The use of Geographic Information Systems Combined with Multicriteria Methods in Organizations: a Systematic Literature Review

Dalvana Lopes Ribeiro, and André Andrade Longaray

***Abstract*—This article describes the investigation of scientific production on the combination of geographic information systems (GIS) and multicriteria methods (MCDM/A). For this, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol was followed. As a result, from 8.001 initial records, a portfolio of 97 articles aligned with the research theme was selected, using the Web of Science and Scopus databases. The analysis was conducted with the support of the CiteSpace, VOSviewer and Bibliometrix R package software, allowing us to understand the trends and development of the areas over time. The results point to significant challenges, such as the need for more intuitive interfaces, training of management teams, greater flexibility of systems and difficulties in operationalizing decision-making. This study contributes to the understanding of the evolution of the field and highlights gaps that can guide future research.**

Link to graphical and video abstracts, and to code: https://latamt.ieeer9.org/index.php/transactions/article/view/9784

***Index Terms*—Geographic Information Systems (GIS), Multicriteria Decision-Making (MCDM/A), CiteSpace , VOSviewer,Decision Support Systems.**

I. Introduction

ORGANIZATIONS today face significant challenges arising from rapid social, economic, and technological changes. In this scenario, adaptability has become essential, and strategic agility is critical to navigating an ever-evolving society. To remain competitive, organizations must often reinvent themselves by acquiring new resources and adopting innovative approaches [1], [2]. A central element in this process is the manager's decision-making capacity.

Decision-making, however, occurs in increasingly dynamic contexts, with high volumes of information and multiple influencing factors [3], [4]. Often, decisions must be made quickly, with limited time for comprehensive analysis of alternatives and consequences [5]. Managers are thus faced with complex, multidimensional choices.

To address this complexity, efficient tools and decision-support methods have become indispensable [6]–[8]. Among the most widely adopted are multicriteria decision-making/analysis (MCDM/A) and geographic information systems (GIS). These tools provide structured frameworks for analyzing options across various factors, increasing the confidence and clarity in decision-making [9]–[11].

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A. Multicriteria Analysis

MCDM/A encompasses a range of methodologies designed to help decision-makers evaluate multiple, often conflicting, criteria. In strategic and political contexts, where choices are complex and numerous, MCDM/A reduces cognitive burden and improves analytical clarity [12], [13].

The decision support process in MCDM/A typically unfolds in three stages: structuring, evaluation, and recommendation. In the structuring phase, the problem, stakeholders, and relevant criteria are identified [14]. The evaluation phase involves applying a model to analyze the consequences of alternatives—focusing on choice, classification, or ranking [15]–[17]. The recommendation phase suggests improvements based on unmet criteria.

MCDM/A methods can be classified into continuous (MODM) and discrete (MADM) models [18], with prominent examples including: AHP (Analytic Hierarchy Process) [19], MACBETH [20], TOPSIS [21], and ELECTRE [22].

These methods have proven flexible and are often integrated with other systems to enhance decision quality [23].

B. Geographic Information Systems

GIS originated in the 1960s and has evolved alongside computer science to support a variety of applications in academia, government, and private sectors [24]–[26]. The key distinction of a GIS lies in its ability to store both attribute data and spatial geometries [27].

The main components of a Geographic Information System (GIS) comprise hardware, software, human resources, and spatial data, which can be represented in vector form (such as points, lines, and polygons) or raster form (such as grids or pixels) [28]. Mathematical modeling in GIS often involves simulation or optimization, with applications ranging from basic visualization to probability estimation using techniques like kernel density.

By combining multiple layers of data and producing spatially explicit visualizations, GIS supports complex decision scenarios—particularly when integrated with decision models like MCDM/A.

C. Integration of GIS-MCDM/A Tools within Decision Support Systems

Decision Support Systems (DSS) are frameworks that assist complex decision-making by integrating data, analytical models, and user interfaces [29]. In spatial decision problems, combining GIS and MCDM/A offers a powerful synergy.

