The calculation of the TCI uses temperature data obtained from the LST, while that of the VCI is based on NDVI vegetation data reflecting soil moisture conditions. The VCI indicates standardized values (in %) reflecting vegetative stresses related to low moisture content, while the TCI reflects values (in %) of vegetative stresses related to high temperatures. The VHI is, therefore, a representative indicator of the general health of the vegetation present in an area at the time of satellite data acquisition. It is a balanced estimate between the observation period's thermal state and plant tissue's moisture content [30]. In detail, the VHI manifests increasing drought conditions<sup>8</sup>, below threshold value 40, where some territories present a high vegetative stress status [31,32]. The spatialization of the VHI enables the authors to identify water stress gradients that, when adequately correlated with specific context information, can indicate the potential propensity of a specific forest or tree type to drought stress and fire exposure. The VHI allowed us to investigate the behavior of areas of high ecosystem value concerning the possible specific impact of drought. The authors considered the relationship whereby the impact of drought decreases the provision of ecosystem services (ESs) in the long term; thus, to maintain the provision of these services, the assessment enabled the identification of areas most susceptible to climate impacts.

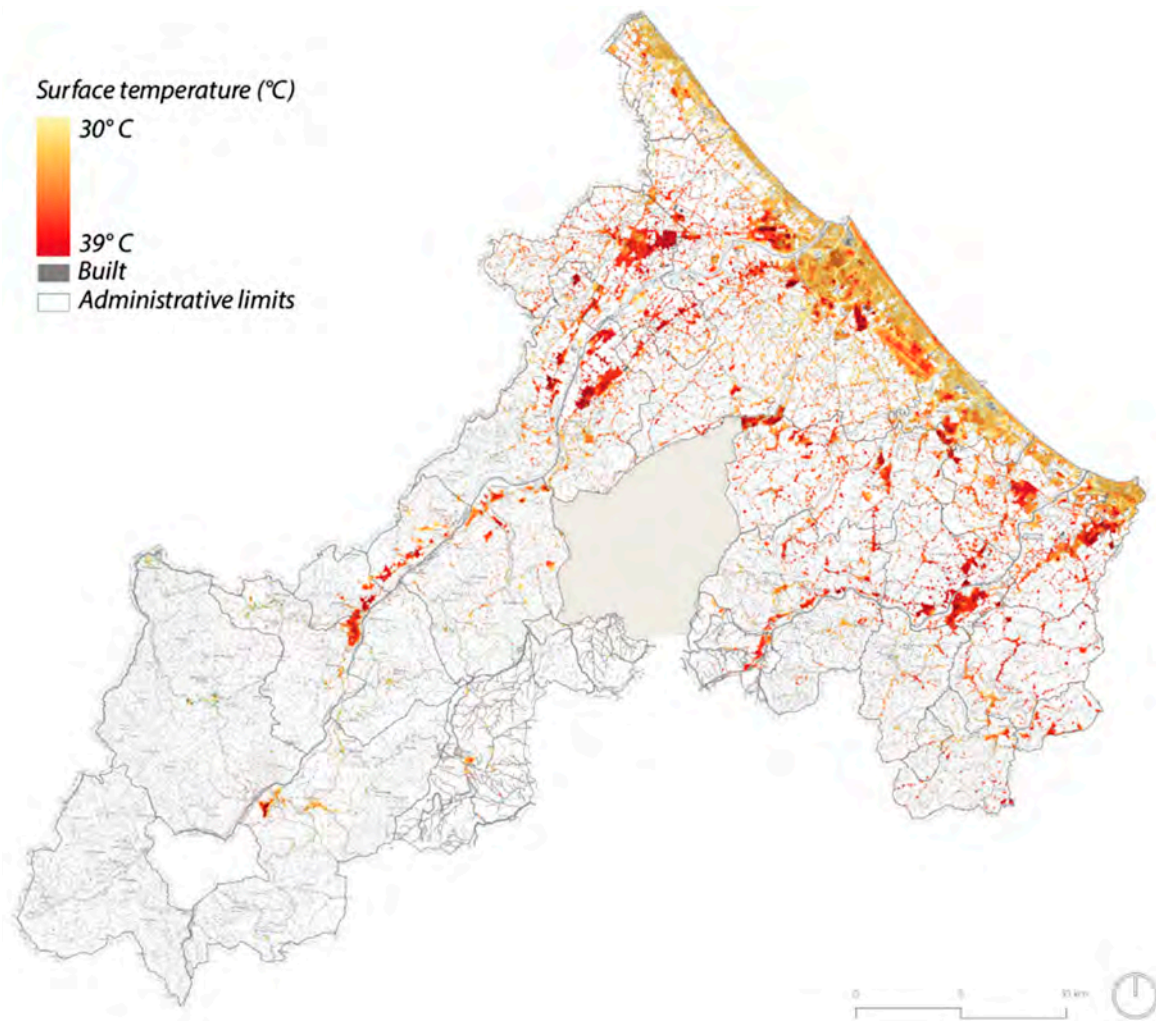
Two specific time frames were analyzed: one following a rainfall event and one during a period of prolonged drought, both identified through satellite imagery. This comparison made it possible to observe and identify two main behaviors, distinguishing poorly performing areas in which there is strong ecological fragmentation (in red in Figure 8) and areas that still maintain a positive characterization but which should be alerted to as they have threshold values at a minimum (in yellow in Figure 8).

Given that climatic variations follow a worsening trend, it is essential to prioritize action in these areas where ecological continuity must be ensured to guarantee the provision of ESs.

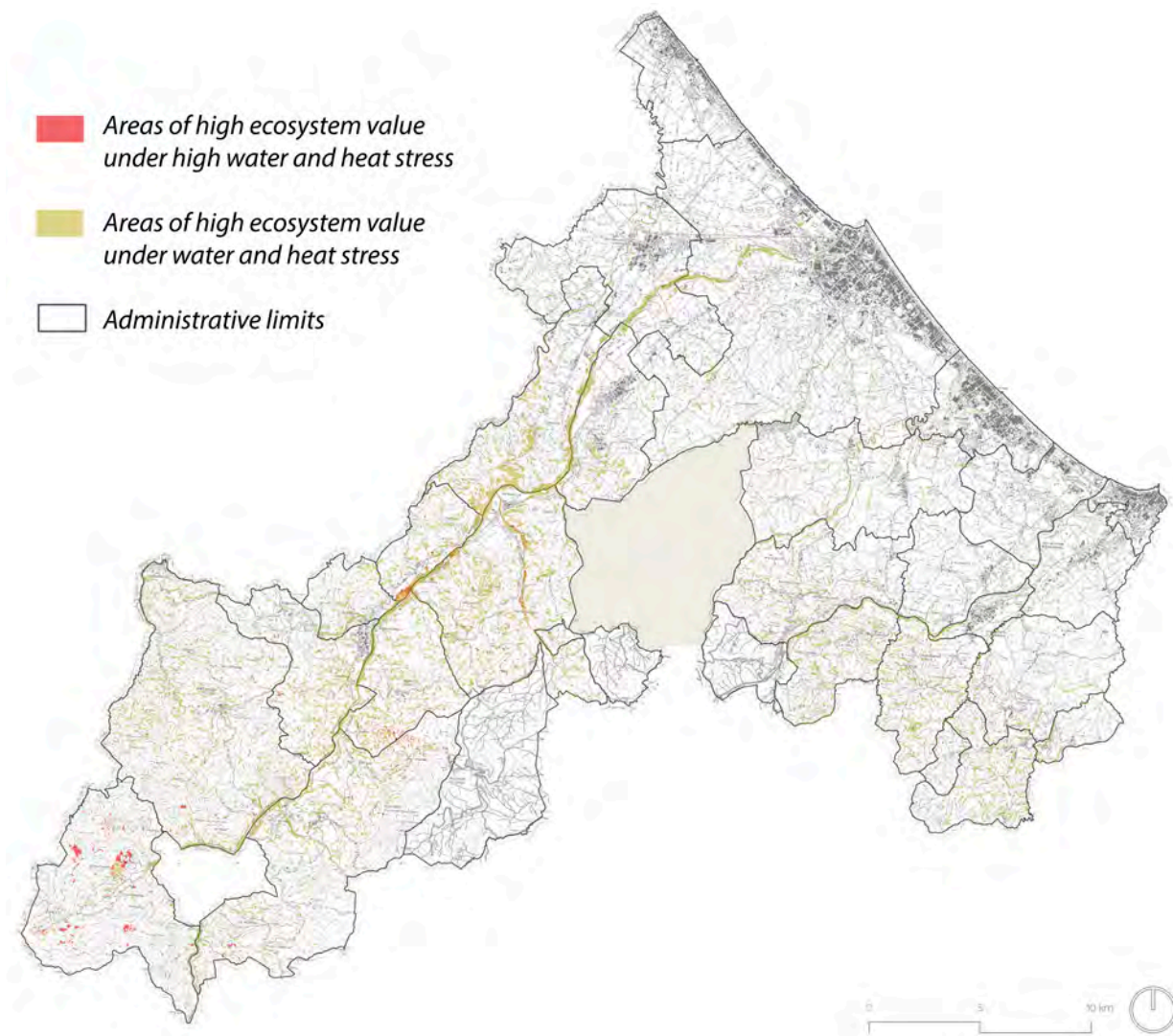
The last impact assessment concerned the floods (Figure 9). In the context of settlements, one of the most widespread impacts resulting from intense and concentrated rainfall events is urban flooding or flash floods. When heavy rain falls in built-up areas and flows into underground drainage networks, it causes localized water overloads, leading to temporary flooding [33]. CC exacerbates the inefficiency of drainage systems, emphasizing the need to analyze, represent, and interpret surface runoff paths and the diverse relationships between urban and rural areas. The study investigated the spatial correlation between surface runoff and land use patterns to address this territorial vulnerability. This helped identify the most vulnerable urban structures and their ability to retain rainwater, facilitating a rethinking of land use planning by designing new transformations into a climate resilience system. This work calculates the potential impact of flooding by simulating rainwater runoff, according to the Maragno et al. (2021) methodology [34].



