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A spatial decision support system for multi-dimensional sustainability assessment of river basin districts: the case study of Sarno river, Italy

Giuliano Poli [*], Stefano Cuntò, Eugenio Muccio, Maria Cerreta

University of Naples Federico II, Department of Architecture, Italy

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ABSTRACT

Effective management of the complex Socio-ecological systems (SES) of the river basin, influenced by a range of social, economic, and environmental variables, requires multi-purpose Spatial Decision Support Systems (SDSSs) to identify and select balanced and sustainable regeneration scenarios. In many cases, the lack of cooperation between administrative institutions and the low level of participation of the stakeholders involved are the main obstacles to effective planning and regeneration practices and call for new forms of governance. However, to address these critical issues, few studies use quantitative approaches to assess the multidimensional resources of river basins in an integrated perspective in terms of their capacity to activate cooperation networks between river-crossed cities. This study aims to suggest a methodological approach combining Multi-Criteria Decision Analysis and Geographic Information Systems to achieve integration in pursuing sustainable regeneration pathways for a river basin district, analysing the case study of the Sarno River, composed of 20 administrative units, in Southern Italy. The specific purpose is to provide decision-makers with an SDSS to evaluate sustainability scenarios based on the multi-dimensional performances of River Basin District Units (RBDU). The results delivered four partial rankings of RBDU related to social, cultural, ecological, and economic scenarios and one overall ranking for an integrated sustainability scenario. Each ranking includes a clustering of municipalities according to three classes: Leader, Link and Follower. The outcome is twofold: to provide decision-makers with recommendations for supporting governance models based on sustainability pathways and to suggest valuable methods and tools for dealing with the spatial misfits, considered as the mismatch between the physical boundaries of a natural system and the management area of an organization.

1. Introduction

The river basin, conceived as a complex Socio-ecological system (SES), is affected by a range of multidimensional variables, and thus requires multi-purpose Spatial Decision Support Systems (SDSSs) to select more balanced and sustainable regeneration scenarios for an effective management.

Handling complex systems presents a challenge for practitioners as the outcomes of such systems result from interactions among different social and biophysical variables that are context-dependent. These components, indeed, may be common to many systems or unique to a particular system. The context-dependence of social-ecological dynamics makes it exceptionally difficult to draw general conclusions for governance, while generic design factors may also be too abstract to apply to a specific environment (Cox, 2011; Stoker, 2019; Gong and Tan, 2021).

In this perspective, the European Water Framework Directive (WFD) released guidelines to promote territorial strategies based on cooperation among municipalities at different hydrological and institutional scalar dimensions (Hein et al., 2006), through the monitoring of existing resources and the co-production of new values derived from sustainable regeneration pathways (Chambers et al., 2021). Furthermore, the paradigm shift from a "hydrocratic" top-down model to a collaborative, decentralized, and multidimensional model becomes crucial when sustainable water management addresses local community needs and cooperation among decision-makers (Neto et al., 2020).

In 2015, the Organisation for Economic Co-operation and Development (OECD) released the twelve Principles on Water Governance based on three drivers for sustainable water management: effectiveness, efficiency, and capacity to generate trust and engagement (OECD, 2015). Among the twelve, three Principles particularly concern this contribution, which aims to propose an integrated methodological approach to

* Corresponding author.
E-mail addresses: giuliano.poli@unina.it (G. Poli), stefano.cunto@unina.it (S. Cuntò), eugenio.muccio@unina.it (E. Muccio), maria.cerreta@unina.it (M. Cerreta).

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support River Basin Management (RBM) and refer to the need to manage water at suitable scales and to foster coordination between such scales (Principle 2); the requirement to provide, update and share knowledge through consistent, comparable and policy-relevant water data and information (Principle 5); and the need to promote methodologies for stakeholder engagement at bottom-up level (Principle 10).

River Basin Management (RBM) is conceived as a set of tasks to understand, organise and manage complex SES (Holling, 2001; Gunderson and Holling, 2002; Folke, 2006; Gain et al., 2020), taking into account the multiple interactions between their physical, chemical, biological and socio-economic processes (Agramont et al., 2021; Wang et al., 2022). Indeed, it encompasses a range of activities, including water allocation and distribution, water quality monitoring and management, flood and drought management, ecosystem conservation and restoration, and stakeholder engagement and participation. To perform these activities, RBM uses methods and technical tools for assessing the ecological integrity of natural resources, such as water chemistry analysis, detection of potential ecological status, environmental monitoring of cumulative effects or disturbances affecting reservoirs, and quantitative analysis of ecosystem degradation.

According to WFD article 2, a river basin district constitutes the primary unit of management of a river basin, which includes "*the area of land and sea, made up of one or more neighbouring river basins together with their associated groundwaters and coastal waters*" (European Communities, 2000).

The heterogeneity of river-crossed administrative units, scarce environmental monitoring, and ineffectiveness of top-down regulation are some of the critical factors associated with the failure of RBM. Nevertheless, further issues related to RBM include, as the most recurring and entangled:

- Climate change, which accelerates the frequency and severity of floods and droughts by altering the natural flow patterns of rivers and should be better integrated into WFD (Quevauviller et al., 2012);
- Limited financial support, which prevents activities such as water quality monitoring, infrastructure maintenance, and water policy coordination among local and national institutions, NGOs, and other stakeholders (Kauffman, 2015);
- Complex political issues, such as conflicts over water rights and land use policies (Watson, 2004), non-operational cooperation between in-charge jurisdictions and problems of spatial fits (Moss, 2004);
- Lack of data at suitable temporal and spatial scales makes it difficult to develop evidence-based management plans (Thompson et al., 2018).

However, the absence of cooperation between administrative units and scarce participation are the main obstacles to effective planning and regeneration practices, calling for new forms of governance (Newig et al., 2016). Furthermore, encouraging local stakeholders' engagement to enhance evidence-based decision-making through fast, easy-to-use, replicable, and spatial assessment methodologies remains a challenge for identifying the multiple landscape values (Euler and Heldt, 2018). At the same time, an integrated, collaborative approach to water management that considers the complex social, cultural, economic, and ecological factors that influence water use and protection is needed in designing an efficient but sustainable river basin management plan (Zilio et al., 2018).

Spatial qualitative and quantitative data integration is a crucial factor to consider in the context of RBM, especially in performance-based planning (De Toro et al., 2020; Pelorosso, 2020). SDSSs have been designed to provide decision-makers with formalized approaches for accessing, understanding, and interpreting information derived from data, models, and analyses, focusing on the geographic components of decision-making (Campagna, 2005; Sugumaran and Degroote, 2010; Cerreta et al., 2020).

SDSSs represent a significant improvement over earlier Decision Support Systems (Simon, 1960; Rodela et al., 2017) by facilitating stakeholders' access to decision problems, organizing multidimensional knowledge tiers, streamlining the process of linking data to decisions through geographical mapping (Keenan and Jankowski, 2019), and supporting choice through multi-criteria aggregation rules and spatial GIS techniques (Malczewski and Rinner, 2015; Cerreta et al., 2021).

To the best of our knowledge, few studies have used quantitative approaches to assess river basin economic, social, environmental, and cultural resources in an integrated manner concerning their capacity to activate cooperation network between river-crossed cities (Ahmadi et al., 2019; Brillinger et al., 2022; Nucci et al., 2022).

The methodological approach proposed in this study suggests a way to achieve integration in pursuing sustainable regeneration pathways for a river basin district, analysing the case study of the Sarno River, composed of 20 administrative units, in Southern Italy.

This research aims to provide decision-makers with an SDSS to evaluate sustainability scenarios based on the multi-dimensional performances of river basin district units (RBDU).

The research questions underlying this paper are as follows:

- Can SDSSs effectively boost decision-making processes for a sustainable RBM?
- Which methods and tools help collect and process spatially explicit data from local knowledge?
- How does a multidimensional performance assessment of a river basin district aid territorial clusters to emerge?

Therefore, the article aims to show a geographic, indicators-based, and site-specific SDSS for assessing suitable scenarios to foster collaborative and multi-level governance between municipalities within a river basin district. The outcome is twofold: to provide decision-makers with recommendations for activating governance models based on pathways of sustainability and to suggest valuable methods and tools to deal with spatial misfits, considered as the mismatch between the physical boundaries of a natural system and the management area of an organization (Moss, 2012).

The remainder of the article proceeds as follows: after the introduction, Section 2 presents the study area, collected data, and the methodological workflow related to the proposed SDSS. Section 3 aims to explain the SDSS procedural phases of "Intelligence" and "Design", along with data processing methods and tools. Section 4 expands on results by presenting the outcomes of the "Choice" phase. Finally, Section 5 concludes the article by discussing limitations, potentials, and further development.

2. Study area, data collection, and methodology

2.1. Study area

The study area covers 333 km^2 and includes 20 administrative units with an overall population of approximately 1.300.635 inhabitants and an average population density of 1.818 people per km^2 (Fig. 1). It is located by the Sarno river basin, between the Metropolitan City of Naples and the Agro Nocerino-Sarnese, province of Salerno, in the Campania region (Southern Italy). Different landscape types shape the study area from mountain to coastal, alternating primary agricultural uses with complex cultivation patterns and dense urban cores. Natural reservoirs safeguard the focus area for an amount of approximately 60 km^2, including two Regional parks and one National park, respectively referred to as "Regional Park of Monti Lattari", "Regional Park of Sarno River", and "Vesuvius National Park".

The Sarno River extends for around 24 km and originates in the Picentini mounts behind the Sarno town at approximately 30 m above sea level. It flows into the Bay of Naples between the two municipalities of Torre Annunziata and Castellammare di Stabia. Many secondary tributaries enrich Sarno's hydrographic network, the most important of

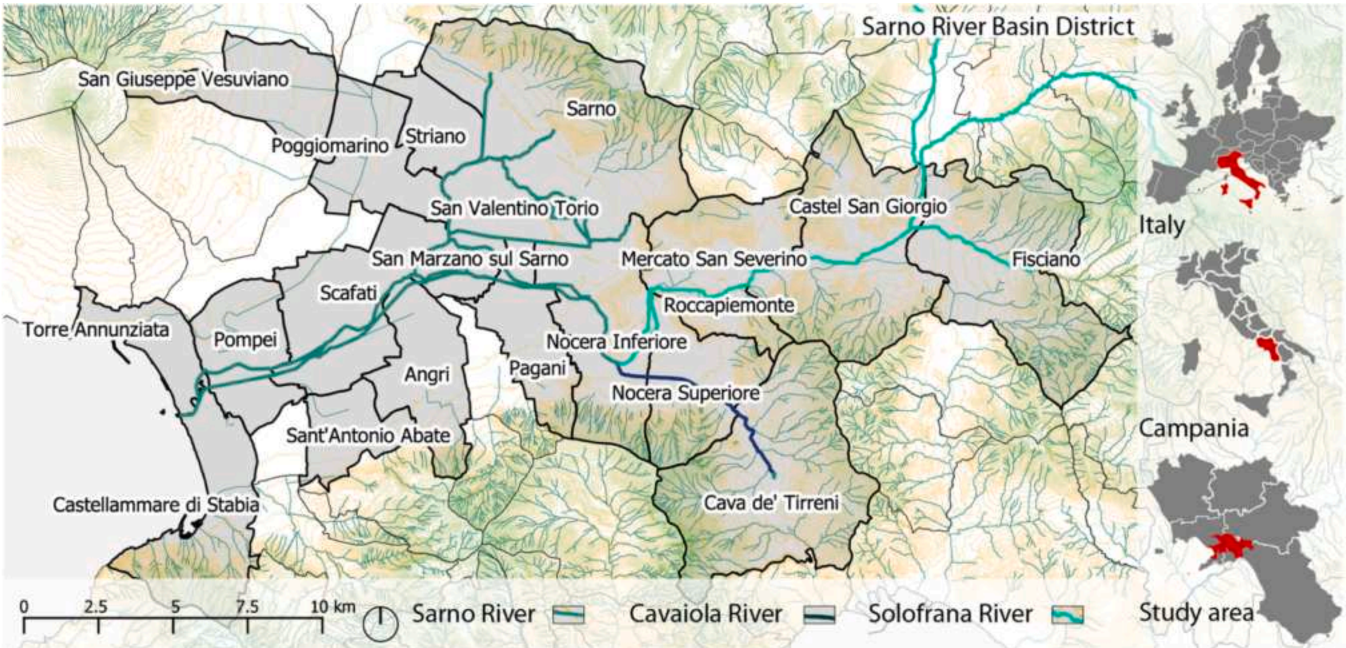


Fig. 1. The study area.

which are Solofrana and Cavaiola streams.

Investigations carried out by the Basin Authority showed that the great environmental potential was counteracted by strong anthropic pressure. Approximately 180 km of riverbeds have been transformed into roads, and 98 km have been tombed, while 70% of the linear development of the entire network remains in its natural state. The authors, therefore, selected the Sarno river basin district as the testing area for the proposed methodological approach, due to its high spatial complexity, relevant governance gaps, high population density, and critical environmental conditions due to massive uses of chemical pesticides in agriculture and uncontrolled industrial development (Montuori et al., 2015).