GIS provides the spatial infrastructure to manage and analyze georeferenced data, while MCDM/A supplies structured models to evaluate alternatives based on diverse criteria [30], [31]. This integration enhances the capacity to handle decisions involving multiple conflicting objectives—common in areas like environmental planning, corporate strategy, and public administration [32].

The theoretical foundations of DSS involve three components: data management, model management, and dialog management [33]. GIS-MCDM/A applications naturally align with these by managing spatial databases, applying decision models, and offering user interfaces for interaction and scenario exploration [34].

However, many studies use these combined tools without explicitly referring to the DSS framework. This paper aims to address this gap through a systematic literature review.

This article examines how the use of Geographic Information Systems (GIS) combined with Multicriteria Decision Making/Analysis (MCDM/A) has been addressed in organizational contexts. To guide this examination, a systematic literature review was conducted. The structure of the article is as follows: the next section presents the research methodology; the following section discusses the main findings; and the final section offers concluding remarks and outlines key implications for research and practice.

II. METHODOLOGY

This study adopts an approach based on the classification proposed by [35], with a focus on the characteristics of qualitative-quantitative research. In mixed methods research, the literature approach varies between qualitative and quantitative methods depending on the strategy employed [36]. The qualitative component derives from secondary data collected from scientific databases, while the quantitative aspect is captured through bibliometric analysis.

The research follows the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [37], which includes a 27-item checklist and a four-step flowchart. To this end, systematic searches were conducted in two main databases: Web of Science and Scopus, guided by the research question formulated: How can GIS, combined with multi-criteria decision-making methods, enhance corporate management? To explore this, the following objectives were defined: (i) to map and characterize the scientific production on GIS and multi-criteria decision-making methods in organizational sectors through bibliometric analysis; (ii) to identify the main multi-criteria techniques used with GIS in corporate, public, and environmental contexts; (iii) to evaluate the contributions and limitations in corporate management in these studies; The search strategy followed the PRISMA guidelines, using three sets of terms combined with Boolean operators (AND, OR) and truncation symbols (*), ensuring comprehensive retrieval of relevant studies. The terms were grouped into three thematic domains: (i) geospatial data and systems, (ii) multi-criteria decision support methods, and (iii) organizational contexts. The Boolean query was:

("Geographic Data" OR "GIS Science*" OR "Geographic Information System*") AND ("Multi-Criteria Decision Analysis*" OR "Decision Making" OR "Decision Support System") AND ("Organization" OR "Management" OR "Corporation*").

This search sequence was adapted to the specific syntax of each database. A visual representation of the strategy is shown in Fig. 1.

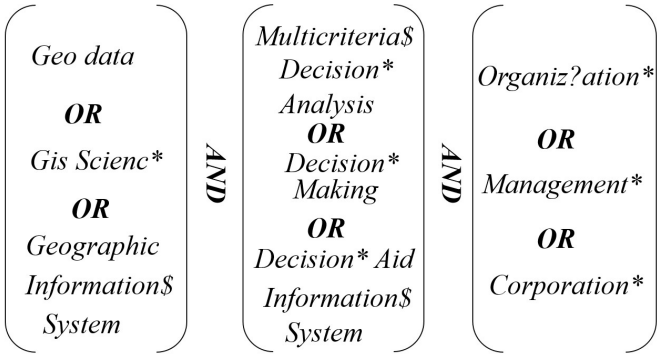

Fig. 1. Conceptual representation of the search strategy, illustrating the combination of geographic information terms, multicriteria decision-making terms, and organizational/management terms using Boolean operators.

In addition to the Boolean search, a rigorous inclusion/exclusion process was followed. Articles addressing the integration of Geographic Information Systems (GIS) and multi-criteria decision-making methods applied to organizational management contexts were included in the analysis. Studies that did not meet these criteria were excluded. The screening process was performed by two independent reviewers, with discrepancies resolved through consensus. A detailed PRISMA flow diagram, describing the screening and selection steps, is provided in Fig.3.