**Figure 6.** Climate impacts considered in the sensitivity assessment (Section 2.2) and related indicators: LST for urban heat island (Huang & Ye, 2015) [29], VHI for water stress (Zeng et al., 2022) [32], and hydraulic vulnerability for urban flooding (Maragno et al., 2021) [34].

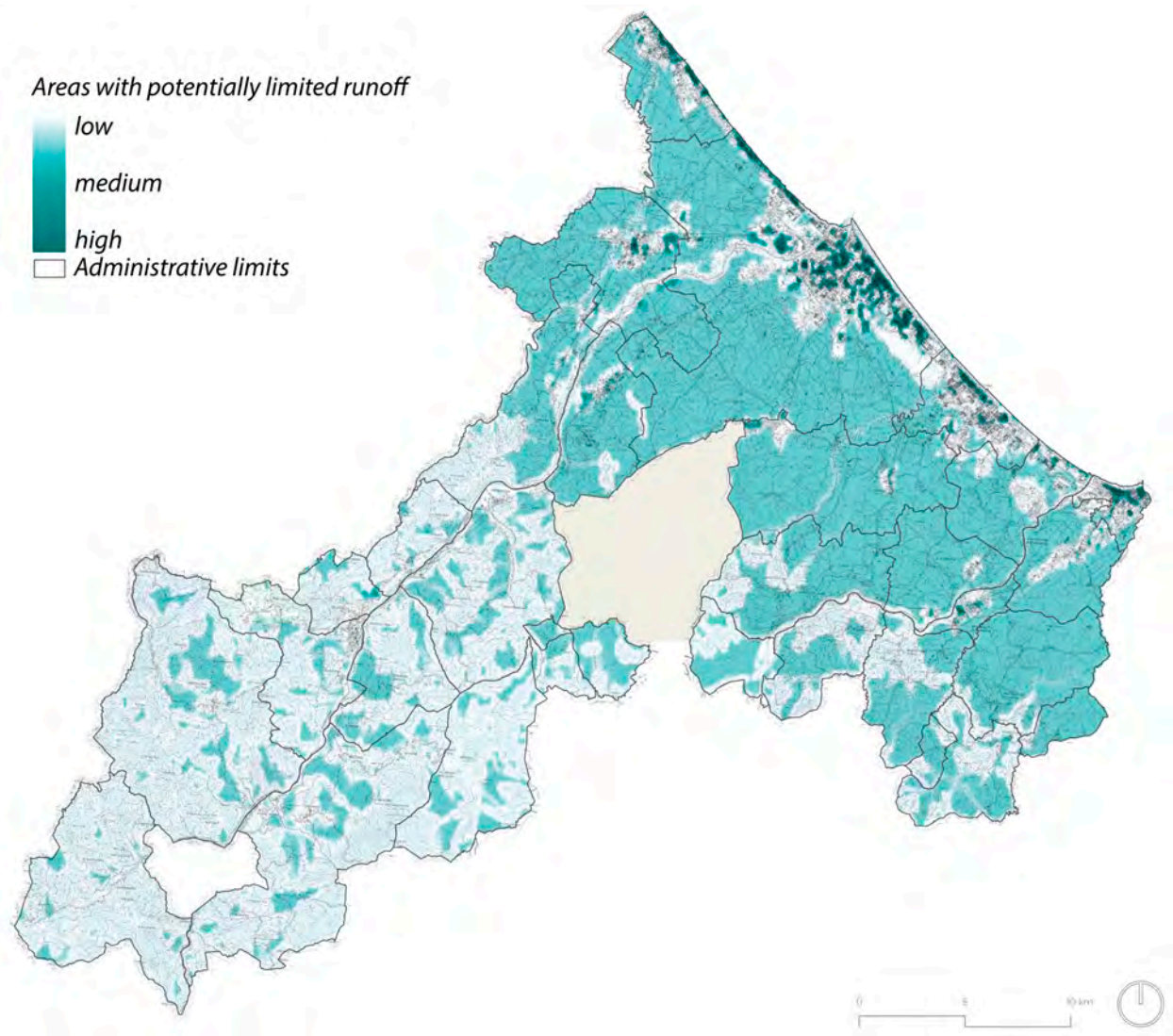


**Figure 7.** Heat waves: areas vulnerable to high temperatures (based on Copernicus data and Huang and Ye (2015) [29] Land Surface Temperature methodology).



**Figure 8.** Drought map: vegetation component subjected to water and heat stress (based on Copernicus data and Kogan (1995) [30] Vegetation Health Index methodology).

Consequently, the delineation of inflow and outflow areas is associated with the morphology of the land and its hydraulic response, which allows for the spatial estimation of the surface runoff related to land uses. The study employs a spatial index of hydraulic vulnerability derived from a combination of soil sealing levels (determined using the Curve Number procedure, a parameter of the surface runoff training model equation) and land morphologies (such as slopes, depressions, elevations, and low-lying areas). The methodology allows for an assessment of surface runoff dynamics and estimated hydraulic impacts based on changes in land cover, monitored through the European Corine Land Cover project (CLC 2018). This research facilitates the creation of different scenarios of surface runoff, measured considering specific rainfall reactivity indicators (such as H 30 mm), which are spatially associated with the corresponding soil saturation volume. The methodology returns a trend that describes the different hydraulic performances of the study area.



**Figure 9.** Vulnerabilities from surface runoff (based on Copernicus data and Maragno, Pozzer (2021) [34] Urban Flooding assessment methodology).

### 2.3. Ecosystem Services Evaluation Approach

The Centre for Natural Ecological Research (CREN) developed a methodology for assessing ESs. This methodological approach represents a valuable tool for decision-makers in territorial planning, providing criteria for evaluating ecosystem services. It aims to integrate scientific knowledge of ecological relationships within a complex framework encompassing social, political, and value aspects. The long-term goal is to protect and preserve ecosystems [35]. The authors obtained the data and information necessary for the analyses from the Emilia-Romagna Region and ISPRA<sup>9</sup> Database (Figure 10).