2.2. Data collection

Data collected and processed for this study were derived from open-source and authoritative sources; about the former, limitations due to missing data were esteemed to be acceptable compared to the cost-effectiveness and the ease of information retrieval. The main open-source data were, thus, gathered with the following collection methods: documentation, observation, social media platforms, and miscellaneous reports. About the authoritative sources, the primary data were extracted from the Italian Ministry of the Interior dataset (2020); the Territorial Regional Plan of Campania Region (Italy); the Italian Ministry of Education dataset (2020), the Hydrogeological Structure Plan of Campania Region (Italy), and the Corine Land Cover EU projects (2018).

2.3. Methodology

The methodological workflow, shown in Fig. 2, was structured into the three phases of decision-making conceived by Simon (1960) - Intelligence, Design, and Choice - to generalise the procedural steps and make them exportable, but with the concern of generating context-aware knowledge to inform local communities and decision-makers and developing shared future scenarios (Simon, 1960).

The declared goal of the proposed methodological approach aims to provide decision-makers with an SDSS to evaluate sustainability scenarios based on multi-dimensional performances of RBDU. The operational objectives related to the main goal are the following: i) to collect data and engage stakeholders in developing sustainability scenarios; ii) to evaluate scenarios for administrative units to be ranked against the performance-based ability in pursuing them; iii) to develop a spatial tool in supporting the selection of the best-fit cooperation scenarios for groups of administrative units within the river basin district.

Starting from the main goal, the methodological steps were defined:

1. *Intelligence*: the data collection phase, concerning decision-making problem structuring and definition of the 4 sustainability criteria for the classification of information.
2. *Design*: the data processing phase, concerning the construction of the 12 indicators core-set, the spatial visualisation of data and the planning of the 4 alternative scenarios with prioritisation of the indicator dimensions.
3. *Choice*: the data aggregation phase, concerning the evaluation of alternatives through TOPSIS method and the definition of ranking weighting methods for criteria and sub-criteria.

The Outcome delivered four partial rankings of RBDU related to each scenario and one overall ranking for the sustainability scenario. Each ranking includes a clustering of municipalities obtained with the K-Means algorithm (Pelleg and Moore, 1999; MacKay, 2003) according to three classes: Leader, Link and Follower.

After introducing the study context, a detailed description of SDSS's phases has been provided in the following Sections 3 and 4.

3. SDSS phases, data processing, and tools

3.1. Intelligence

The Intelligence phase concerned identifying the conditions that require a decision-making process, also known as problem structuring or formulation. In the context of Sarno River District management, several institutional levels are involved in the decision-making process. At the national level, the "Ministry of Ecological Transition" is responsible for policy-making and funding. At the regional level, the "Campania Region" implements national directives and oversees economic management and strategic planning. In particular, the region, through the "Sarno River

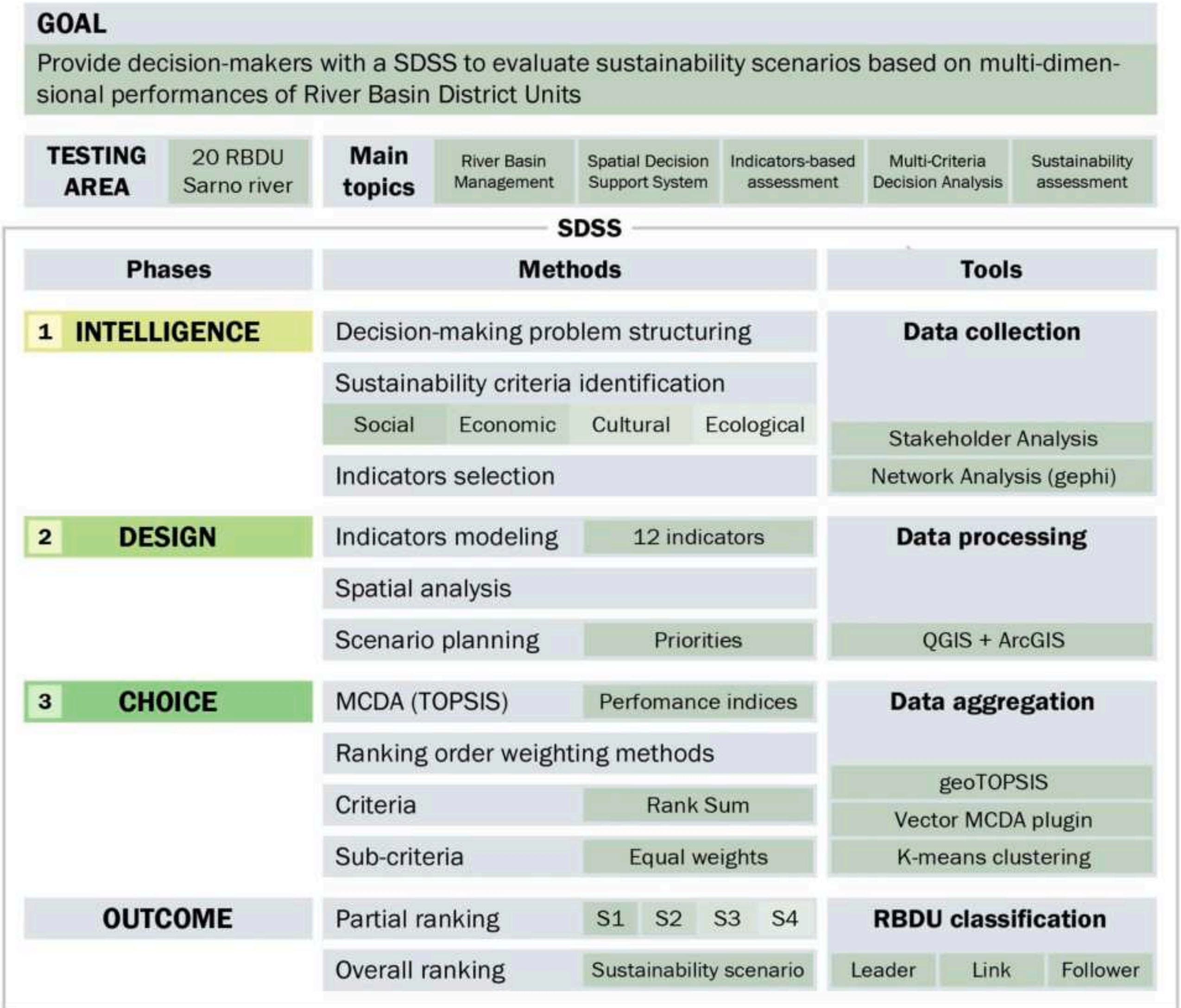


Fig. 2. The SDSS workflow.

Basin Authority," which operates over 61 municipalities in the river basin, is responsible for hydrogeological risk reduction. In parallel, through the "Sarno River Regional Park Authority," it protects naturalistic values in a restricted area that includes the 11 municipalities of the Sarno River. The advisory and propositional unit of the Park Authority is the "Park Community," composed of the Presidents of the Campania Region, the Metropolitan City of Naples, the Province of Salerno and the Mayors of the municipalities in the Park area. Although it is an ideal decision-making forum where different levels of administration converge, it provides guidance without directly implementing actions on the territory. In fact, in accordance with the governing instruments of river basin management and environmental and landscape protection, the implementation of any interventions of urban regeneration and reconnection of the river system to urban systems is delegated to the urban planning instruments of respective municipalities. In this complex multi-scalar and multi-actor decision-making context, the focus was on addressing the key challenge of providing a tool that can inform collaborative decision-making processes by integrating the issues of hydrogeological risk, social vulnerability, landscape regeneration, and governance gaps, which were identified as the most important in structuring and broadening the decision-making problem based on the research questions. The goal was to provide institutional stakeholders, particularly from the regional to local level, with an SDSS that would serve as a starting point for a more efficient RBM.

The primary data collection and selection operations were crucial in uncovering the context and highlighting the main local challenges. This was achieved using site-specific open-source and authoritative sources. In addition, institutional and local stakeholders were engaged to define potential scenarios by implementing Network Analysis (NA) (Chiesi, 2001), which helped identify the relational system through which local stakeholders interact. This enabled key criteria to be inferred and related indicators were selected as tools for monitoring the performance of district units. NA was particularly useful in analysing the relationships among local stakeholders (associations, third parties, institutions) who proposed sustainable solutions, projects, and regeneration actions at the river basin scale. NA provided visual representations of the river basin system, which could be valuable for communicating with stakeholders, including government agencies, communities, and environmental organizations. It supported in creating a shared understanding of the basin and its challenges. Furthermore, NA fits with the purpose of this study since it allows Decision-Makers to simulate and evaluate the potential outcomes of different management strategies before implementation. Fig. 3 illustrates the territorial network of 33 associations, civic committees, and groups with a declared interest in the Sarno River basin district, referring to four governance levels: local (municipality level), city-region (metropolitan city level), regional and national. Therefore,

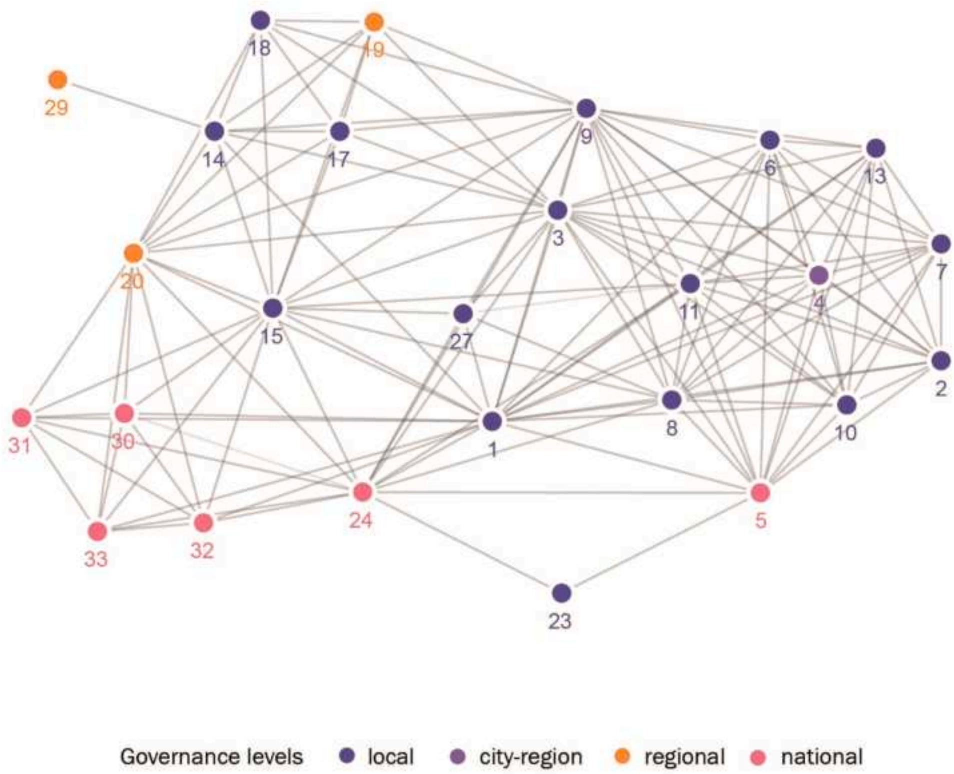


Fig. 3. The stakeholders' network and governance levels.

five primary scopes of the network were detected: environmental protection, cultural interest, civic promotion, sport, and welfare (Table A1).

The indicators used to construct the SDSS informative tiers were selected to concisely express the relevant characteristics associated with the study area for assessing transformation and enhancement scenarios. Information needed to build the indicators was derived from spatially explicit and implicit data collected. Regarding the latter, data processing operations were carried out on homogeneous mapping units, considering the institutional perimeters of the municipalities within the Sarno RBDU provided by the Italian National Institute of Statistics (ISTAT).

3.2. Design

According to the data combining methods classification provided by Malczewski and Jankowski (2020), the approach implemented in this study falls within Type 6, which relates to a mixed-use of Authoritative Geographic Data (AGD), Crowdsourced Geographic Data (CGD), and Crowdsourced Preference Data (CPD), referred to the use of social media platforms for data elicitation through photos, video, and text (Malczewski and Jankowski, 2020).

AGD and CGD have informed a Scenario Planning (SP) approach to spark participative bottom-up planning by selecting development pathways linked to the four sustainability pillars (Hawkes, 2001; Soini and Birkeland, 2014) referred to as "Social", "Cultural", "Ecological", and "Economic" scenarios.

Furthermore, the spatial component of decision-making was conceived as one of the strengths to improve the communication of results that support the collaborative process of building networks of administrative units involved in RBM (Wissen Hayek et al., 2016).

Following previous studies (Cerreta et al., 2020), statistical and geographical adjustments were addressed to make spatially explicit the selected indicators referring them to RBDU, corresponding with the NUTS 3 level (Eurostat, 2022). Gathered data have been, thus, transferred in the Geographic Information System (GIS) through Q-GIS open source software's spatial analysis and geoprocessing tools. In particular, spatial components have been attached to raw data to build indicators i03, i04, i05, i08, and i11 with GIS (Table A2).

Following Sub-Sections were addressed to explain in more detail the SP approach, indicators modelling, and processes to produce explicit spatial indicators from spatially implicit information.

3.2.1. Scenario planning approach

According to Stewart et al. (2013), the term *scenario*, among different definitions, can relate to exploring future conditions or environments within the context of creating possible development pathways as a starting point for planning (Slaughter, 1996; Stewart et al., 2013).