The search strategy focused on three main axes: (i) spatial analysis, (ii) multi-criteria decision-making, and (iii) organizational management. The combination of Boolean operators (OR, AND), truncation, and special characters (*, ? and $) ensured a broad and precise search for relevant studies [38].

To address concerns regarding the scope of the research question, the study operationalizes it through the three aforementioned sub-objectives, each aligned with bibliometric methods and analytical clarity. Furthermore, the term corporate management is interpreted in an inclusive manner, encompassing not only private sector applications but also public and environmental decision-making contexts. This broader perspective acknowledges that many public sector and environmental initiatives involve organizational structures, strategic planning, and decision-making processes comparable

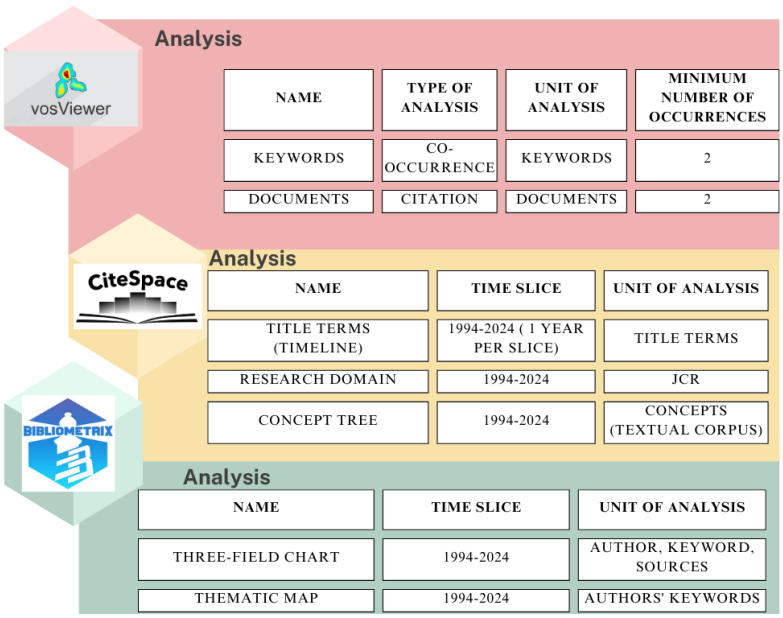

Fig. 2. Types of bibliometric and scientometric analyses performed using VOSviewer, CiteSpace, and Bibliometrix, along with their respective parameters.

to those in corporate environments. Thus, the findings provide insights relevant to a wide range of institutional and managerial settings.

A. Analysis Tools

Bibliometric software plays an important role in building structures, schemes, and networks that help identify patterns and trends in different aspects of science [39].This study employed three specialized bibliometric tools to analyze research trends and knowledge structures. CiteSpace [40] excels in temporal analysis and burst detection, identifying emerging trends through network visualization and similarity measures (Salton cosine, Jaccard index) [41]. VOSviewer [42] provides superior network visualization capabilities, using association strength to optimize cluster mapping and reveal collaboration patterns [43]. Bibliometrix [44] offers comprehensive statistical analysis with its R-based framework and user-friendly Biblioshiny interface, supporting multiple databases for robust bibliometric indicators. Together, these tools enable a multi-dimensional analysis of research dynamics, with the complete methodology illustrated in Fig. 2.

Compared with traditional bibliometric methods, visual analysis of scientific knowledge graphs is more intuitive and readable [45].

III. Results and Discussion

The diagram based on the PRISMA protocol for this review is shown in Fig. 3.