The first step in this methodology is creating a digital map of the environmental system to initiate the evaluation of ESs. This map is a fundamental cognitive system for further analyses within a GIS environment.

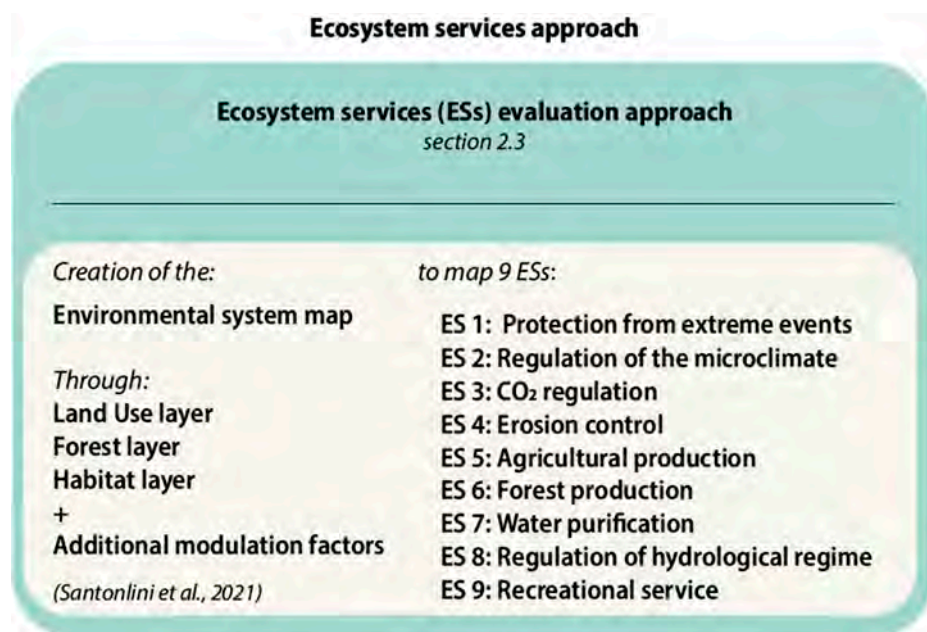
The map incorporates three spatial information layers covering the entire province:

1. Land Use Layer (updated to 2020): this layer provides information about how land uses within the province;

2. Forest Layer (updated to 2014): this layer focuses on the province’s distribution and characteristics of forests. It provides valuable insights into the forest ecosystem and its potential services;
3. Habitat Layer (updated to 2020): this layer highlights the presence and distribution of different habitats within the province, offering crucial information about the diversity and richness of local ecosystems.

The environmental system map is the basic level required for the calculation of the following ESs:

- ES 1: Protection from extreme events;
- ES 2: Regulation of the microclimate;
- ES 3: CO<sub>2</sub> regulation;
- ES 4: Erosion control;
- ES 5: Agricultural production;
- ES 6: Forest production;
- ES 7: Water purification;
- ES 8: Regulation of the hydrological regime;
- ES 9: Recreational service.



**Figure 10.** ESs evaluation framework (Section 2.3), based on the integration of land use, forest, and habitat layers with additional factors to map nine ESs (Santolini et al., 2021) [35].

The authors chose these ESs because they connect to the ecological support and regulatory functions fundamental to delivering all other services. Secondly, the choice was due to the study area’s physical, geomorphological, and settlement conformation, where different ecological and structural elements coexist but are pivotal to much of the regional territory. In the adopted methodology, each ecosystem service is influenced by specific environmental variables, referred to as “additional modulation factors”, which are inherently defined within the methodological framework. Therefore, the second step involves integrating the additional modulation factors into the environmental system map, which changes depending on the ES evaluated (Table 1).

**Table 1.** Additional modulation factors for each ES (elaboration based on CREN methodology).

Modulation Factors	ES 1	ES 2	ES 3	ES 4	ES 5	ES 6	ES 7	ES 8	ES 9
Forest cover (%)	X		X				X	X	
Slope (class)	X				X	X	X	X	
Current increase in forest biomass (m <sup>3</sup> /ha)						X			
Influence of road infrastructure (m)		X			X		X		
Organic carbon stock in soil 0–100 cm (Mg/ha)			X						
Land Capability Classification (LCC) (class)					X				
Evapotranspiration coefficient (KC) (index)									X
Deep Water Infiltration (WAR) (index)									X
Aquifers in rock clusters									X
Purification capacity (BUF) (index)							X		
Current erosion (RUSLE) (Mg/ha/year)				X					
Distance to urban centers (m)									X
Distance to the road network (m)									X
Distance to trails and cycle paths (m)									X
Distance to protected areas (m)									X

Integrating the environmental system map with the additional modulation factors results in the “Evaluation Matrix” for each ES evaluated. Each assessment matrix has within its values established by the methodology itself, called “weights”, which depend on the land use of the environmental system map and the modulation factors.

For example, in the case of ES1: protection from extreme events, the weights used, in addition to those derived from the environmental system map, are associated with forest cover and slope modulation factors. The assignment of the weights (from 0 irrelevant to 5 very relevant) determines how much the presence of the modulation factors affects the delivery of a specific ES.

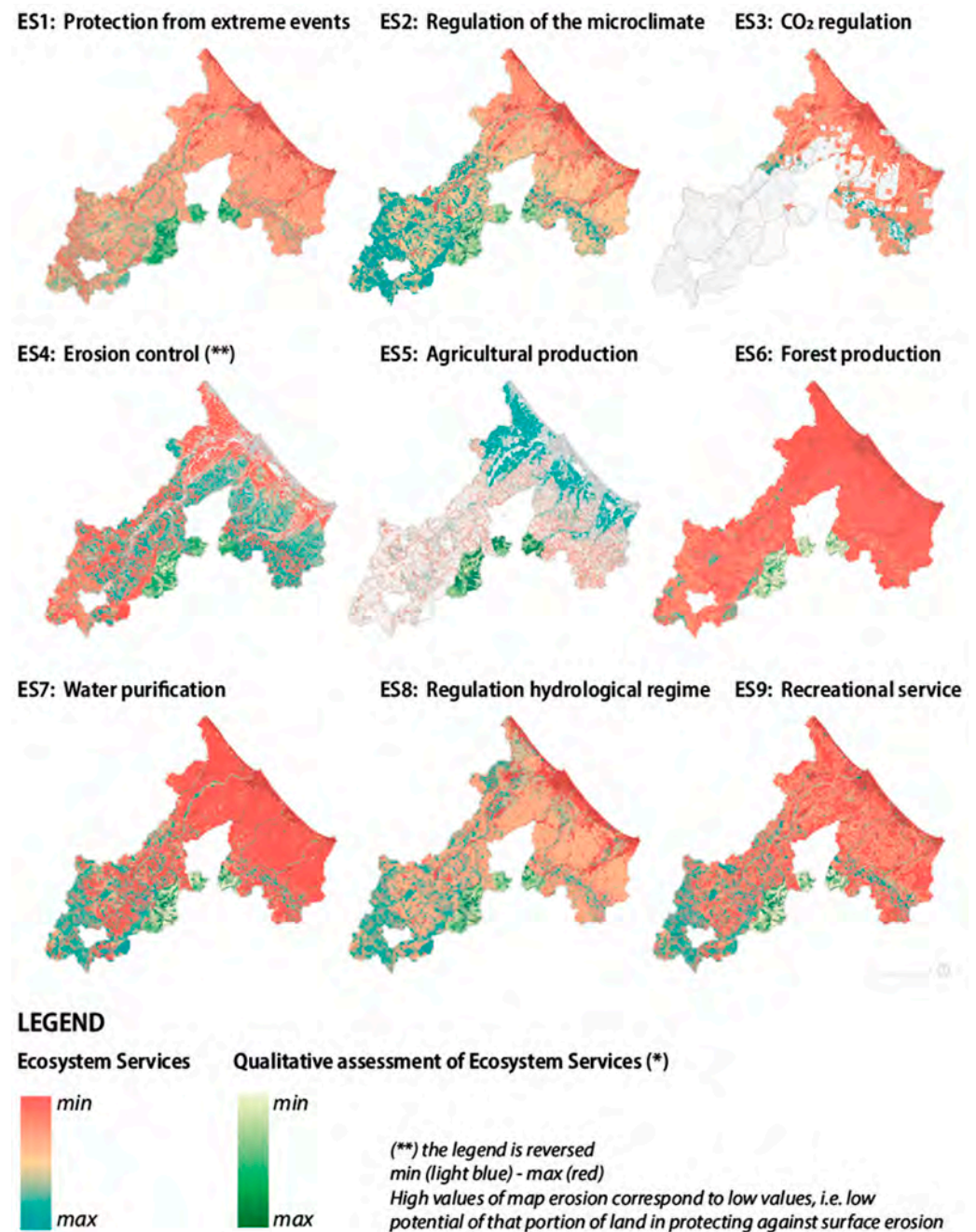
#### 2.4. Defining and Mapping Ecosystem Services in GIS

Following the described methodological approach, the performance level of nine ESs in the Province of Rimini was assessed and mapped (Figure 11).