The primary characteristics of a decision-making problem addressed to the river basin district management are inherent to the co-existence of different and conflicting actors with incommensurable and divergent interests (i), the presence of important intangibles linked to local communities' value systems (ii), and the relevance of key uncertainties linked to the multiple variables to be considered into decisions (Marshall, 1997). In this perspective, as argued by Mingers and Rosenhead (2004), the Scenario Planning (SP) approach is congruent with a Problem Structuring Method (PSM) since it allows multiple and conflicting viewpoints to be combined and considered together, enabling the evolving representation to contribute to an inclusive problem-solving process (Mingers and Rosenhead, 2004). The identification and implementation of partial or localised improvements, which is one of the features of PSMs, inform the decision-making process without the need for a global solution that would involve the merging of different interests. Meanwhile, SP simplifies multidimensionality by reducing data into a limited number of possible states (Schoemaker 1998).

In this framework, SP was expected to be a valuable tool to imagine future development perspectives to trigger a participative planning process for the Sarno River district.

In this meaning, scenarios were derived to include stakeholders' priorities considering the four pillars of sustainability, explored and made explicit by the 12 spatial indicators.

The stakeholders' views were acknowledged during an institutional meeting, allowing four narratives of community scenarios to be inferred, each characterised by a priority sustainability criterion. The four scenarios relate to the promotion of policies for the Sarno River Basin districts' management, depending on specific territorial development outlooks, as shown in Table 1:

S1. Bottom-up social empowerment: a society-driven perspective, based on the promotion of bottom-up social policies in the fields of environmental protection, cultural interest, civic promotion, and welfare, maximising the Social criterion.
S2. Territorial investments: economy-driven perspective, based on the resource management efficiency for sustainable development, maximising the Economic criterion.
S3. Cultural promotion: culture-driven perspective, based on historical heritage conservation and awareness-raising, and human capital enhancement, maximising the Cultural criterion.
S4. Ecosystem conservation: ecology-driven perspective, based on human impacts and environmental risk mitigation, and natural resources conservation and enhancement, maximising the Ecological criterion.

CPD has informed S-MCDA in providing scenarios weights processed through the TOPSIS method (Yoon and Hwang, 1995). Consequently, the recommendation system based on partial and overall performance rankings of RBDU has been derived.

3.2.2. Social indicators

A mapping of the main associations with environmental, cultural, civic engagement and welfare purposes, operating in the area and involved in projects to enhance the Sarno River basin has allowed the processing of social indicators through NA.

Two metrics have been calculated to express the municipalities' ability to network:

- Degree Centrality (i01).
- Eigenvector Centrality (i02).

Degree Centrality (i01) is recognised as the most straightforward metric in the NA and represents the number of direct connections to other actors in the network. Its meaning refers to the importance of an actor within the entire network since the larger the number of adjacent nodes, the more relevant the node. In the examined network, a high Degree of Centrality refers to an increased number of projects an actor has managed as a leader involving other associations, highlighting its independence and capacity building within the network. Such a metric can be formalised through the Eq. (1).

Eigenvector Centrality (i02) expresses the potential that derives from connections between a network node and those nodes that have the highest number of links and, thus, are well-connected within the graph. Such a metric seeks to identify the importance of a node without merely counting the number of its links but by analysing the quantity and quality of the connections with high-scoring nodes. In this study, Eigenvector Centrality has served the purpose to detect those administrative units with few but well-connected-to-leaders actors.

The processed indicators were transferred into each RBDU by selecting the maximum relative value for both the metrics calculated within the municipal boundaries. The spatial representation of the social indicators in the GIS environment was provided in five classes using the classification method "Equal Intervals", which is suitable to emphasise the relative number of connections belonging to one district unit compared to the others (Fig. A1).

Table 1
The four scenarios and related priority order of sustainability criteria.

ID	Scenario description	Priority order according to sustainability criteria			
		Social	Economic	Cultural	Ecological
S1	**Bottom-up social empowerment**	I	II	III	IV
S2	**Territorial investments**	II	I	III	IV
S3	**Cultural promotion**	III	IV	I	III
S4	**Ecosystem conservation**	IV	III	II	I

3.2.3. Economic indicators

The indicators of the economic dimension were selected by focusing on the expenditures incurred by the municipalities - expressed in per capita terms - contained in the final balance sheet of the municipalities and expressed for the three macro categories of investments, which in turn were identified considering the sustainability pillars. These categories (and related expenditure items) are:

- *Per capita expenditure on enhancing cultural heritage and activities* (i03): historical heritage valorisation; cultural activities and interventions in the cultural sector.
- *Per capita expenditure on sustainable development and land and environmental protection* (i04): soil protection; environmental protection, enhancement, and recovery; waste; integrated water service; protected areas, natural parks, nature protection and forestation; protection and enhancement of water resources; sustainable development of small municipalities in mountain areas; air quality and pollution control.
- *Per capita expenditure on social rights, social policies, and family* (i05): interventions for childhood, kindergartens, disability, elderly, people at risk of social exclusion, families, right to housing; planning and governance of the network of social and health services; cooperation and associations; necropsy and cemetery service.

As with the indicators of the social dimension, the collected data were reported to a univocal MMU that corresponds to each RBDU. The spatial representation of indicators in the GIS environment involved the selection of the "Natural breaks (Jenks)" classification method, which allowed for natural groupings of data for the creation of classes (Fig. A2). The resulting intervals were set to show maximum variance between individual classes and least variance within each class.

3.2.4. Cultural indicators

Three indicators were selected to measure the cultural dimension, which on the one hand, quantify the built heritage of historical interest on a local scale, and on the other, identify the existing educational services. The indicators, both scaled up to the RBDU and spatially identified, are as follows:

- *Archaeological Sites and Heritage* (i06), including the most relevant archaeological sites and parks in the Sarno valley (e.g., the Archaeological Park of Pompeii and its peripheral sites of Longola, Oplontis, Scafati, Stabiae).
- *Historical Centres* (i07), which quantifies the area of the foundation cores of RBDUs in square kilometres, identifying and displaying their shape on a map.
- *Schools* (i08), which measures the number of schools that have promoted educational activities in their territory on the topic of sustainability and have engaged in Sarno River valorisation projects.

Regarding the spatial representation of indicator i05, the categorical classification method was chosen due to the reduced number of points for each RBDU. Indicators i07 and i08, instead, were classified according to the "Natural breaks (Jenks)" method (Fig. A3).

3.2.5. Ecological indicators

The indicators of the Ecological dimension have been identified based on two main concerns: first, the risk associated with the coexistence between the river and the urban fabric, and second, the impact of human activities on the ecological level of surface water and soil.

The following indicators, as shown in Fig. A4, have been scaled up to the RBDU:

- *Flood areas* (i09): This indicator measures the areas historically affected by the river flooding phenomenon in square kilometres.
- *Hydrological Risk* (i10): This indicator identifies the four hydrogeological risk classes - referred to as areas of very high (R4), high (R3), medium (R2) and moderate (R1) hydraulic risk - that the Italian territory is exposed to based on vulnerability and hazard.
- *Ecological status of surface water* (i11): This indicator reconstructs the ecological status of surface water by using the average values of monitoring points on the river course. It refers to a synthetic index - namely *LIMeco* - that integrates some physical-chemical elements to express the river's degree of naturalness in percentage terms.
- *Hemeroby impact level* (i12): This indicator classifies the hemeroby-level-based to land use types based on the polygon features of the CLC, grouped according to the main land cover categories defined by the CORINE nomenclature (European Environment Agency, 2018). It expresses the degree of human impact on the land (Frondoni et al., 2011; Walz and Stein, 2014). Each municipality was assigned the hemeroby class found to prevail within the administrative limits.

Following the classification proposed by Szilassi et al. (2017), the levels of hemeroby impact on soil - used to build the last-mentioned indicator - were divided into seven categories, as shown in Table A3. Since no ahemerobic areas are present in the Sarno river basin district, the authors divided the CLC levels characterizing the study area into six categories, excluding category one.

4. Results

4.1. Choice

The Choice phase's target was to combine scenario planning with MCDA in a GIS environment to derive overall and partial rankings for RBDU. The defined problem was modelled with the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS), a compensatory multi-criteria analysis method (Yoon and Hwang, 1995) founded into the following elements:

- Criteria, which have included four main domains referred to sustainability pillars in social, economic, cultural, and ecological terms.
- Sub-criteria, which correspond to spatial indicators selected and which were processed as proxy-variables to specify the main criteria.
- Alternatives, which have been identified with the RBDU of the decision-making problem.
- Scenarios, which represent the conditions under which the best-performing alternatives have been assessed against the selected criteria.

In this phase, S-MCDA has allowed performance indicators related to RBDU to be aggregated through mathematical combinatorial rules and partial rankings and overall ranking to be derived as the output of SDSS.

TOPSIS has allowed RBDU to be assessed concerning social, cultural, economic, and ecological indicators under conditions of the four scenarios (S1, S2, S3, S4). Therefore, TOPSIS was chosen as the best-fit MCDA method to integrate the spatial components of criteria and alternatives into classification maps based on the best/worst performance indicator values for each administrative unit. In addition, the possibility of implementing MCDA in a GIS environment is crucial in the context of RBDU management. Indeed, the geographical location of administrative units is very significant for decision-making, as they represent, with their ability to satisfy the evaluation criteria, the spatial alternatives against which policy and governance actions can be defined. The final ranking was obtained by ordering alternatives according to the relative closeness (C_i^*) through the Eq. (2).

The ideal point algorithm - implemented through the Q-GIS vector-mcda plugin released by Rocchi et al. (2020) - was used to perform the assessment and produce geographical choropleth maps with the ranking of Municipalities. Furthermore, to enable the comparison of the 4 scenarios' index values resulting from the assessment performed through the TOPSIS method, the numerical indices were normalized so that values measured on different scales were adjusted to a common scale between 0 and 1.

The weights were derived by applying two ranking order criteria weighting methods (Roszkowska, 2013), referred to as Rank Sum (RS) and Equal Weights (EW). At the level of criteria, RS can be formalised through Eq. (3), which allows the individual normalized ranks to be obtained by dividing by the sum of the ranks.

The stakeholder's priorities were turned into weights on a scale from 0.1 (least influential criterion) to 0.4 (criterion to be maximised). At the level of sub-criteria, EW - formalised through Eq. (4) - was used because no specific information about single indicator priority can be extracted at this stage since it would require the introduction of expert knowledge. The weights imputation with both weighting as mentioned above methods has been performed through the *vector-mcda* plugin.

The *K-Means* algorithm was implemented in Python through the Machine Learning module *sci-kit learn* to cluster RBDU into three categories: Leader, Link, and Follower. The K-Means is a popular clustering algorithm used to group data points into k clusters based on their similarity. It starts by randomly selecting k initial cluster centres and then iteratively assigns each data point to the nearest cluster centre based on the chosen similarity measure. After all data points have been assigned, the algorithm recalculates the centre of each cluster based on the mean of the data points assigned to that cluster. This process of assigning data points and recalculating cluster centres is repeated until convergence, when the cluster assignments no longer change (Bock, 2007).

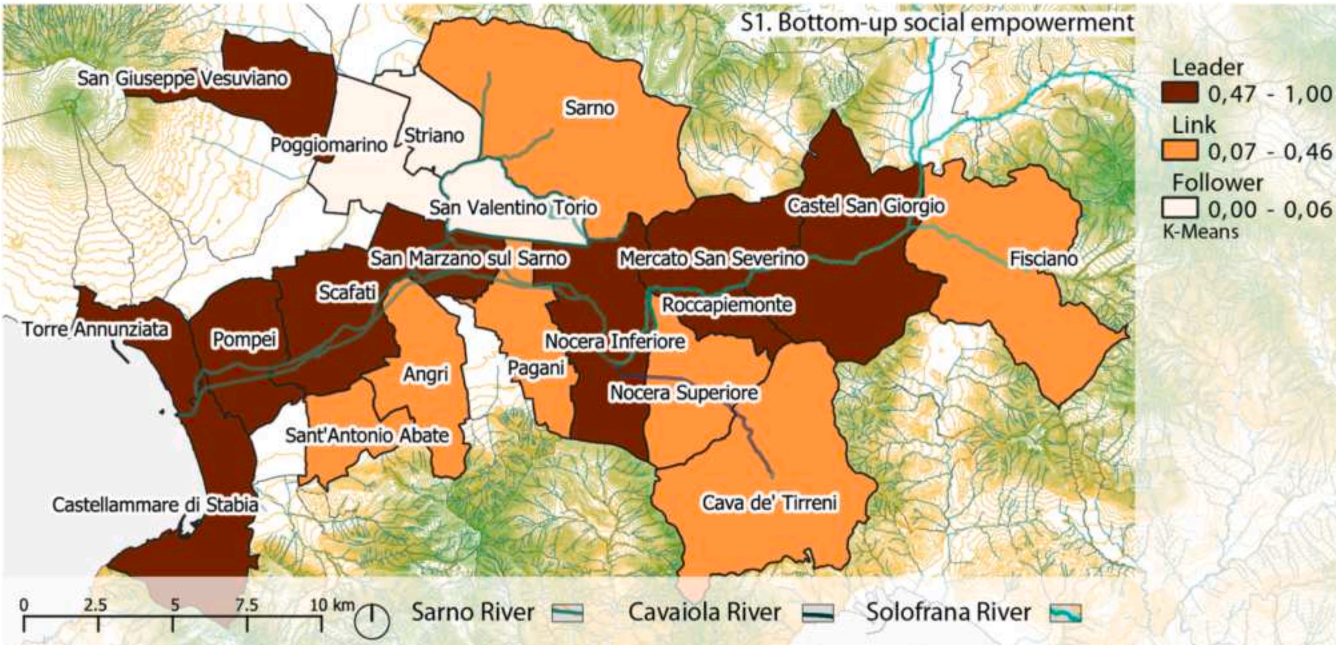
4.2. Spatial ranking partial results

The results of the previous phases have allowed administrative units to be ranked against the performance-based ability in pursuing scenarios. To facilitate a critical reading of the results, a categorisation of municipalities by the three clusters mentioned above - referred to as Leader, Link, and Follower - was carried out for each scenario map. This addresses the purpose of supporting decision-making in a strategic planning context and thus identifying those municipalities that, due to their best performances, can lead the way in achieving the perspectives of the respective scenarios.