According to Fig. 3, 8.001 records were identified that constituted the initial Bibliographic Portfolio (BP). After this identification, a screening was carried out considering the potential connection with the theme through the analysis of titles and abstracts. The following eligibility criteria were

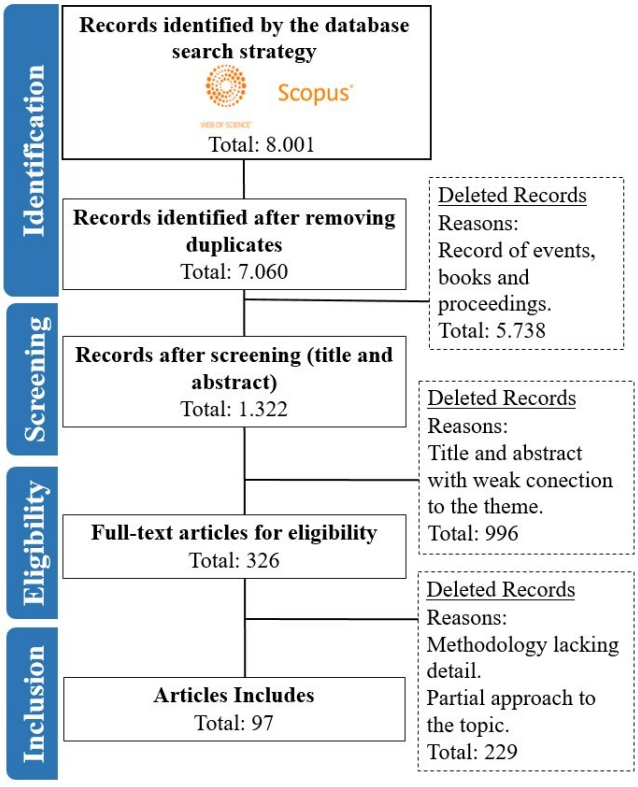

Fig. 3. Bibliographic portfolio selection process. Adapted from [46].

taken into account: a) publications in peer-reviewed journals, b) clear and detailed methodology, c) approaches focused on management, d) applications of GIS techniques and multicriteria methods, and e) written in English. Articles that did not meet these criteria were excluded, resulting in a final BP composed of 97 articles. Once the final BP was

organized, bibliographic analyses were conducted.

A. Production Analysis

To assess scientific production, an analysis of the variation in publications per year was conducted. For this purpose, the distribution of the number of articles in the portfolio, comprising 97 documents from 1994 to 2024, was examined (Fig. 4).

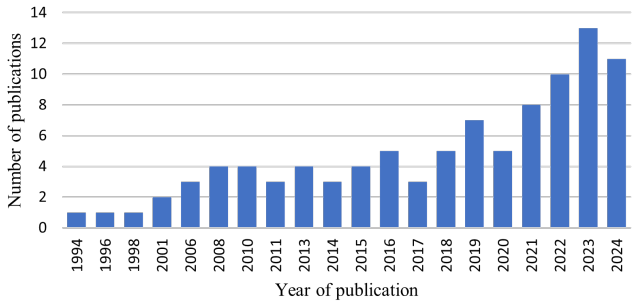

Fig. 4. Annual evolution of the number of publications between 1994 and 2024, showing a progressive increase in research output over the period.

Fig.4 shows the number of publications per year between 1994 and 2024, highlighting a gradual increase until 2006, followed by a more consistent rise from 2007 onwards. After 2018, a marked growth is observed, with a peak in 2023 (13 publications). The overall trend indicates a significant increase in interest and relevance of the topic over time, especially in recent years, suggesting greater academic attention to the subject in the most recent period.

1) Analysis of Collaboration between Countries and Institutions: The objective of this analysis was to examine the contribution of countries and institutions to the development of the theme. For this purpose, the country of origin of the first author of each article was considered. Fig.5 presents the spatial distribution of countries and their respective number of publications, while TableI highlights the main institutions and their contributions.