The analysis employed ecological phenomena that support and regulate the ecosystem’s functioning to estimate crucial thresholds for utilization. Such an approach aids decision-making regarding when, where, and to what extent action should be taken to ensure the stable provision of ESs and the protection of biodiversity within a territory.

Assessing ESs’ direct and indirect contributions to human well-being is a crucial step in determining the “minimum critical dimension of impact needed to safeguard the collective function of the asset over time, including social utility and resulting well-being” [35].

This assessment enables the development and promotion of strategies and interventions for ES preservation or enhancement during the planning phase [36]. For this reason, the nine ESs, once processed, were synthesized into a single information layer by raster summation. The sum of the individual ecosystem service maps allows the development of an ecosystem value map that describes ESs’ overall trend and distribution in the study area. In this way, the summary map allows for understanding the areas with a higher concentration of ESs.



**Figure 11.** Nine ESs (\*) The gradient in green on the map depicts two municipalities recently annexed to the province of Rimini and for which the information layers required for ecosystem assessments were not available. For this reason, while waiting for these information layers, an assessment was carried out on a qualitative basis. (\*\*) In the ES “Erosion control” the legend is reversed.

### 3. Results

The resulting maps locate significant impacts and disruptions. The maps identify priority areas where action is necessary to address climate impacts and to protect and enhance ecosystem values. Thus, in this section, climate-related impacts and ecosystem values within the study area will be identified and spatially integrated to highlight areas where both aspects coexist and where climate change-related pressures and ecosystem values are simultaneously present (Figure 12).

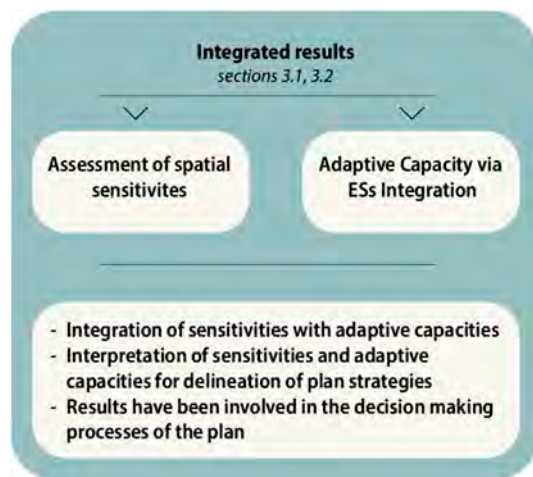


Figure 12. Workflow of the integrated results.

### 3.1. Integrated Assessment of Spatial Sensitivities

The results of the climate impact assessment maps highlight the areas in the entire area of the Province of Rimini that are susceptible to high temperatures and flash floods. It is observable that these areas are concentrated in the municipalities alongside the coastline (Figure 13).

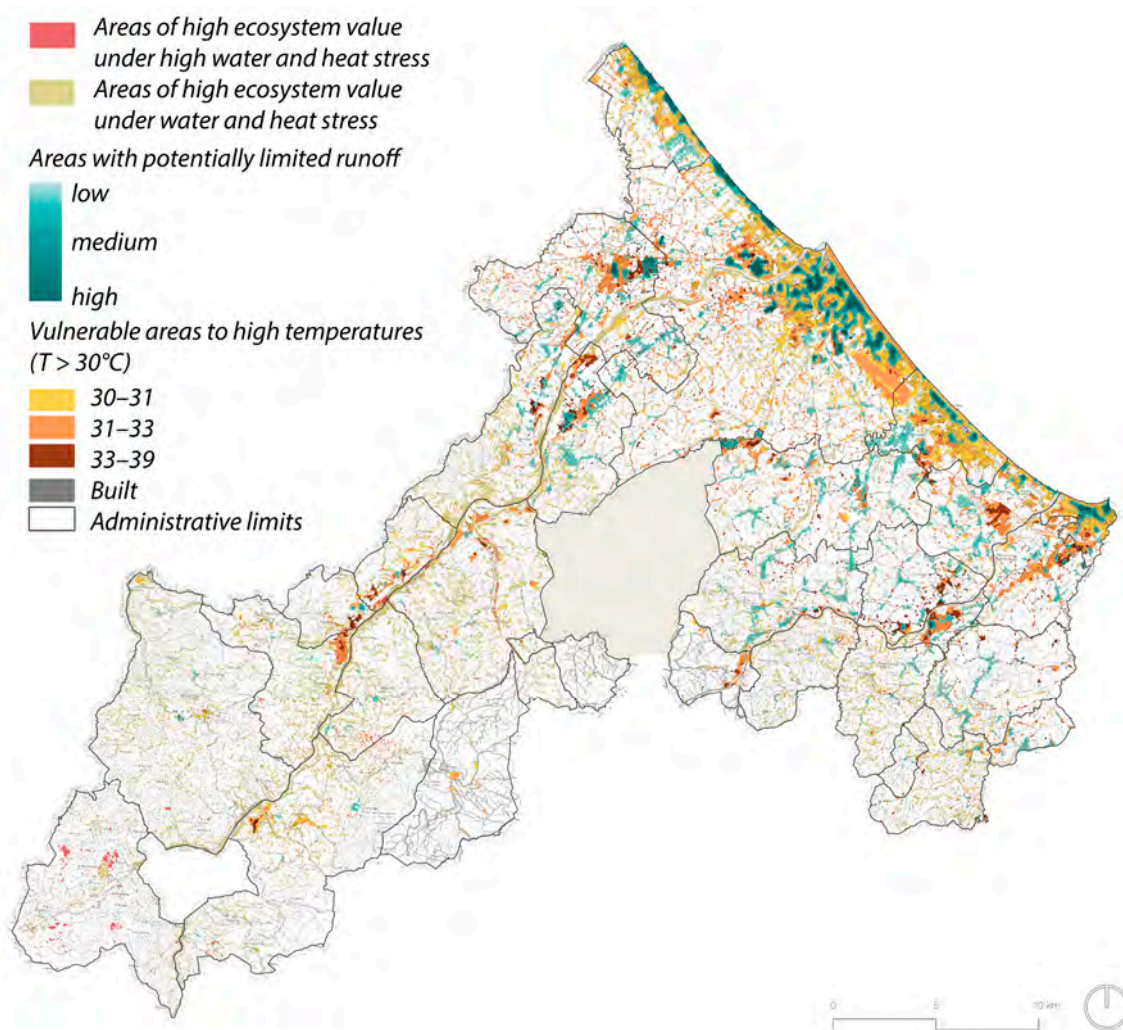


Figure 13. Climate impact sensitivity map.

This result draws attention to the urban areas affected by the phenomenon by allowing the adoption of some adaptation strategies to mitigate the temperature range [37]. The map (Figure 14) reveals that the municipalities with the biggest spots vulnerable to high temperatures are Cattolica, Riccione, Bellaria-Igea Marina, Rimini, and Misano Adriatico municipalities, characterized by urbanization focusing on tourism.