Regarding the S1 scenario "Bottom-up social empowerment", which maximised the weight of the Social dimension, the evaluation results show 10 Leader municipalities (led by Castellammare di Stabia), 7 Link municipalities and 3 Follower municipalities (with San Valentino Torio ranked last), as shown in Fig. 4.

The municipalities of Cava de' Tirreni and Sarno rank as Link municipalities for the S1 scenario despite their worse performances in the Social dimension since in calculating the index, they are compensated by performances in the Economic and Cultural dimensions for Cava de' Tirreni and Cultural and Ecological dimensions for Sarno. On the other hand, with equal values for the Social dimension indicators, the municipality of San Giuseppe Vesuviano ranks higher than San Marzano because it performs significantly better on the other dimensions (in particular, Economic and Cultural).

Regarding the S2 scenario "Territorial investment", which maximised the weight of the Economic dimension, we obtain 6 Leader municipalities (led by San Giuseppe Vesuviano), 9 Link municipalities and 5 Follower municipalities (with San Valentino Torio ranked last), as



Municipality (RBDU)	S1	K-Means	Municipality (RBDU)	S1	K-Means	Municipality (RBDU)	S1	K-Means
Castellammare di Stabia	1,000	Leader	Pompei	0,607	Leader	Pagani	0,232	Link
Scafati	0,896	Leader	San Marzano sul Sarno	0,603	Leader	Fisciano	0,220	Link
Torre Annunziata	0,893	Leader	Nocera Inferiore	0,580	Leader	Nocera Superiore	0,193	Link
San Giuseppe Vesuviano	0,831	Leader	Cava de' Tirreni	0,462	Link	Poggiomarino	0,065	Follower
Roccapiemonte	0,704	Leader	Sarno	0,351	Link	Striano	0,045	Follower
Castel San Giorgio	0,691	Leader	Angri	0,298	Link	San Valentino Torio	0,000	Follower
Mercato San Severino	0,658	Leader	Sant'Antonio Abate	0,283	Link			

Fig. 4. Partial ranking of RBDU according to Scenario 1 (Bottom-up Social empowerment).

shown in Fig. 5.

With equal performances on the Economic indicators' values, the municipality of Mercato San Severino ranks as Link by keeping a good values average across all dimensions (with a prevalence of Social and Ecological ones). In contrast, Scafati ranks as Leader thanks to above-average performances, especially on Social and Cultural dimensions.

Regarding the S3 scenario "Cultural promotion", which maximised the weight of the Cultural dimension, there is only one Leader municipality (Castellammare di Stabia), 13 Link municipalities and 6 Follower municipalities (with Sant'Antonio Abate ranked last), as shown in Fig. 6.

Despite the municipality of Castellammare di Stabia showing a slight gap in the average value of the Cultural indicators compared to Cava de' Tirreni, it obtains a doubled score that ranks it first among Leaders, as it maximises the Social and Ecological dimensions by a large gap.

Finally, concerning the S4 scenario "Ecosystem conservation", which maximised the weight of the Ecological dimension, the ranking shows 4 Leader municipalities (led by Castellammare di Stabia), 9 Link municipalities and 7 Follower municipalities (with Angri ranked last) as shown in Fig. 7.

It is noteworthy that the municipality of Sarno ranks as second in the scenario ranking, despite the worst performance in the Social dimension, while Torre Annunziata ranks among the Link municipalities, as it largely prevails in the Social dimension and moderately in the Economic one, despite the worst performance in the Ecological dimension.

4.3. Overall spatial ranking

Performing the TOPSIS assessment against the indices of the municipalities for the 4 scenarios, giving equal weights, resulted in the final ranking describing the performance of the municipalities against the overall Sustainability scenario (Fig. 8). Furthermore, the spatialised results read in accordance with the Leader, Link and Follower classifications, obtained by applying the K-Means method, allow identification of territorial clusters.

Concerning the municipalities that can be considered Leaders in the promotion and management of the river resource, two main clusters can be identified. The first comprises 4 municipalities, starting with those located at the river mouth, Castellammare di Stabia and Torre Annunziata, which are at the top of the ranking, then rising towards the municipalities of Pompei and Scafati.

The second cluster is made up of 5 municipalities located in the inland area of the river system, starting with the upstream municipalities of Castel San Giorgio and Cava de' Tirreni, which is home to the source of the Cavaiola torrent, and ending in the municipality of Nocera Inferiore, the most central in the valley.

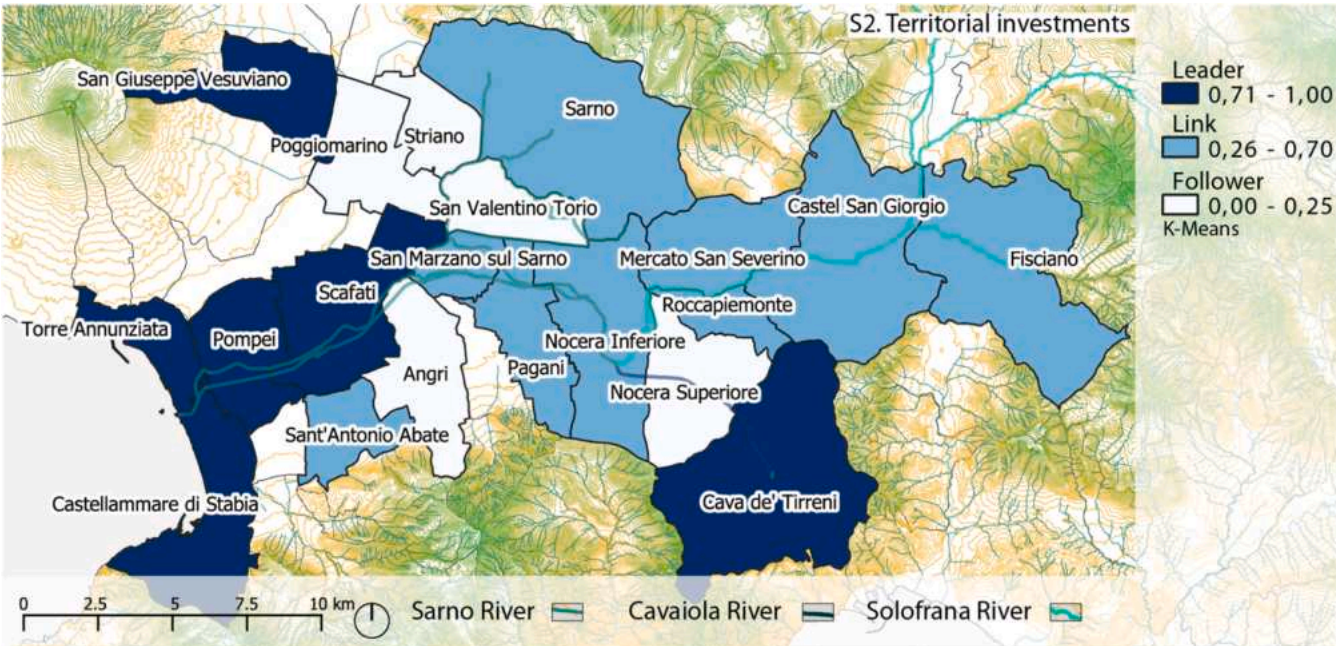
The municipalities that rank as Links constitute a main cluster composed of 4 municipalities located in the most central part of the valley and 3 detached municipalities, including Fisciano, among the last in the class, Nocera Superiore and Sarno, which, in addition to hosting the source of the Sarno river, ranks as first in its class.

Follower class municipalities are concentrated in a single cluster of 3 municipalities (Poggiomarino, Striano and San Valentino Torio) located in the valley's northern part, towards the Sarno river's spring.

5. Discussion

5.1. Potentials and limitations of the SDSSs for Sarno River Basin District

Several potentials arise from the integration of SDSS and RBM. First, SDSS boost RBM by providing decision-makers with spatial information



Municipality (RBDU)	S2	K-Means	Municipality (RBDU)	S2	K-Means	Municipality (RBDU)	S2	K-Means
San Giuseppe Vesuviano	1,000	Leader	Castel San Giorgio	0,620	Link	Pagani	0,384	Link
Castellammare di Stabia	0,968	Leader	Roccapiemonte	0,616	Link	Nocera Superiore	0,257	Follower
Torre Annunziata	0,925	Leader	Mercato San Severino	0,570	Link	Angri	0,252	Follower
Scafati	0,829	Leader	Sarno	0,553	Link	Poggiomarino	0,106	Follower
Cava de' Tirreni	0,763	Leader	San Marzano sul Sarno	0,541	Link	Striano	0,086	Follower
Pompei	0,741	Leader	Sant'Antonio Abate	0,499	Link	San Valentino Torio	0,000	Follower
Nocera Inferiore	0,701	Link	Fisciano	0,395	Link			

Fig. 5. Partial ranking of RBDU according to Scenario 2 (Territorial Investment).

and tools to evaluate and visualise the complex data associated with river basins. In particular, SDSS supports RBM by integrating spatial and non-spatial data to provide a comprehensive view of the river basin, allowing decision-makers to identify areas of concern, such as water quality, quantity, and ecosystem health. Furthermore, it allows decision-makers to simulate scenarios, visualise alternatives, and perform a multicriteria evaluation of various management options. This enables better-informed decisions to be made and helps to identify the most effective management strategies.

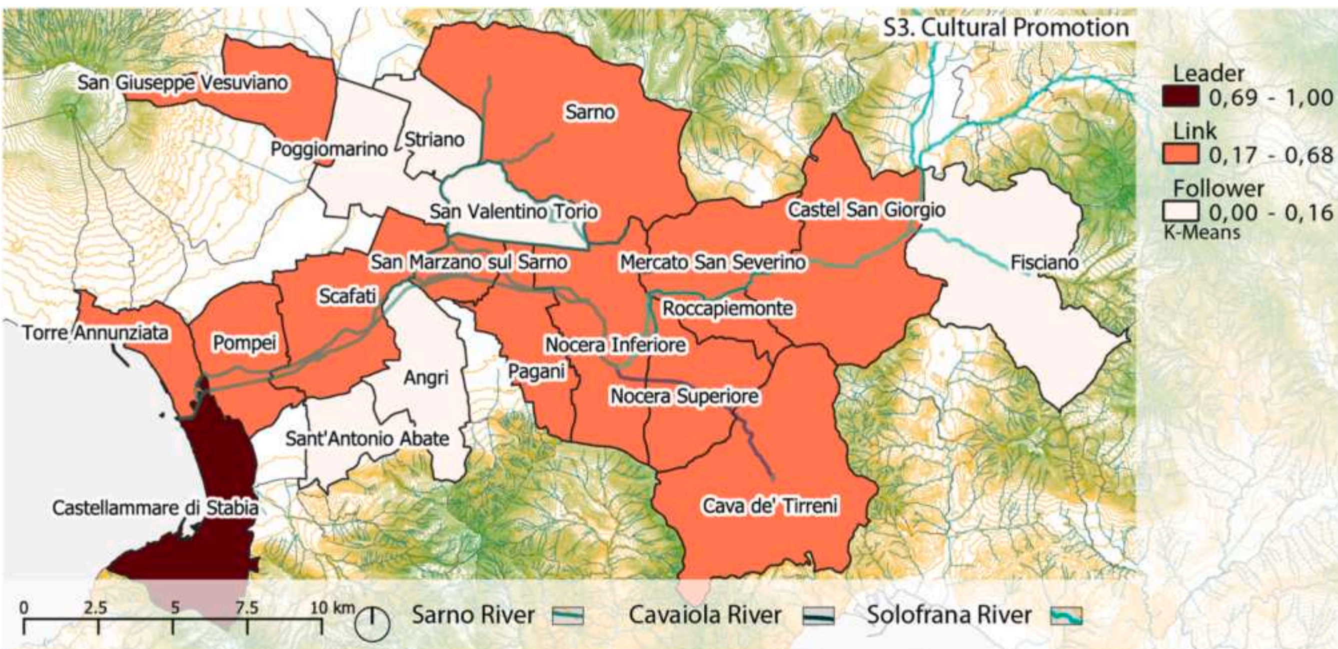
The interpretation of river basins as SES, an expression of multilevel systems in which ecological and social elements interact through bidirectional interactions and feedback loops, underlines the need to make explicit the complex and dynamic interdependencies between social and ecological components and support the sustainable management of resources, based on integrated and multidimensional assessments.