According to Fig.5, China and Iran were the countries that contributed the most to the topic, totaling 24 articles and accounting for 24.74% of the portfolio. They are followed by Turkey (10.30%), the United States (8.24%), and Greece (6.18%). Table I presents the 15 institutions that contributed the most. According to Tab.I, the North China University

TABLE I
PUBLICATIONS BY INSTITUTIONS

Institution	Nº of publications	Representation (%)
North China Electric Power University	7	7.22
Bureau of Geological and Mining Research (BRGM)	5	5.15
Democritus University of Thrace	5	5.15
Chinese Academy of Sciences	4	4.12
Gaziantep University	4	4.12
Azad Islamic University	4	4.12
Yunnan University	4	4.12
Adana Alparslan Turkestan University of Science and Technology	3	3.09
Western University (University of Western Ontario)	3	3.09

of Electric Power leads contributions to the topic, with 7 publications (7.22

Other institutions, such as the Chinese Academy of Sciences, Gaziantep University, Islamic Azad University, and Yunnan University (4 publications each, 4.12

Tab.I also highlights the role of emerging institutions, such as Ahvaz Jundishapur University of Medical Sciences (AJUMS), which applies GIS and MCDM/A in healthcare, and the University System of Georgia, which coordinates regional initiatives.

The broad geographic distribution and interdisciplinary focus reflect the global nature of GIS and MCDM/A. The leadership of Chinese institutions underscores China's growing prominence in international research, while the diversity of contributors demonstrates the applicability of these approaches across various contexts, including urban planning, environmental management, and healthcare. This distribution also suggests opportunities for global collaboration and the strengthening of international research networks.

2) Author Analysis: Authors are the foundation of scientific research [47]. By identifying their publications and collaborative networks, it is possible to gain insight into how specific topics are approached within the scientific community. TableII presents the three most influential researchers—ranked by the number of citations—in the field of geographic information systems and multicriteria methods between 1994 and 2024.

TABLE II
PUBLICATIONS BY AUTHORS

Author	Nº of publications	Representation (%)	Citation
Malczewski, J	2	2.06	1615
Chen, Y	1	1.03	472
khan, Y	1	1.03	472

Based on Tab. II, Malczewski, J [34] is the author with the highest number of citations (1615), followed by Chen, J [48], and Khan, S (472) [49]. Regarding the papers of these authors, Fig. 6 displays the most cited papers.

In Fig. 6, the author Malczewski is highlighted with the article "GIS-based multi-criteria decision analysis: a survey of the literature" published in 2006 in the International Journal of Geographic Information Science. The coloring indicates that he was one of the first to study the subject and summarize the combination of areas and their applications. In 2010, Chen et al. [48] (Spatial Sensitivity Analysis of Multi-Criteria Weights in GIS-Based Land Suitability Evaluation) addressed the integration of Geographic Information Systems (GIS) with Multi-Criteria Decision Analysis (MCDM/A) methods, emphasizing the importance of sensitivity analysis (SA) to assess the influence of variations in the weights of the criteria on the final results. In 2013, the work of Aydi et al. [50] (Minimization of environmental risk of landfill site using fuzzy logic, analytical hierarchy process, and weighted linear combination methodology in a geographic information system environment) presented an integrated methodology for selecting suitable locations for landfills, aiming to minimize environmental risks. The study, focused on the Ariana region, Tunisia, combines fuzzy logic, the Analytical Hierarchy Process (AHP), and the Weighted Linear Combination (WLC) within a Geographic Information System (GIS). Since 2020,