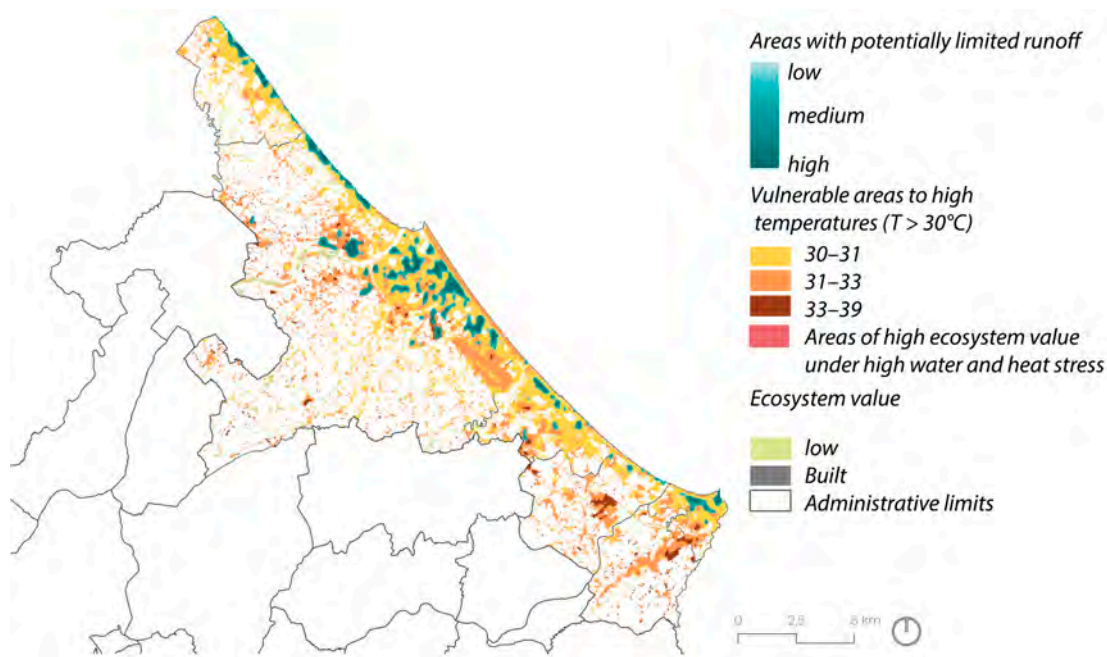


Figure 14. Climate impact sensitivity map: focus on coastal areas.

Considering only the portion of the territory affected by these climatic vulnerabilities, this extends over 6000 hectares in the Province of Rimini and reports Land Surface Temperatures above the 30 °C threshold during the hottest days of the year. These areas have been classified into three levels, reflecting different priorities for intervention: first, second, and third levels (Table 2).

Table 2. Classification of vulnerable areas to high temperatures (T > 30 °C).

Coastal Municipalities	Total Surface of the Municipalities (km <sup>2</sup> )	Urban Surface Vulnerable to High Temperature (km <sup>2</sup> )	Third-Level Priority (Class 30–31 °C on Urban Areas Surface)	Second-Level Priority (Class 31–33 °C on Urban Areas Surface)	First-Level Priority (Class 33–39 °C on Urban Areas Surface)
Bellaria-Igea Marina	18.08	6.57	5.5 km <sup>2</sup> (83.7%)	1.06 km <sup>2</sup> (16.1%)	0.01 km <sup>2</sup> (0.2%)
Cattolica	6.06	4.3	2.8 km <sup>2</sup> (65.6%)	1.3 km <sup>2</sup> (30.9%)	0.2 km <sup>2</sup> (3.5%)
Misano	22.36	6.01	2 km <sup>2</sup> (33.4%)	3.4 km <sup>2</sup> (56.1%)	0.6 km <sup>2</sup> (10.5%)
Riccione	17.45	10.62	7.5 km <sup>2</sup> (70.4%)	2.9 km <sup>2</sup> (28.1%)	0.2 km <sup>2</sup> (1.5%)
Rimini	135.27	39.7	21.1 km <sup>2</sup> (53%)	17.3 km <sup>2</sup> (43.5%)	1.3 km <sup>2</sup> (3.5%)

In contrast to the coastal area and Conca Valley regions, the Marecchia Valley shows a less severe presence of heat islands. The presence of vegetation on the slopes localizes the phenomenon primarily along the valley floor, where urban areas and spaces dedicated to human activities, such as industrial and commercial zones, are concentrated and intercon-

ected by central infrastructure nodes. Like urban heat islands, the risk of surface runoff reveals a spatial reality that significantly impacts the densely built areas of coastal cities. The spatial representation of climatic stress, linked to land use patterns, highlights significant hydraulic vulnerability in territorial contexts characterized by high population density and extensive pavement. It can be observed that the coastal communities of Bellaria-Igea Marina, Rimini, Cattolica, and, to a lesser extent, Riccione and Misano are particularly prone to flooding events caused by heavy rainfall. Three levels of priority of intervention have also been distinguished here (Table 3). The tendency for flooding in the coastal area is thus more pronounced in complex urban areas lacking permeable zones or green spaces. Conversely, rural areas with low urbanization rates in the Marecchia and Conca Valleys exhibit less evident data concerning these phenomena. This trend is therefore connected to the presence of vegetated areas having a rather high health status, as seen in the map. The ecological component, unconnected to the urban and industrial areas, maintains a high conservation status and simultaneously helps mitigate the effects and consequences of heat islands and flooding. Also, in the map, it is possible to observe how there is, in the areas described, a temperature-calming effect due to the evapotranspiration mechanisms carried out by the vegetation and how the properties of the land, combined with the hypogeal systems of vegetation, contribute to a decrease in surface runoff. The study of extreme weather events highlights the need to establish a spatial correlation between surface runoff, heat, and land use. Furthermore, the results demonstrate how these impacts have adverse consequences for the economic well-being of the territories. The increased vulnerability of coastal areas to CC may also affect the attractiveness and tourism value of the region shortly.

**Table 3.** Classification of areas with potentially limited runoff.

Coastal Municipalities	Total Surface of the Municipalities (km <sup>2</sup> )	Urban Flooding Total Surface (km <sup>2</sup> )	Third-Level Priority	Second-Level Priority	First-Level Priority
Bellaria-Igea Marina	18.08	10.56	10.1 km <sup>2</sup> (95.9%)	0.2 km <sup>2</sup> (1.8%)	0.26 km <sup>2</sup> (2.3%)
Cattolica	6.06	1.71	1.3 km <sup>2</sup> (74.9%)	0.3 km <sup>2</sup> (17.5%)	0.1 km <sup>2</sup> (7.6%)
Misano	22.36	13.45	13.4 km <sup>2</sup> (99.6%)	0.05 km <sup>2</sup> (0.4%)	0 km <sup>2</sup> (0%)
Riccione	17.45	4.5	4.3 km <sup>2</sup> (94.3%)	0.2 km <sup>2</sup> (4.8%)	0.04 km <sup>2</sup> (0.9%)
Rimini	135.27	94.87	90.9 km <sup>2</sup> (95.8%)	2.5 km <sup>2</sup> (2.7%)	1.4 km <sup>2</sup> (1.5%)