The preliminary findings of this study have highlighted the dual role of the evaluation process that underlies SDSS. Firstly, the purpose is to manage multidimensional resources and select scenarios that better meet complex and conflicting needs. Secondly, it addresses building incremental knowledge processes and mutual learning, which facilitate the identification and generation of new values in an integrated and collaborative perspective (Vilsmaier et al., 2015). Indeed, public involvement, supported by legislative instruments and improved in its procedures by technical/informatics tools capable of guiding participatory processes, has a positive impact on decision-making (Rega and Baldizzone, 2015). At the same time, evidence-based decision-making, if implemented by site-specific, geographic, and comprehensive indicators, stakeholders engagement and NA, generates an interface between policy and scientific research that aims to increase the level of multidimensional sustainability in planning decisions for RBM (Förster et al., 2015).

The methodological approach tested for the RBM of the Sarno River implements an incremental, dynamic, and iterative evaluation process, which involves different insights, leading to the exchange, synthesis, and co-production of knowledge and values in a complex decision-making context (Strang, 2007). The active involvement of expert groups and communities in decision-making is, therefore, an evaluation tool for self-learning and identifying new collective values (Closs and Antonello, 2011; Cerreta et al., 2021). In addition, the structured decision-making process allows for the testing of methodological procedures that can be scaled up in different contexts, using a multiscale approach that incorporates local instances and avoids over-generalization of problems when the knowledge underlying the collected data is place-based and context-aware (Handoyo and Sensuse, 2017). The proposed methodology, structured according to the three phases of decision making, has been designed to facilitate its replicability and exportability to other geographic contexts within the framework of RBM. Specifically, the selected composite indicators involve the use of largely easy-to-find Authoritative Geographic Data, and partly of Crowdsourced Geographic Data (Najwer et al., 2022). The availability of the latter is conditional on the possibility of adapting the corresponding indicators selected as meaningful.This contingency could constitute a constraint or ultimately a possible obstacle to the immediate replicability and adaptability of the evaluation framework.

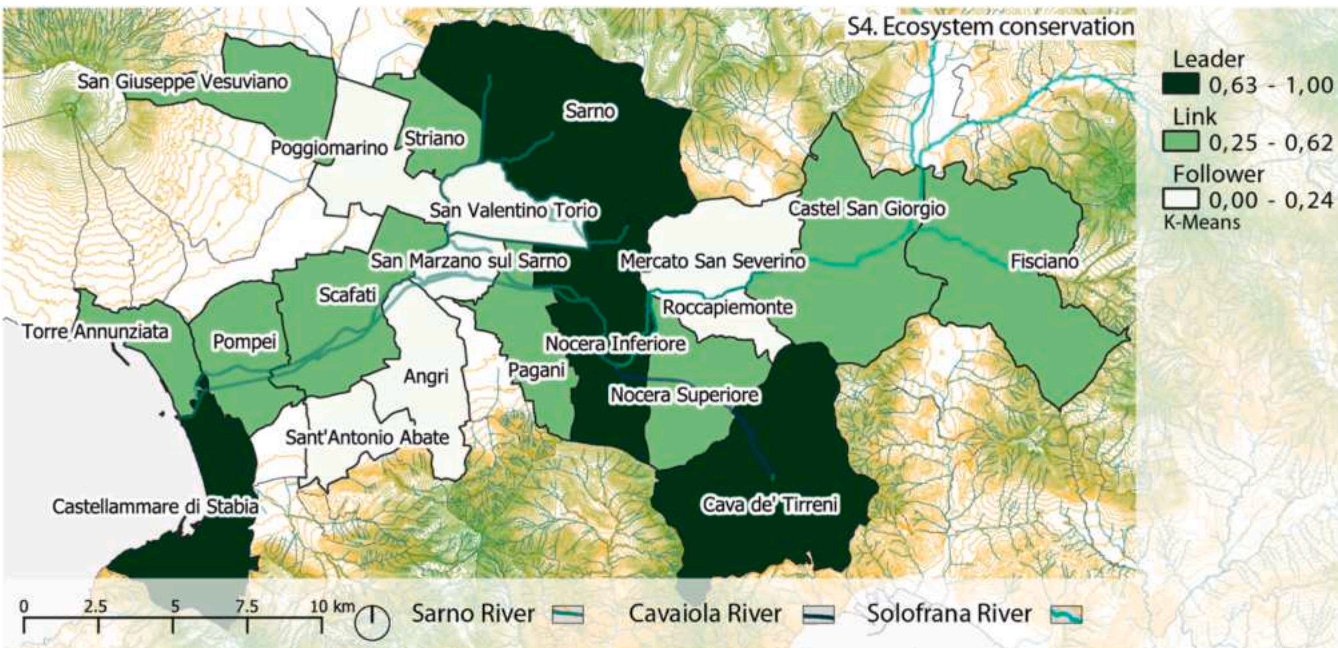
Limitations of this study can be recognised in some aspects of the proposed methodological approach, which has been conceived to support the hypothesis of structuring a decision-making process for RBM according to the formal rules of SDSS.

First, the amount and typology of selected indicators in the Knowledge phase requires multi-disciplinary expert validation to provide



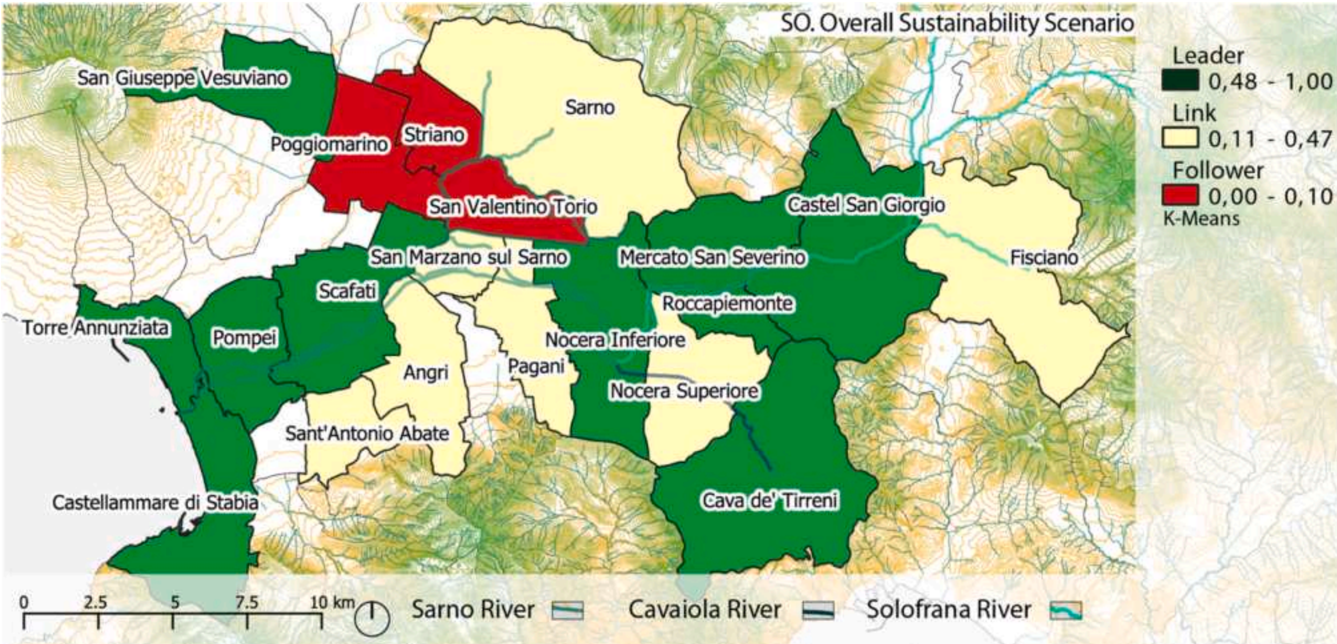
Municipality (RBDU)	S3	K-Means	Municipality (RBDU)	S3	K-Means	Municipality (RBDU)	S3	K-Means
Castellammare di Stabia	1,000	Leader	Castel San Giorgio	0,450	Link	Angri	0,167	Follower
Scafati	0,688	Link	Pompei	0,429	Link	Fisciano	0,133	Follower
Torre Annunziata	0,656	Link	Roccapiemonte	0,428	Link	Poggiomarino	0,121	Follower
Nocera Inferiore	0,625	Link	Cava de' Tirreni	0,427	Link	Striano	0,047	Follower
Mercato San Severino	0,519	Link	Nocera Superiore	0,376	Link	San Valentino Torio	0,036	Follower
San Giuseppe Vesuviano	0,488	Link	San Marzano sul Sarno	0,318	Link	Sant'Antonio Abate	0,000	Follower
Sarno	0,465	Link	Pagani	0,280	Link			

Fig. 6. Partial ranking of RBDU according to Scenario 3 (Cultural Promotion).



Municipality (RBDU)	S4	K-Means	Municipality (RBDU)	S4	K-Means	Municipality (RBDU)	S4	K-Means
Castellammare di Stabia	1,000	Leader	San Giuseppe Vesuviano	0,516	Link	Castel San Giorgio	0,215	Follower
Sarno	0,927	Leader	Pompei	0,507	Link	Poggiomarino	0,169	Follower
Cava de' Tirreni	0,904	Leader	Fisciano	0,498	Link	Roccapiemonte	0,119	Follower
Nocera Inferiore	0,845	Leader	Mercato San Severino	0,498	Link	San Marzano sul Sarno	0,018	Follower
Scafati	0,621	Link	Pagani	0,466	Link	Sant'Antonio Abate	0,009	Follower
Torre Annunziata	0,598	Link	Striano	0,342	Link	Angri	0,000	Follower
Nocera Superiore	0,575	Link	San Valentino Torio	0,242	Follower			

Fig. 7. Partial ranking of RBDU according to Scenario 4 (Ecosystem Conservation).



Municipality (RBDU)	SO	K-Means	Municipality (RBDU)	SO	K-Means	Municipality (RBDU)	SO	K-Means
Castellammare di Stabia	0,9832	Leader	Castel San Giorgio	0,5652	Leader	Sant'Antonio Abate	0,2824	Link
Torre Annunziata	0,7817	Leader	Roccapiemonte	0,5558	Leader	Fisciano	0,2689	Link
Scafati	0,7805	Leader	Cava de' Tirreni	0,5493	Leader	Angri	0,2361	Link
San Giuseppe Vesuviano	0,7037	Leader	Sarno	0,4733	Link	Poggiomarino	0,1032	Follower
Nocera Inferiore	0,6383	Leader	San Marzano sul Sarno	0,4675	Link	Striano	0,0925	Follower
Mercato San Severino	0,5788	Leader	Pagani	0,3057	Link	San Valentino Torio	0,0548	Follower
Pompei	0,5758	Leader	Nocera Superiore	0,2989	Link			

Fig. 8. Overall ranking for the sustainability scenario.

feedback about effective relevance and significance. Furthermore, a validation of sustainability objectives and selected indicators matching is needed in future research development since the SDSS's Design phase was conceived to spark a collaborative decision-making process for the Sarno RBDU, where the decision problem is still ill-structured or absent due to political fragmentation, spatial misfits, and entangled governance.

The methodological approach under consideration faces additional limitations. One key issue stems from the fact that the selection of indicators was not a product of a collaborative co-design process involving stakeholders. Instead, the selected indicators were derived from macro-objectives elicited during a participatory process that engaged public decision-makers, associations, and the local citizens within the Sarno river basin. This deviation from a co-design approach may impact the relevance and suitability of the selected indicators, as they were not directly informed by the diverse perspectives and needs of the stakeholders. Further development of this research should involve considering stakeholders' viewpoints during the co-design phase for searching and selecting suitable data and indicators.

Finally, expert knowledge of information systems becomes essential when there is a need to oversee the development, updates, and implementation of SDSS, and this may require time-consuming procedures, training of practitioners, planning of the different stages, as well as the engagement of third parties which cooperate to develop the system in its different phases.

5.2. Conclusions

The proposed study has suggested a way to achieve data integration in pursuing sustainable regeneration pathways for the Sarno river basin district in Southern Italy. The research questions at the foundation of this contribution have explored the effectiveness of a SDSS in boosting decision-making processes for sustainable RBM, the methods and tools for collecting and processing spatially explicit data from local knowledge, and how multidimensional performance assessments of a river basin district can aid territorial clusters to emerge. The purpose has been to provide decision-makers with a geographic, indicators-based, and site-specific SDSS for assessing suitable scenarios for fostering collaborative and multi-level governance among RBDU.

It has been highlighted that RBM faces critical challenges such as climate change, limited funding, ineffective coordination, complex political issues, and lack of data. In addition, policy implications can be identified from the implementation of SDSS in RBM. One of the primary concerns pertains to data integration and sharing, as inter-agency collaboration becomes crucial to ensure that all pertinent data and stakeholders' perspectives are taken into account throughout the SDSS's Intelligence phase.

New approaches and modes of interactions are emerging which are disrupting the conventional approach to regulating water governance, in a more holistic and inclusive perspective. In order to assess the interconnected effects of changes in various scopes of the river basin that may have adverse consequences for other economic sectors (e.g. agriculture, ecosystems conservation, and spatial planning), the SDSS promotes a more comprehensive and critical approach at diverse political, institutional, and spatial levels. Consequently, these changes need to be integrated into the broader context of regional development and to be aligned with its larger goals in order to yield effective outcomes.

The actions undertaken within the Sarno RBM are often local initiatives, partial and localised responses to systemic and interconnected problems. The lack of an integrated tool is reflected in a poor correspondence between policies and territorial contexts, and therefore in poor or uneven impacts of the same, depending on the geographical context.

Ensuring public access to the SDSS promotes transparency by facilitating participation in decision-making processes, building trust and accountability among inhabitants especially for risk management and mitigation policies.

Encouraging local stakeholders' engagement and using SDSS to integrate qualitative/quantitative information with authoritative/crowdsourced geographical data can help to overcome these challenges and design efficient and sustainable RBM plans.

Nevertheless, reorganising water management around a river basin will solve some spatial mismatches, but could generate new ones. Creating a river basin agency could also complicate decision-making processes.

Spatial fit and RBM should be considered as an adaptive co-management practice able to take into account viewpoints of a wide range of relevant stakeholders operating in different river basin areas and on different scales.

Future research and policy on spatial fit should be addressed to stress work with and across boundaries, which in any case should not be conceived of as purely physical, but should reflect the political, socio-economic, and cultural geographies of an ecosystem or natural resource. In this context, more work is needed on those boundary organizations that strive to span the various geographies of resource management.

CRediT authorship contribution statement

Giuliano Poli: Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Stefano Cuntò:** Writing – original draft, Software, Data curation, Visualization. **Eugenio Muccio:** Writing – review & editing, Writing – original draft, Visualization, Data curation, Methodology. **Maria Cerreta:** Writing – review & editing, Validation, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

We have shared all data in the attached files

APPENDIX A

Table A1
Data input for Network Analysis.

ID	Scope	Municipality	Latitude	Longitude	Governance levels	Name	Degree Centrality (i01)	Eigenvector Centrality (i02)
1	Environmental	Scafati	40746833	14531586	local	Comitato "Scafati a Difesa del Sarno"	40	1
2	Environmental	San Giuseppe Vesuviano	40836397	14491042	local	Comitato "Vasca a Pianillo"	22	693606
3	Civic	Castellamare di Stabia	40702948	14482641	local	Gruppo civico "La Città Armonica"	38	985661
4	Sport	Napoli	40851126	14267333	regional	U.I.S.P. Comitato Regionale Campania	22	693606
5	Environmental	Castel San Giorgio	40781014	14698545	national	Circolo Legambiente "Francesco Di Pace"	26	751663
6	Civic	Scafati	40742423	14531197	local	Comitato "Cappella ed Oltre"	22	693606
7	Sport	Roccapiemonte	4076059	14693487	local	Associazione "I Tre Castelli"	22	693606
8	Environmental	Torre Annunziata	40739104	14473166	local	Associazione "Golfo delle Meraviglie"	28	829788
9	Environmental	Meta di Sorrento	40646461	14410542	local	Gruppo "La Grande Onda"	38	985661
10	Civic	San Marzano sul Sarno	40774942	14590001	local	Comitato "San Marzano in Movimento"	22	693606
11	Environmental	Scafati	40742062	14520585	local	Associazione "Per la Nostra Terra"	27	813456
13	Civic	Torre Annunziata	40735401	14472612	local	Associazione "Petra Hercules"	22	693606
14	Civic	Pompei Via Astolelle	40744823	14502802	local	Comitato "Via Astolelle e Sant'Abbondio"	18	43091
15	Welfare	Roccapiemonte	40764115	14672348	local	Ass. Nuove Prospettive Onuls)	32	723801
17	Cultural	Castellammare di Stabia	40698477	144898	local	Associazione "Achille Basile - le ali della lettura"	14	354099
18	Cultural	Castellammare di Stabia	40702909	14482748	local	Associazione Culturale "ARS Nea - didattica e cultura"	14	354099
19	Environmental	Salerno	40679474	14756924	city-region	CAI TAM - Club Alpino Italiano - Salerno	14	354099
20	Environmental	Napoli Castel dell'Ovo	40828316	14247604	city-region	CAI TAM - Club Alpino Italiano - Napoli	26	571585

(*continued on next page*)

Table A1 (*continued*)

ID	Scope	Municipality	Latitude	Longitude	Governance levels	Name	Degree Centrality (i01)	Eigenvector Centrality (i02)
23	Welfare	Castellammare di Stabia	40699331	14488078	local	Città Viva ODV	4	112215
24	Environmental	Mercato San Severino	40768107	1470241	national	CNSBII	27	663402
27	Environmental	Nocera Inferiore	4074606	14647489	local	Gruppo civico “Aquamunda - uniti per il Sarno”	13	443789
29	Environmental	Salerno	40647162	14830496	city-region	associazione provinciale Accademia Kronos	2	35144
30	Environmental	Torre Annunziata	40757746	14439936	national	Legambiente Giancarlo Siani Torre Annunziata	13	289625
31	Environmental	Castellammare	40690677	14488572	national	Circolo Legambiente Woodwardia	14	314298
32	Environmental	Angri	40737541	145747	national	Circolo Legambiente Oikos Angri	14	314298
33	Environmental	Nocera Inferiore	4074346	14636164	national	Circolo Legambiente Leonia Nocera Inf	14	314298

Table A2
The indicators set.

Dimension	ID	Indicator	Source type	Year	Spatial Method	Unit of Measure	Raw Data Feature
Social	i01	Degree Centrality	CGD | documentation, observation, social media platform, miscellaneous report	2020	Network Analysis + GIS (Join Table)	number	Spatially Explicit
	i02	Eigenvector Centrality	CGD | documentation, observation, social media platform, miscellaneous report	2020	Network Analysis + GIS (Join Table)	number (range 0–1)	Spatially Explicit
Economic	i03	Per capita expenditure on the enhancement of cultural heritage and activities	AGD | Italian Ministry of the Interior	2020	GIS georeferencing	€/inh/yr	Spatially Implicit
	i04	Per capita expenditure on sustainable development and land and environmental protection	AGD | Italian Ministry of the Interior	2020	GIS georeferencing	€/inh/yr	Spatially Implicit
	i05	Per capita expenditure on social rights, social policies and family	AGD | Italian Ministry of the Interior	2020	GIS georeferencing	€/inh/yr	Spatially Implicit
Cultural	i06	Archaeological Sites and Heritage	AGD | Territorial Regional Plan (Campania Region, Italy)	2008	GIS (Join Table)	number	Spatially Explicit
	i07	Historical centres	AGD | Territorial Regional Plan (Campania Region, Italy)	2008	GIS (Join Table)	SqKm	Spatially Explicit
	i08	Schools	AGD | Ministry of Public Education	2022	GIS georeferencing	number	Spatially Implicit
Ecological	i09	Flood areas	AGD | Territorial Regional Plan (Campania Region, Italy)	2008	GIS (spatial statistics)	SqKm	Spatially Explicit
	i10	Hydrological Risk	AGD | Hydrogeological Structure Plan (Campania Region, Italy)	2015	GIS (spatial statistics)	SqKm	Spatially Explicit
	i11	Ecological status of surface waters	CGD | Italian environmental association "Legambiente"	2019	GIS (spatial statistics)	%	Spatially Implicit
	i12	Hemerobic impact level	AGD | Corine Land Cover (European Commission)	2018	GIS (Join Table)	surface class (SqKm)	Spatially Explicit

*AGD = Authoritative Geograaphic Data; CGD = Crowdsourced Geographic Data

Table A3
The hemeroby level for CLC class.

ID	Class	Description	CLC ID
1	Ahemerobic	Natural ecosystems that are largely untouched by human activity	There are no areas without anthropic impact in the Sarno river basin district
2	Olygohemerobic	Ecosystems that have been subject to weak human impact, but still largely retain their natural character	3111_3113_3112_3114_3115
3	Mesohemerobic	Ecosystems that have been moderately altered by human activity, but still retain some aspects of their original character	3211_3212_3132_324_3231_333
4	Alpha-euhemerobic	Ecosystems that are in the process of being transformed from a natural or semi-natural state to a more human-dominated state	243_141_231
5	Beta-euhemerobic	Ecosystems that are heavily influenced by human activity and management, but still contain some elements of natural or semi-natural systems	242_334_142_2111_222_223
6	Polyhemerobic	Ecosystems that are created and maintained entirely by human activity, such as agricultural fields, urban parks, or gardens	112_131
7	Meta-hemerobic	Ecosystems that are strongly dominated by human activity and have lost most of their original natural character, such as urban areas or heavily degraded landscapes	111_121_123_

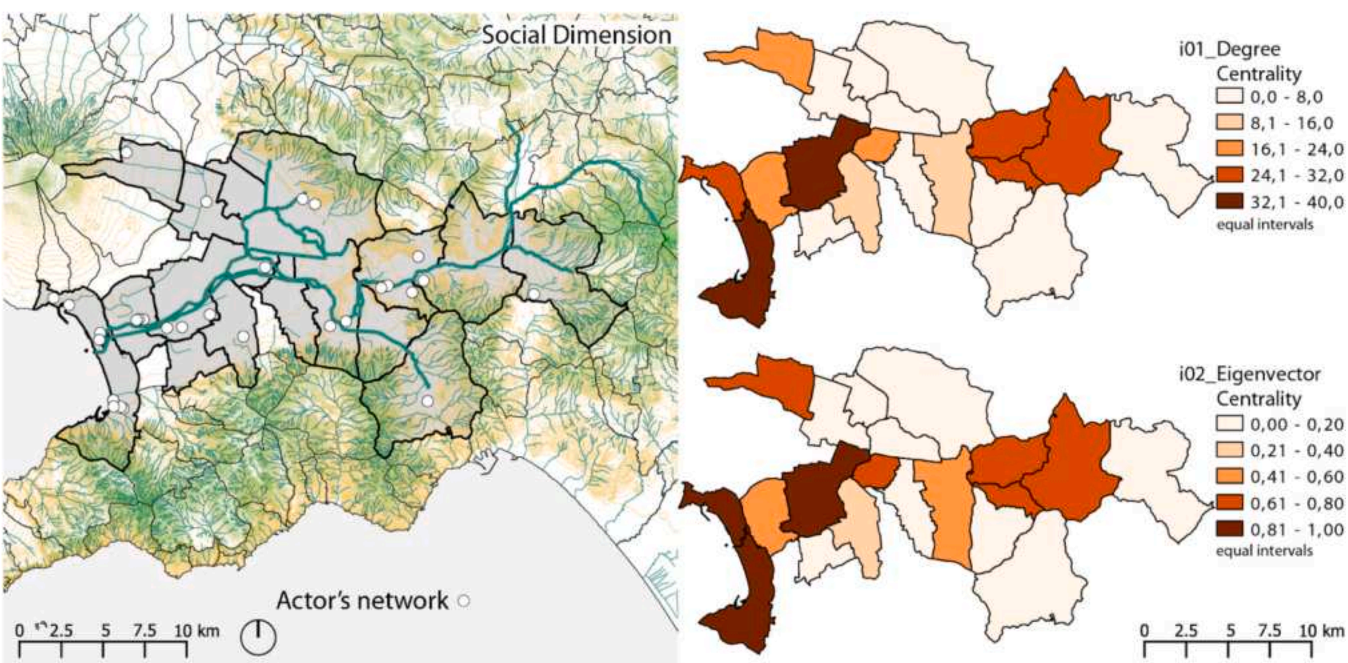


Figure A1. Social Indicators spatial maps.

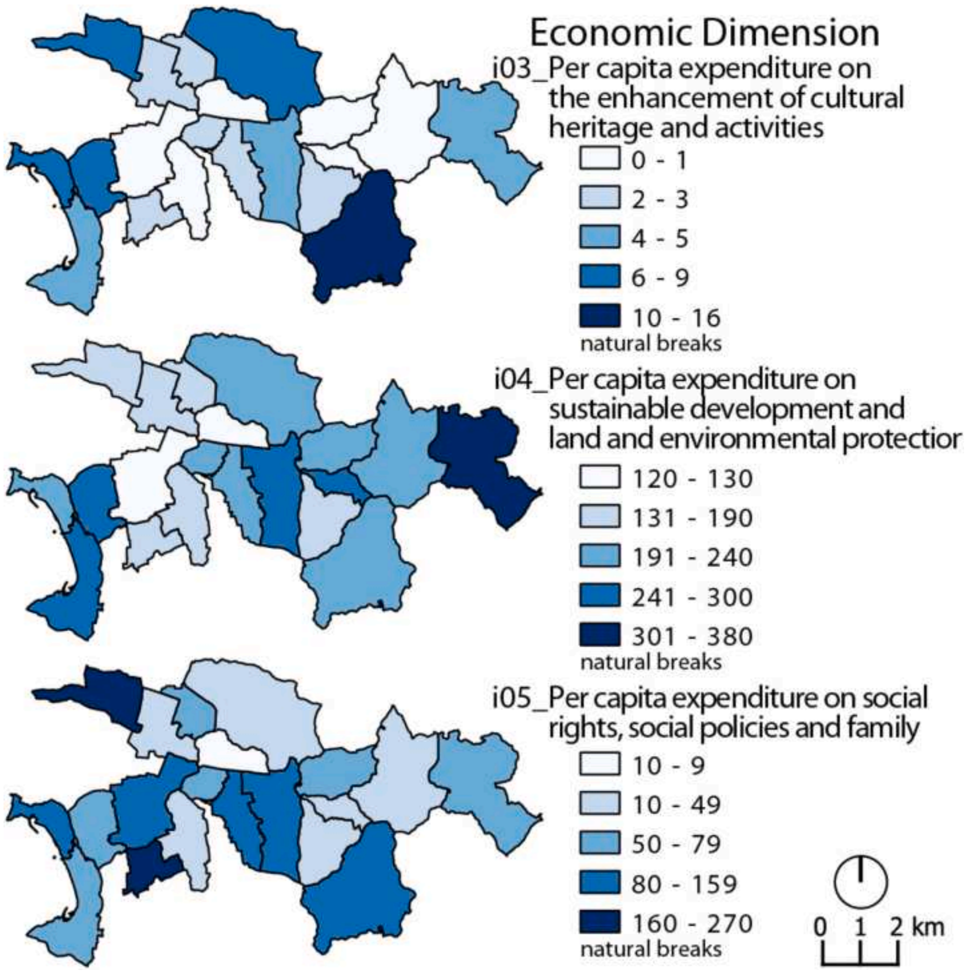


Figure A2. Economic Indicators spatial maps.