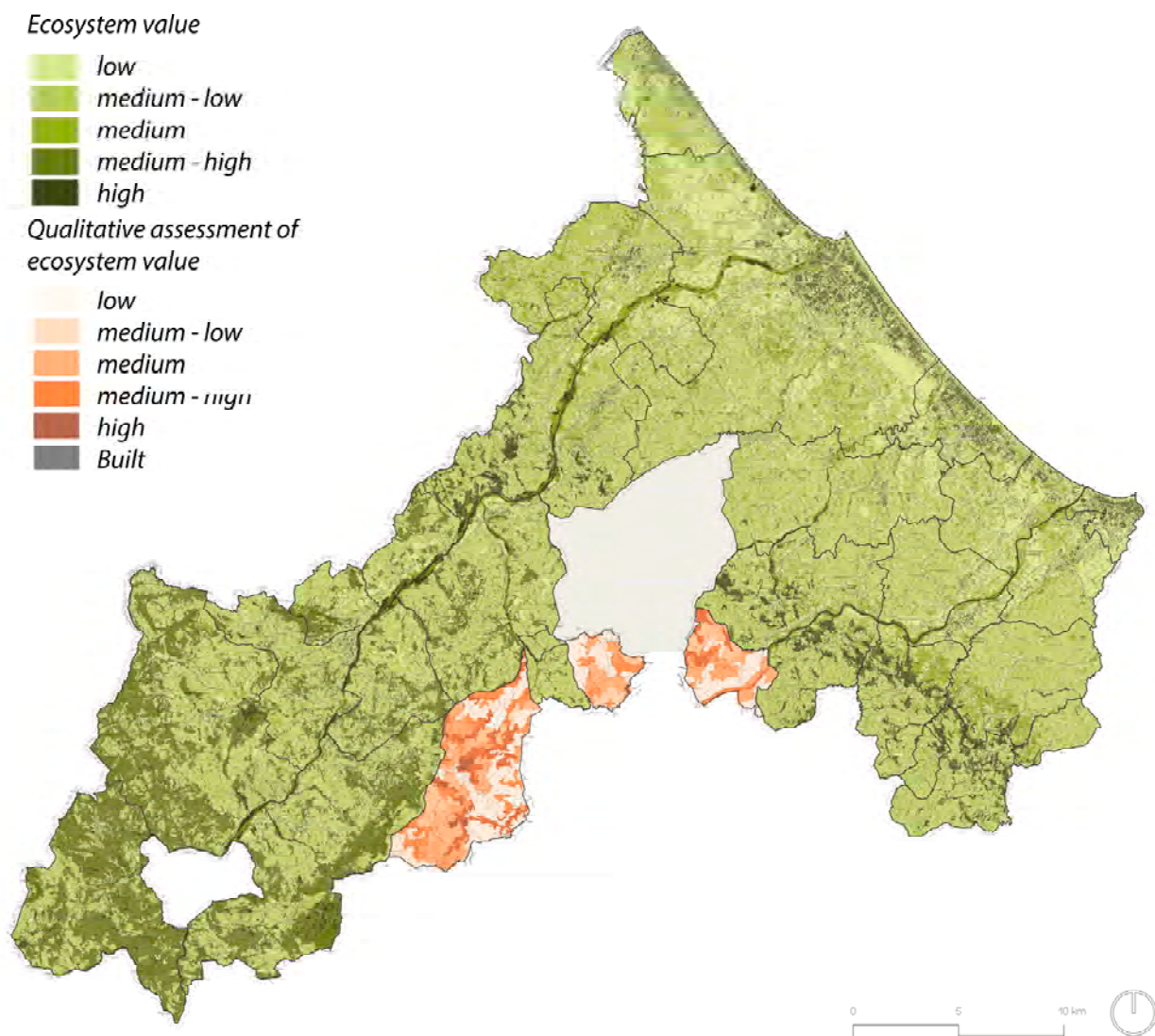
### 3.2. Identification of Adaptive Capacities Through the Integration of ESs

In the provincial territory of Rimini, the condition of ecosystem components is highly diverse, both in terms of individual ecosystem services and across different areas of the territory (Table 4; Figure 15).

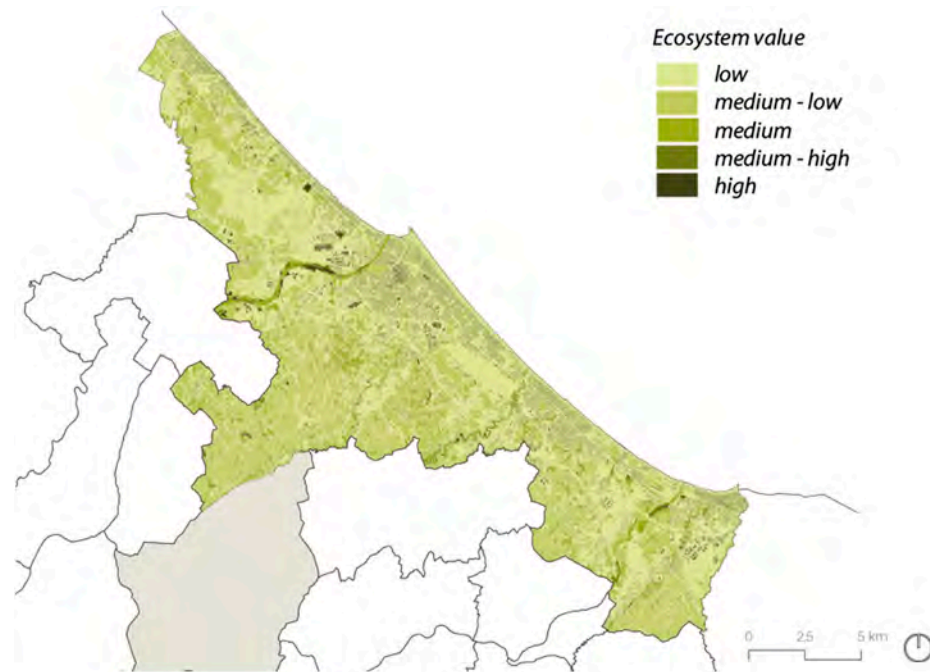
On average, there is a low presence of ESs in the coastal zone (Figure 16), and, therefore, in this area, particular attention should be given to existing and newly planned settlements and infrastructure to protect and safeguard existing ESs and enhance their extent, including through dedicated projects and investments.

**Table 4.** Classification of ESs according to (5) classes.

Coastal Municipalities	Total Surface of the Municipalities (km <sup>2</sup> )	Low	Medium-Low	Medium	Medium-High	High
Bellaria-Igea Marina	18.08	10.74 km <sup>2</sup> (59.4%)	6.15 km <sup>2</sup> (33%)	1.17 km <sup>2</sup> (6.5%)	0.2 km <sup>2</sup> (1.1%)	0 km <sup>2</sup> (0%)
Cattolica	6.06	5.1 km <sup>2</sup> (84.2%)	0.4 km <sup>2</sup> (6.9%)	0.3 km <sup>2</sup> (4.7%)	0.06 km <sup>2</sup> (0.9%)	0.2 km <sup>2</sup> (3.3%)
Misano	22.36	10.62 km <sup>2</sup> (47.5%)	8.75 km <sup>2</sup> (39.1%)	2.72 km <sup>2</sup> (12.2%)	0.27 km <sup>2</sup> (1.2%)	0 km <sup>2</sup> (0%)
Riccione	17.45	12.65 km <sup>2</sup> (72.5%)	3.09 km <sup>2</sup> (17.7%)	1.33 km <sup>2</sup> (7.6%)	0.38 km <sup>2</sup> (2.2%)	0 km <sup>2</sup> (0%)
Rimini	135.27	68.15 km <sup>2</sup> (50.4%)	49.89 km <sup>2</sup> (36.88%)	15.15 km <sup>2</sup> (11.2%)	1.64 km <sup>2</sup> (1.2%)	0.44 km <sup>2</sup> (0.32%)



**Figure 15.** Ecosystem value map. The gradient in orange on the map depicts two municipalities recently annexed to the Province of Rimini and for which the information layers required for ecosystem assessments were not available. For this reason, while waiting for these information layers, an assessment was carried out on a qualitative basis.



**Figure 16.** Ecosystem value map—focus on coastal areas.

There are diversified situations for different ESs in the lowland and early Apennine areas. Therefore, the need emerges to pay contextual and particular attention to ecosystem services (ESs) and the type of project/investment under consideration. Finally, in the Apennine area, ESs have a general state of well-being, with exceptions related to specific areas. However, this area also demonstrates the need for special attention to maintain the current ESs.