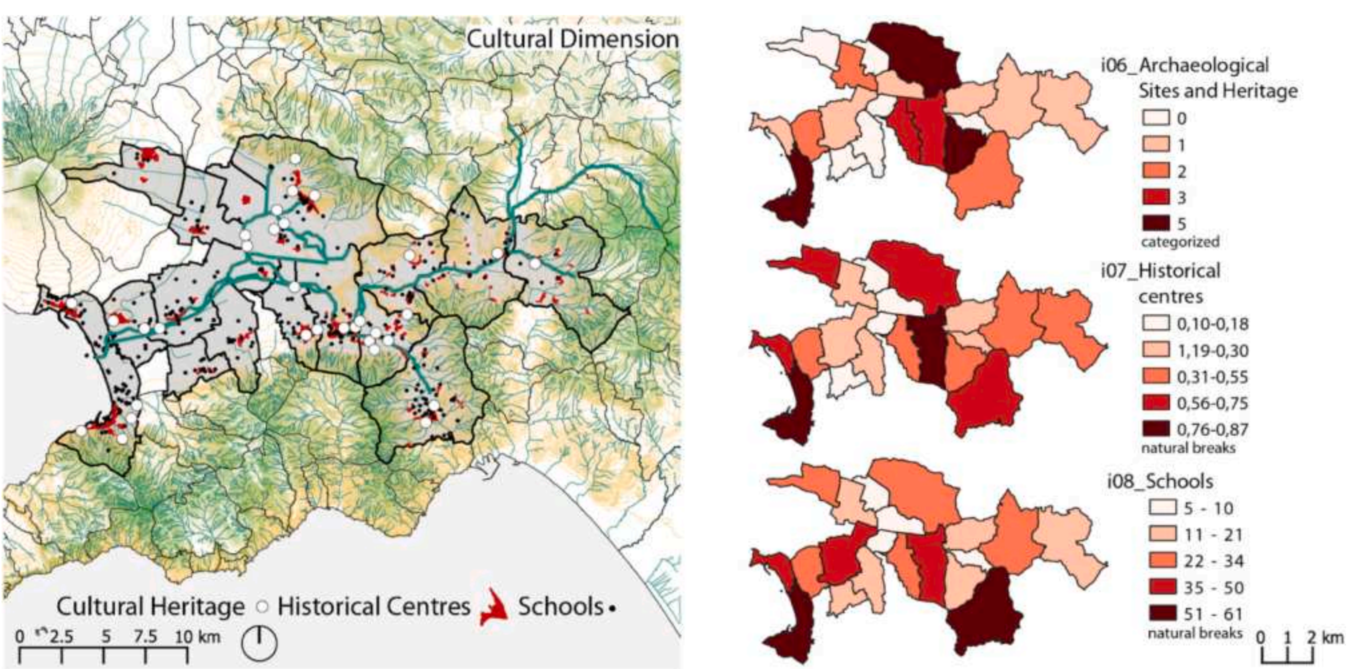


Figure A3. Cultural Indicators spatial maps.

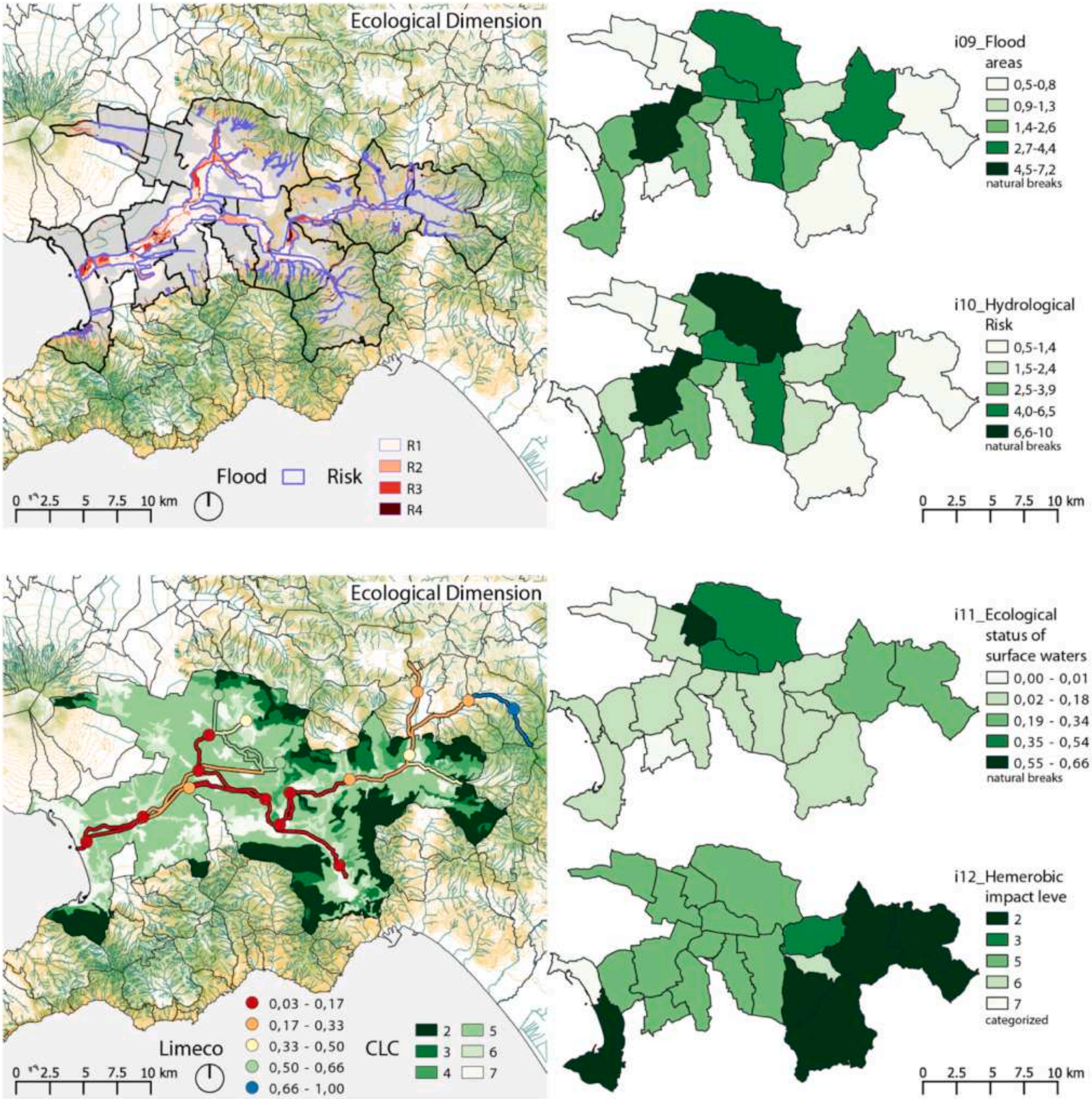


Figure A4. Ecological Indicators spatial maps.

APPENDIX B. 1. Eq. (1): DEGREE CENTRALITY

$$d(i) = \sum_j m_{ij} \quad (1)$$

where $m_{ij} = 1$ if a link among nodes i and j exists, and $m_{ij} = 0$ if a link does not exist.

2. TOPSIS METHOD [Eq. (2): RELATIVE CLOSENESS]

TOPSIS method (Technique for Order Preference by Similarity to Ideal Design) (Yoon and Hwang, 1995), main steps derived by Rocchi et al. (2020)

Step 0 - Given a decisional problem, in which there are n alternatives and k attributes, a related “decisional matrix” can be constructed:

Alternative designs	Attributes			
	y_1	y_2		
a_1	y_{11}	y_{12}	y_k	
a_2	y_{21}	y_{22}	…	y_{1k}
…	…	…	…	y_{2k}
a_n	y_{n1}	y_{n2}	…	…

in which y_{ij} is the value of the attribute y_j for the alternative $a_i(i = 1,\ldots,n; j = 1,\ldots,k.)$.

Step 1 - the normalized decisional matrix must be defined, whose elements are:

$$z_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{n} y_{ij}^2}}, i = 1,\ldots,n \quad j = 1,\ldots k.$$

Step 2 - the weighted normalized decisional matrix is subsequently defined, whose elements are:

$$x_{ij} = w_j z_{ij}, i = 1,\ldots,n; j = 1,\ldots,k.$$

where w_j is the weight of j-th attribute.

Step 3 - an ideal point a^* and a worst point a^- (nadir) are defined as follows:

$$a^* = \left\{ \left(\max_i x_{ij} | j \in J\right), \left(\min_i x_{ij} | j \in J^\wedge\right) | i = 1,\ldots n \right\} = \left\{x_1^*, x_2^*, \ldots, x_k^*\right\}$$

$$a^- = \left\{ \left(\min_i x_{ij} | j \in J\right), \left(\max_i x_{ij} | j \in J^\wedge\right) | i = 1,\ldots n \right\} = \left\{x_1^-, x_2^-, \ldots, x_k^-\right\}$$

where J is the set of the indices to be maximized (e.g. benefits) while J^ is the set of the indices to be minimized (e.g. costs).

Step 4 - the distance of the alternative from the ideal point a^* (i.e. an ideal or perfect alternative) is calculated as follows:

$$S_i^* = \sqrt{\sum_{j=1}^{k} \left(x_{ij} - x_j^*\right)^2}, i = 1,\ldots,n$$

and the distance from the negative ideal point a - is calculated as well:

$$S_i^- = \sqrt{\sum_{j=1}^{k} \left(x_{ij} - x_j^-\right)^2} \quad i = 1,\ldots,n$$

Step 5 - The "relative closeness" of each design from the ideal point is calculated:

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad i = 1,\ldots,n \tag{2}$$

Step 6 - Finally, ordering the alternatives according to $C^*{}_i$, we obtain their ranking from the best to the worst; indeed, if $C^*{}_i > C^*{}_j$ then a_i "surpasses in degree" a_j.

3. Eq. (3): RANK SUM

$$w_j(RS) = \frac{n - r_j + 1}{\sum_{k=1}^{n} n - r_k + 1} = \frac{2(n + 1 - r_j)}{n(n + 1)} \tag{3}$$

where r_j is the rank of the $j-$ th criterion, $j = 1, 2, \ldots, n$.

4. Eq. (4): EQUAL WEIGHTS

$$w_j(EW) = \frac{1}{n} \tag{4}$$

where $j = 1, 2, \ldots, n$.

Appendix C. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2024.107123.

References

Agramont, A., van Cauwenbergh, N., van Griesven, A., Craps, M., 2021. Integrating spatial and social characteristics in the DPSIR framework for the sustainable management of river basins: a case study of the Katari River Basin, Bolivia. Water Int. *47* (1), 8–29. https://doi.org/10.1080/02508060.2021.1997021.

Ahmadi, A., Kerachian, R., Rahimi, R., Skardi, M.J.E., 2019. Comparing and combining Social Network Analysis and Stakeholder Analysis for natural resource governance. Environ. Dev. 32, 100451. https://doi.org/10.1016/j.envdev.2019.07.001.

Bock, H.-H., 2007. Clustering methods: a history of K-means algorithms. Selected Contributions in Data Analysis and Classification. Springer Berlin Heidelberg,, pp. 161–172. https://doi.org/10.1007/978-3-540-73560-1_15.

Brillinger, M., Scheuer, S., Albert, C., 2022. Deliberating options for nature-based river development: insights from a participatory multi-criteria evaluation. J. Environ. Manag. *317*, 115350 https://doi.org/10.1016/j.jenvman.2022.115350.

Campagna, M., 2005. GIS for sustainable development. CRC Press,. https://doi.org/10.1201/9781420037845. Original work published 2005.

Cerreta, M., Mele, R., Poli, G., 2020. Urban ecosystem services (UES) assessment within a 3D virtual environment: a methodological approach for the larger urban zones (LUZ) of Naples, Italy. Appl. Sci. 10 (18), 6205. https://doi.org/10.3390/app10186205.

Cerreta, M., Panaro, S., Poli, G., 2021. A spatial decision support system for multifunctional landscape assessment: a transformative resilience perspective for vulnerable inland areas. Sustainability 13 (5), 2748. https://doi.org/10.3390/su13052748.

Chambers, J.M., Wyborn, C., Ryan, M.E., Reid, R.S., Riechers, M., Serban, A., Bennett, N. J., Cvitanovic, C., Fernández-Giménez, M.E., Galvin, K.A., Goldstein, B.E., Klenk, N. L., Tengö, M., Brennan, R., Cockburn, J.J., Hill, R., Munera, C., Nel, J.L., Österblom, H., Pickering, T., 2021. Six modes of co-production for sustainability. Nat. Sustain. *4* (11), 983–996. https://doi.org/10.1038/s41893-021-00755-x.