The maps produced make it possible to enrich the urban digital heritage of the Province of Rimini. In addition to mapping the vulnerabilities to CC and ESs of the study area, the cognitive layers produced aim to support and guide the plan in an integrated manner, digitally aggregating spatial information related to social and economic issues.

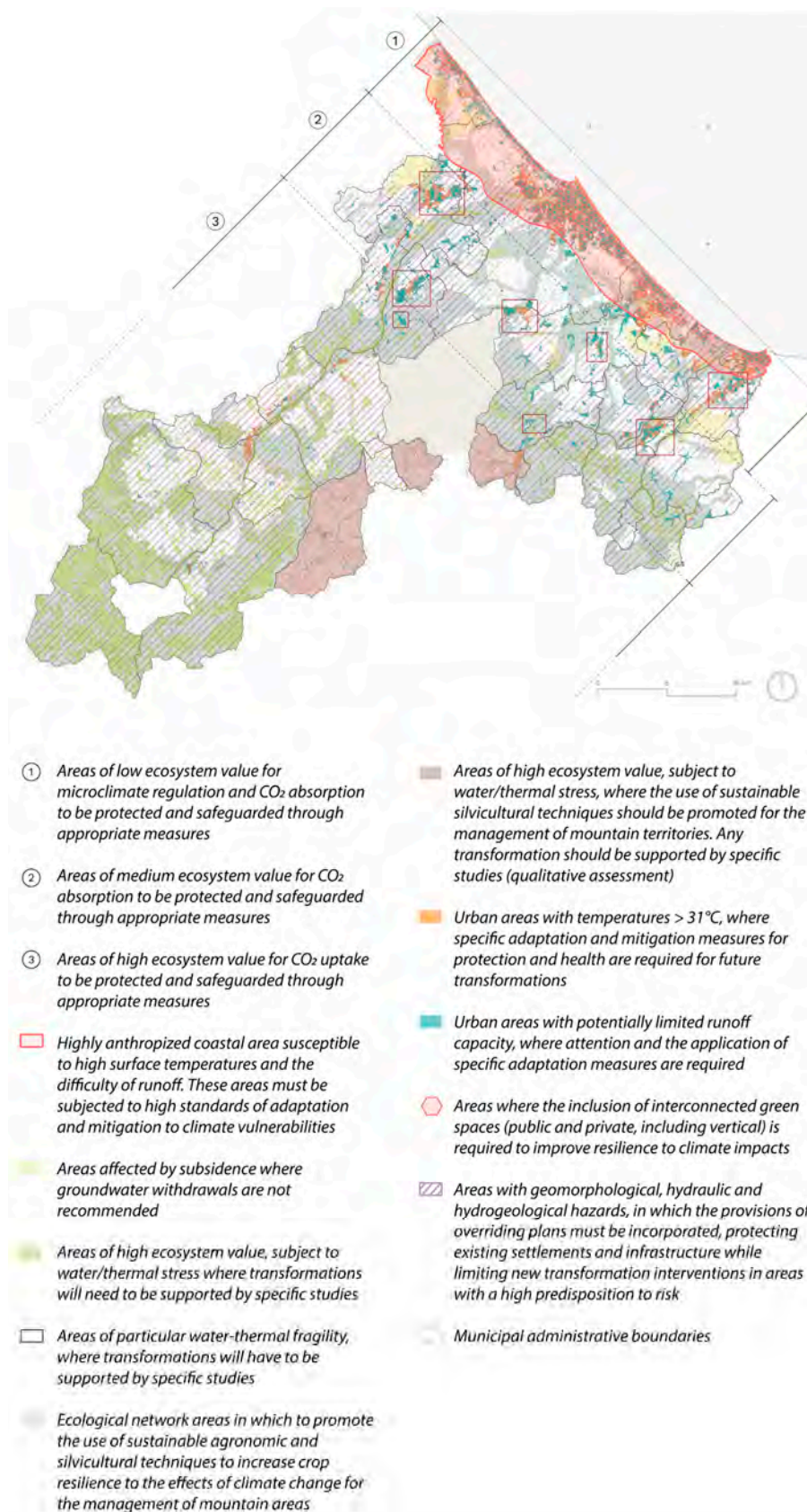
From the integration of the two maps obtained, areas where there is a coexistence of both CC impacts and ES values have been identified and localized at a territorial level. Integrating the two themes proved fundamental for identifying priority areas for intervention and directing the strategies to be undertaken at the planning level.

#### 4. Discussion

The location of the main impacts makes it possible to determine the areas to intervene as a matter of priority to cope with climatic impacts and protect and enhance ecosystem values, which are also understood, but not limited to, as adaptive capacity.

The integration of the processed information layers has supported the identification of all those natural or semi-natural areas where ecosystem values are still high. In these areas, it becomes a priority to maintain and protect the presence of the ecological components, which help to moderate the criticality caused by climate impacts while increasing the quality of life. The strengthening of the provincial and regional ecological network system, the valorization of the primary and transversal ecological linking elements, and the connection with urban green areas, therefore, emerge as indispensable aspects, also identifying the peri-urban coastal sphere (Figure 17) as a priority sphere of action both for the strengthening of ecosystem performance and for the reconnection and creation of continuous and interconnected green nets. In the case of the coastal peri-urban sphere, it be-

comes necessary to protect the currently existing ecosystem values while also contributing to their enhancement to calm the effects of high temperatures and limited runoff.



**Figure 17.** Map of strategies where the synthesis map of ecosystem services and the climate change map were integrated.

The results from the methodological approach described fit into various phases of drawing up the wide-area plan, helping to innovate the contents and nature of the planning instruments. Firstly, the elaborations make it possible to increase the knowledge related to the territory by using innovative interpretative keys: climatic and ecosystemic.

This contributes to expanding the knowledge framework by enabling a more cross-cutting analysis of the territory. In addition to the environmental and socio-economic components, indispensable elements to be analyzed within an urban context, information is added concerning the interactions that these elements may have, in positive or negative terms, with the ecosystem values present in the territory and consequently with the possible climatic impacts that may occur.

In addition to the purely cognitive phase, the results also contribute to outlining objectives and strategies with a strong interest in the issues of climate change and ecosystem services. In this way, the plan orients toward proposals and policies to cope with the impacts of climate change while protecting and enhancing the ecosystem values in the territory.

The elaborations on CC contribute to outlining actions aimed at security and increasing territorial resilience. Securing infrastructures and urban areas while respecting the environmental characteristics, matrices, and elements of the territory enhances its development potential and helps mitigate the vulnerabilities exposed by the climate crisis.

These results translate into indications for municipalities aimed at the following:

- Incorporating and integrating knowledge about the territory's risks, considering both the traditional and known framework of risks (hydrogeological, geomorphological, seismic risk) and risks linked to critical climatic conditions. The objective is manifold: on the one hand, to increase the level of awareness of territorial and climatic risks in such a way as to defend and protect existing settlements and infrastructures while limiting new transformation interventions in areas with a high predisposition to risk;
- Identifying critical issues caused by climate impacts and integrating this information into the planning, design, and assessment processes. When planning a transformation of the territory, every municipality must use the information layers related to critical climatic conditions provided by the province to assess the feasibility of the planned interventions. When intending to transform an area located in portions of the territory with a high predisposition to one or more criticalities related to temperature, runoff, water, and thermal stress of vegetation, the municipality must carry out a climate impact assessment. In this way, the municipalities, studying the specifics of their territory, identify and assess the areas most exposed to climatic criticalities and where to act to mitigate impacts while avoiding land transformations with negative consequences;
- Restoring ecosystem and ecological values by integrating them into adaptation strategies and climate compensation devices when a land transformation occurs.

Elaborations on ESs contribute to environmental protection and enhancement policies. The value provided by ESs is recognized as a fundamental resource for life and health protection [38]. Ecosystem valuation, therefore, becomes a key element in estimating land quality and differentiating environmental improvement actions. The ecosystem value becomes no longer a negligible element for defining urban planning and the admissibility conditions of territorial and urban transformations.

Guidance has also been developed for municipalities to conduct ecosystem assessments aimed at the following:

- Considering the ES assessment within ordinary environmental and territorial sustainability assessment procedures. ESs are considered indispensable for assessing the quality of the territory, which is why their protection becomes increasingly important;

- Strengthening the ecological network system by integrating ecosystem services and green and blue infrastructure in such a way as to reinforce ecosystem performance while promoting local green plans integrated with general planning.

It is important to underline that the methodology remains strongly dependent on data availability; in the absence of adequate data, analyses concerning both climate and ecosystem values cannot be effectively carried out. While one of the main constraints in climate-related assessments lies in the need for clean, error-free satellite imagery, the limitations affecting ecosystem service evaluations are of a different nature. The regional methodology adopted for mapping ecosystem services (ESs) and applied in this study relies extensively on pre-existing information layers that cannot be independently produced (e.g., organic carbon maps, forest cover data, and other informational layers produced by the Emilia-Romagna Region). Consequently, it depends on the timely updating of datasets by external actors—such as regional authorities, research institutes, and scientific organizations—posing considerable challenges for replicating the approach in other territorial contexts.

Moreover, the lengthy timeframes required for generating and updating these data layers limit the adaptability and responsiveness of the methodology. For this reason, the present contribution should not be interpreted as a final product but rather as a preliminary step in the ongoing process of updating and innovating spatial planning practices. In this respect, the qualitative approach adopted for the newly annexed municipalities (Figure 13) represents our starting point for the development of a standardized and replicable methodology applicable to other Italian contexts.

## 5. Conclusions

This paper presents the analysis developed during the formulation of the Territorial Plan for the Province (PTAV) of Rimini, with a specific focus on the integration of climate change impacts and ecosystem services into spatial planning. These themes are innovative within urban planning as they are typically not addressed in standard planning instruments. The climate change assessment focused on the impacts of heat and extreme precipitation, while the analysis of ecosystem services addressed multiple functions such as microclimate regulation, protection against extreme events, CO<sub>2</sub> regulation, erosion control, agricultural and forest productivity, water purification, hydrological regulation, and recreation.

The proposed methodology integrates climate change and ecosystem services into planning processes from two complementary perspectives: cognitive and strategic (RQ1–RQ2). The cognitive perspective enhances territorial knowledge regarding climate change impacts, increasing the information within the knowledge framework, while the strategic one incorporates climate change impacts into decision-making tools for adaptation planning. Similarly, for ecosystem services, the approach answers “how”, “where”, and “to what extent” to act to ensure a stable provision of services and biodiversity protection.

Innovation is achieved by enriching and dynamically updating the knowledge framework, making it responsive and operational through the integration of new datasets and planning tools. As a result, climate change and ecosystem services offer substantial contributions to the formulation of planning guidelines at the provincial scale, reinforcing the role of existing protected areas while also identifying additional zones for future protection (RQ3). These dimensions are often excluded from ordinary planning instruments, and the present work proposes concrete steps to align spatial planning with emerging environmental priorities. By producing integrated maps that highlight the spatial overlap between climate vulnerabilities and ecosystem values, the PTAV enables the formulation of climate-resilient planning strategies. The methodology transforms the knowledge framework into a diagnostic and adaptive tool capable of supporting the continuous evaluation

of planning effectiveness. The strong interconnection between ecological and climatic dimensions marks a significant advancement in spatial planning, providing practical guidance for public administrations engaged in the ecological transition, territorial resilience, and sustainable development.

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## Abbreviations

The following abbreviations are used in this manuscript:

CC	Climate change
CI	Climate impact
ES/ESs	Ecosystem service/ecosystem services
LST	Land Surface Temperature
VHI	Vegetation Health Index
NDVI	Normalized Difference Vegetation Index
TCI	Thermal Condition Index
VCI	Vegetation Condition Index
CREN	Centro Ricerche Ecologiche Naturalistiche
CLC	Corine Land Cover
ARPAE	Agenzia Regionale per la Protezione Ambiente dell’Emilia-Romagna
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale
PTAV	Piano Territoriale di Area Vasta
GIS	Geographic Information System

## Notes

- <sup>1</sup> The Plan for the Metropolitan Territory of the Province of Rimini (PTAV) is the new general spatial planning tool developed by the province in accordance with Regional Law No. 24/2017. The process began with the drafting of preliminary documents and a public consultation phase, which led to the formulation and publication of the Draft Plan. After its adoption by the Provincial Council, the plan entered the approval phase and is currently under review by the Regional Urban Planning Committee. The PTAV is the instrument that enables provinces to identify the strategic assets of the territorial system in collaboration with their municipalities. The plan aims to promote communities’ well-being and address current and future environmental and climate emergencies.
- <sup>2</sup> Regional Law n. 24, 21 December 2017 “Regional regulation on the protection and use of land” and Article 21: Ecological and environmental endowments 1. The ecological and environmental endowments of the territory consist of the set of spaces, works, and interventions that contribute, together with the infrastructure for the urbanization of settlements, to combat climate change and its effects on human society and the environment, to reduce natural and industrial risks and to improve the quality of the urban environment; [...] 2. The urban and ecological–environmental quality strategy shall provide for the determination of the need for ecological and environmental endowments and the performance requirements to be met by them, coordinating with the

climate change mitigation and adaptation policies established at the European, national, and regional levels and incorporating the indications of sectoral planning [ . . . ].

- 3 The Italian spatial planning system is structured across multiple institutional levels, reflecting the distribution of competences among the state, regions, provinces (or metropolitan cities), and municipalities. At the national level, the state defines general guidelines through framework laws and coordination tools. While it plays a limited role in direct planning, it is essential in ensuring consistency and the protection of national interests. Regions are responsible for drafting Regional Territorial Plans (PTR), which are hierarchically superior to provincial and municipal plans, as they establish strategic objectives, guidelines, and binding rules that subordinate instruments must comply with. Provinces and Metropolitan Cities adopt Provincial Territorial Coordination Plans (PTCP) or Wide-Area Territorial Plans (PTAV), which link regional strategies with local needs. At the municipal level, planning is carried out through general urban plans that must align with higher-level plans, ensuring vertical consistency within the system. In recent years, the Italian planning framework has progressively evolved toward the integration of spatial planning with environmental sustainability and climate adaptation, also in response to European guidelines and national regulations aimed at limiting land take.
- 4 It is crucial to distinguish between the terminology used in regulatory contexts at regional/provincial levels and those in climate assessments (IPCC) due to existing regulatory gaps. Hazard refers to the origin of risk, like heat waves or heavy rain. In this paper, vulnerability is defined as a system's propensity to sustain damage from event-induced stresses, calculated as the difference between sensitivity (physical, morphological, functional, and organizational factors weakening a system) and adaptive capacity.
- 5 The "Regional Agency for Prevention, Environment and Energy of Emilia-Romagna" (ARPAE) is structured on a territorial basis and is committed to environmental protection, prevention, the management of energy resources, and the development of forecasting models aimed at supporting sustainable development.
- 6 To make the most effective use of the potential of Landsat-8 imagery, satellite data must be chosen by assessing temperatures during the most intense heat periods in parallel. A set of satellite imagery is then selected based on four criteria: (i) year of acquisition, (ii) month of acquisition, (iii) daily mean temperature, and (iv) absence of significant cloud cover. The selection evaluates orbital moments of acquisition with fewer clouds in the atmosphere.
- 7 This index is used for various purposes in environmental analysis. For example, it is used to conduct fire risk assessments, to investigate the presence of ground vegetation fraction and its health status, to calculate leaf area in estimating a plant's CO<sub>2</sub> sequestration rate, and to monitor crop and pasture productivity.
- 8 Drought measurement can be performed according to different indices. Among the most widely used and internationally recognized ones is the SPI (Standardized Precipitation Index). This is a standardized indicator for detecting and assessing precipitation deficit (drought) at different time scales. The SPI makes it possible to quantify the water surplus or deficit concerning the climatology of the area under consideration.
- 9 ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) is an Italian public research institute focused on environmental protection, including marine, environmental emergencies, and research.

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