Chiesi, A.M., 2001. Network analysis. In: Smelser, N.J., Baltes, P.B. (Eds.), International Encyclopedia of the Social & Behavioral Sciences. Pergamon,, pp. 10499–10502. https://doi.org/10.1016/B0-08-043076-7/04211-X.

Closs, L., Antonello, C.S., 2011. Transformative learning. J. Transform. Educ. *9* (2), 63–88. https://doi.org/10.1177/1541344611429129.

Cox, M., 2011. Advancing the diagnostic analysis of environmental problems. Int. J. Commons 5 (2), 346. https://doi.org/10.18352/ijc.273.

De Toro, P., Nocca, F., Buglione, F., 2020. Evaluations for a new performance-based approach in urban planning. Arch. Stud. Urbani E Regionali (*127*), 149–180. https://doi.org/10.3280/asur2020-127-s1009.

Euler, J., Heldt, S., 2018. From information to participation and self-organization: visions for European river basin management. Sci. Total Environ. *621*, 905–914. https://doi.org/10.1016/j.scitotenv.2017.11.072.

European Communities, 2000. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy. Off. J. Eur. Union *L 327*, 1–72 https://doi.org/http://data.europa.eu/eli/dir/2000/60/oj.

European Environment Agency. (2018). *Technical library — Copernicus Land Monitoring Service* (European Topic Centres, Ed.). Https://Land.Copernicus.Eu/Pan-European/Corine-Land-Cover. http://land.copernicus.eu/user-corner/technical-library.

Eurostat. (2022, December 1). *Eurostat*. Eurostat. ⟨https://ec.europa.eu/eurostat/web/nuts/background⟩.

Folke, C., 2006. Resilience: the emergence of a perspective for social-ecological systems analyses. Glob. Environ. Chang 16 (3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002.

Förster, J., Barkmann, J., Fricke, R., Hotes, S., Kleyer, M., Kobbe, S., Kübler, D., Rumbaur, C., Siegmund-Schultze, M., Seppelt, R., Settele, J., Spangenberg, J.H., Tekken, V., Václavík, T., Wittmer, H., 2015. Assessing ecosystem services for informing land-use decisions: A problem-oriented approach. Ecol. Soc. *20* (3) https://doi.org/10.5751/es-07804-200331.

Frondoni, R., Mollo, B., Capotorti, G., 2011. A landscape analysis of land cover change in the Municipality of Rome (Italy): Spatio-temporal characteristics and ecological implications of land cover transitions from 1954 to 2001. Landsc. Urban Plan. *100* (1–2), 117–128. https://doi.org/10.1016/j.landurbplan.2010.12.002.

Gain, A.K., Giupponi, C., Renaud, F.G., Vafeidis, A.T., 2020. Sustainability of complex social-ecological systems: methods, tools, and approaches. Reg. Environ. Change 20, 102. https://doi.org/10.1007/s10113-020-01692-9.

Gong, Y., Tan, R., 2021. Emergence of local collective action for land adjustment in land consolidation in China: An archetype analysis. Landsc. Urban Plan. 214, 104160 https://doi.org/10.1016/j.landurbplan.2021.104160.

Gunderson, L.H., Holling, C.S., 2002. Panarchy: understanding transformations in human and natural systems. Island Press,, Washington D.C.

Handoyo, I.T., Sensuse, D.I., 2017. Knowledge-based systems in decision support context: A literature review (November). 2017 4th Int. Conf. N. Media Stud. (CONMEDIA). https://doi.org/10.1109/conmedia.2017.8266035.

Hawkes, J., 2001. The fourth pillar of sustainability: Culture's essential role in public planning. Cultural Development Network and Part of University Press,, Melbourne. ⟨http://www.culturaldevelopment.net.au/community/Downloads/HawkesJon⟩.

Hein, L., van Koppen, K., de Groot, R.S., van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecol. Econ. *57* (2), 209–228. https://doi.org/10.1016/j.ecolecon.2005.04.005.

Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems 4 (5), 390–405. https://doi.org/10.1007/s10021-001-0101-5.

Kauffman, G.J., 2015. Governance, policy, and economics of intergovernmental river basin management. Water Resour. Manag. *29* (15), 5689–5712. https://doi.org/10.1007/s11269-015-1141-5.

Keenan, P.B., Jankowski, P., 2019. Spatial Decision Support Systems: Three decades on. Decis. Support Syst. *116*, 64–76. https://doi.org/10.1016/j.dss.2018.10.010.

MacKay, D., 2003. An Example Inference Task: Clustering. Information Theory, Inference and Learning Algorithms. Cambridge University Press,, pp. 284–292.

Malczewski, J., Jankowski, P., 2020. Emerging trends and research frontiers in spatial multicriteria analysis. Int. J. Geogr. Inf. Sci. *34* (7), 1257–1282. https://doi.org/10.1080/13658816.2020.1712403.

Malczewski, J., Rinner, C., 2015. Multicriteria decision analysis in geographic information science. Springer,. https://doi.org/10.1007/978-3-540-74757-4.

Marshall, T., 1997. Futures, foresight and forward looks: reflections on the use of prospective thinking for transport and planning strategies. Town Plan. Rev. 68 (1), 31–53. ⟨http://www.jstor.org/stable/40113439⟩.

Mingers, J., Rosenhead, J., 2004. Problem structuring methods in action. Eur. J. Oper. Res. 152 (3), 530–554. https://doi.org/10.1016/s0377-2217(03)00056-0.

Montuori, P., Aurino, S., Nardone, A., Cirillo, T., Triassi, M., 2015. Spatial distribution and partitioning of organophosphates pesticide in water and sediment from Sarno River and Estuary, Southern Italy. Environ. Sci. Pollut. Res. *22* (11), 8629–8642. https://doi.org/10.1007/s11356-014-4016-z.

Moss, T., 2004. The governance of land use in river basins: prospects for overcoming problems of institutional interplay with the EU Water Framework Directive. Land Use Policy *21* (1), 85–94. https://doi.org/10.1016/j.landusepol.2003.10.001.

Moss, T., 2012. Spatial fit, from panacea to practice: implementing the EU water framework directive. Ecol. Soc. *17* (3) https://doi.org/10.5751/es-04821-170302.

Najwer, A., Jankowski, P., Niesterowicz, J., Zwoliński, Z., 2022. Geodiversity assessment with global and local spatial multicriteria analysis. Int. J. Appl. Earth Obs. Geoinf. 107, 102665.

Neto, S., Camkin, J., Fenemor, A., Tan, P.-L., Baptista, J.M., Ribeiro, M., Schulze, R., Stuart-Hill, S., Spray, C., Elfithri, R., 2020. OECD Principles on Water Governance in practice: an assessment of existing frameworks in Europe, Asia-Pacific, Africa and South America. In *OECD Principles on Water Governance*. Routledge,, pp. 60–89. https://doi.org/10.4324/9780429448058-5.

Newig, J., Schulz, D., Jager, N.W., 2016. Disentangling puzzles of spatial scales and participation in environmental governance—the case of governance re-scaling through the European Water Framework Directive. Environ. Manag. *58* (6), 998–1014. https://doi.org/10.1007/s00267-016-0753-8.

Nucci, A., Angiolini, C., Manolaki, P., Vogiatzakis, I.N., 2022. An integrated approach to support a river ecological network: a case study from the Mediterranean. Land Use Policy *119*, 106217. https://doi.org/10.1016/j.landusepol.2022.106217.

OECD, 2015. The OECD principles on water governance. OECD,. ⟨https://www.oecd.org/governance/oecd-principles-on-water-governance.htm⟩.

Pelleg, D., Moore, A., 1999. Accelerating exact K-Means algorithms with geometric reasoning. Proceedings of the Fifth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining - KDD '99. ACM Press,, San Diego, California, United States, pp. 277–281. ⟨https://dl.acm.org/doi/10.1145/312129.312248⟩.

Pelorosso, R., 2020. Modeling and urban planning: a systematic review of performance-based approaches. Sustain. Cities Soc. *52* (January 2020), 101867 https://doi.org/10.1016/j.scs.2019.101867.

Quevauviller, P., Barceló, D., Beniston, M., Djordjevic, S., Harding, R.J., Iglesias, A., Ludwig, R., Navarra, A., Navarro Ortega, A., Mark, O., Roson, R., Sempere, D., Stoffel, M., van Lanen, H.A.J., Werner, M., 2012. Integration of research advances in modelling and monitoring in support of WFD river basin management planning in the context of climate change. Sci. Total Environ. *440* (1 December 2012), 167–177. https://doi.org/10.1016/j.scitotenv.2012.07.055.

Rega, C., Baldizzone, G., 2015. Public participation in Strategic Environmental Assessment: A practitioners' perspective. Environ. Impact Assess. Rev. 50, 105–115. https://doi.org/10.1016/j.eiar.2014.09.007.

Rocchi, L., Cortina, C., Paolotti, L., Boggia, A., 2020. Recreation vs conservation in Natura 2000 sites: a spatial multicriteria approach analysis. Land Use Policy *99*, 105094. https://doi.org/10.1016/j.landusepol.2020.105094.

Rodela, R., Bregt, A.K., Ligtenberg, A., Pérez-Soba, M., Verweij, P., 2017. The social side of spatial decision support systems: investigating knowledge integration and learning. Environ. Sci. Policy *76*, 177–184. https://doi.org/10.1016/j.envsci.2017.06.015.

Roszkowska, E., 2013. Rank ordering criteria weighting methods – a comparative overview. Optim. Stud. Èkon. *5* (*65*), 14–33. https://doi.org/10.15290/ose.2013.05.65.02.

Schoemaker, P., 1998. Scenario planning: a tool for strategic thinking. In: Dyson, R., OBrien, F. (Eds.), Strategic Development: Methods and Models. Wiley,, Chichester, pp. 185–208.

Simon, H.A. (1960). The new science of management decision (Harper, New York, Ed.; 1st Online). Harper. ⟨https://babel.hathitrust.org/cgi/pt?id=uc1.b3376401&view=1up&seq=7⟩.

Slaughter, R.A., 1996. The Knowledge base of Future Studies, Vol. 1- 3. Ddm Media,, Hawthorn, Victoria.

Soini, K., Birkeland, I., 2014. Exploring the scientific discourse on cultural sustainability. Geoforum *51*, 213–223. https://doi.org/10.1016/j.geoforum.2013.12.001.

Stewart, T.J., French, S., Rios, J., 2013. Integrating multicriteria decision analysis and scenario planning—review and extension. Omega *41* (4), 679–688. https://doi.org/10.1016/j.omega.2012.09.003.

Stoker, G., 2019. Embracing complexity: a framework for exploring governance resources. J. Chin. Gov. 4 (2), 91–107. https://doi.org/10.1080/23812346.2019.1587859.

Strang, V., 2007. Integrating the social and natural sciences in environmental research: a discussion paper. Environ. Dev. Sustain. *11* (1), 1–18. https://doi.org/10.1007/s10668-007-9095-2.

Sugumaran, R., &#38, Degroote, J., 2010. Spatial decision support systems: Principles and practices. CRC Press,. https://doi.org/10.1201/b10322.

Szilassi, P., Bata, T., Szabó, Sz, Czúcz, B., Molnár, Zs, Mezősi, G., 2017. The link between landscape pattern and vegetation naturalness on a regional scale. Ecol. Indic. *81*, 252–259. https://doi.org/10.1016/j.ecolind.2017.06.003.

Thompson, R.M., Bond, N., Poff, N.L., Byron, N., 2018. Towards a systems approach for river basin management-Lessons from Australia's largest river. River Res. Appl. *35* (5), 466–475. https://doi.org/10.1002/rra.3242.

Vilsmaier, U., Engbers, M., Luthardt, P., Maas-Deipenbrock, R.M., Wunderlich, S., Scholz, R.W., 2015. Case-based mutual learning sessions: knowledge integration and transfer in transdisciplinary processes. Sustain. Sci. *10* (4), 563–580. https://doi.org/10.1007/s11625-015-0335-3.

Walz, U., Stein, C., 2014. Indicators of hemeroby for the monitoring of landscapes in Germany. J. Nat. Conserv. *22* (3), 279–289. https://doi.org/10.1016/j.jnc.2014.01.007.
Wang, B., Wang, H., Zeng, X., Li, B., 2022. Towards a better understanding of social-ecological systems for basin governance: a case study from the Weihe River Basin, China. Sustainability *14* (9), 4922. https://doi.org/10.3390/su14094922.
Watson, N., 2004. Integrated river basin management: a case for collaboration. Int. J. River Basin Manag. *2* (4), 243–257. https://doi.org/10.1080/15715124.2004.9635235.
Wissen Hayek, U., Teich, M., Klein, T.M., Grêt-Regamey, A., 2016. Bringing ecosystem services indicators into spatial planning practice: lessons from collaborative development of a web-based visualization platform. Ecol. Indic. *61*, 90–99. https://doi.org/10.1016/j.ecolind.2015.03.035.
Yoon, K.P., Hwang, C.-L., 1995. Topsis. Multiple attribute decision making. SAGE Publications. https://doi.org/10.4135/9781412985161.
Zilio, M.I., Seitz, C., Scordo, F., Gil, V., Zapperi, P., Costilla, P., Huamantinco Cisneros, M.A., Perillo, G.M.E., Piccolo, M.C., 2018. Is collaborative management always possible? The case of Sauce Grande River Basin, Argentina. Int. J. River Basin Manag. *17* (2), 251–261. https://doi.org/10.1080/15715124.2018.1546727.