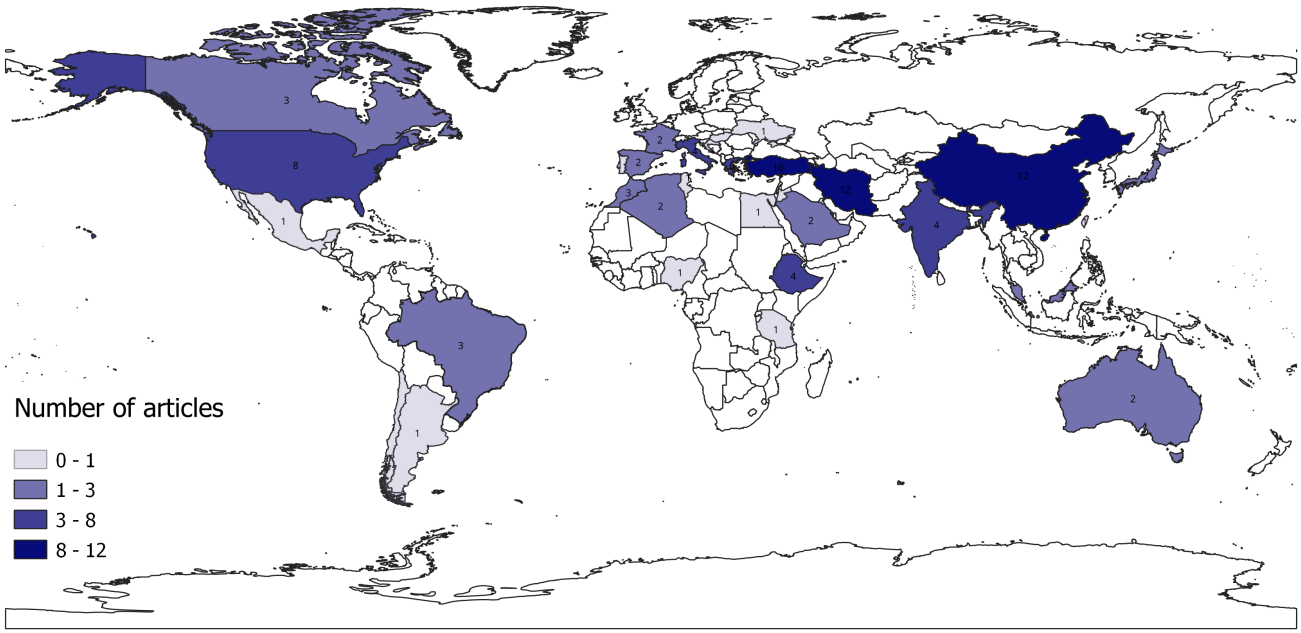

Fig. 5. Geographic distribution of publications by country, classified according to the number of articles.

with the COVID-19 pandemic, there has been a volume of articles focused on the health area. For example, Alemdar et al. [51](Accessibility of Vaccination Centers in COVID-19 Outbreak Control) addressed a methodology for selecting ideal locations for vaccination centers against COVID-19. The study considered criteria such as population density and accessibility, weighted in the decision-making process. Applied in Bağcılar, Istanbul, it identified priority areas for new centers, optimizing population coverage and accessibility. In recent years, many studies have addressed the combination of GIS and MCDM/A in the energy sector, as shown by Wang et al., who proposed a model to evaluate investments in power stations that combine wind, PV, and shared storage.

3) Journal Analysis: Regarding the journals, Table III presents the most representative ones. The journal with the highest representation in the portfolio is Waste Management & Research, which includes five publications.

Table III shows that all selected journals have impact factors of 3.0 or higher, indicating their standing in the field. The results demonstrate significant interdisciplinarity, with research spanning agriculture, urban planning, sustainability, and geography.

To analyze author-journal relationships, we conducted a bibliometric analysis using Bibliometrix. Fig. 7 presents these relationships through a three-field plot, illustrating connections between authors, keywords, and sources.

TABLE III
PUBLICATIONS BY JOURNAL

Journal	Nº of publications	Representation (%)	Impact Factor
Waste Manage. & Res.	5	5.15	3.70
Int. J. Geogr. Inf. Sci.	3	3.09	4.30
Water	3	3.09	3.00
Environ. Sci. Pollut. Res.	3	3.09	5.80
J. Environ. Manage.	3	3.09	8.00
Eng. Geology	2	2.06	6.90
J. Cleaner Prod.	2	2.06	9.80
Resour. Conserv. & Recycl.	2	2.06	11.20
Renew. Energy	2	2.06	9.00
J. Energy Storage	2	2.06	8.90

In the left column, authors such as Malczewski J and Geneletti D emerge as influential figures, reflecting the centrality of their contributions to diverse topics, such as GIS (Geographic Information Systems) and management. The central column, which displays the keywords, highlights the focus on highly relevant contemporary topics, such as renewable energy, decision analysis, and sustainability, indicating clear trends in scientific advancement for solving global challenges. In the right column, high-impact sources,

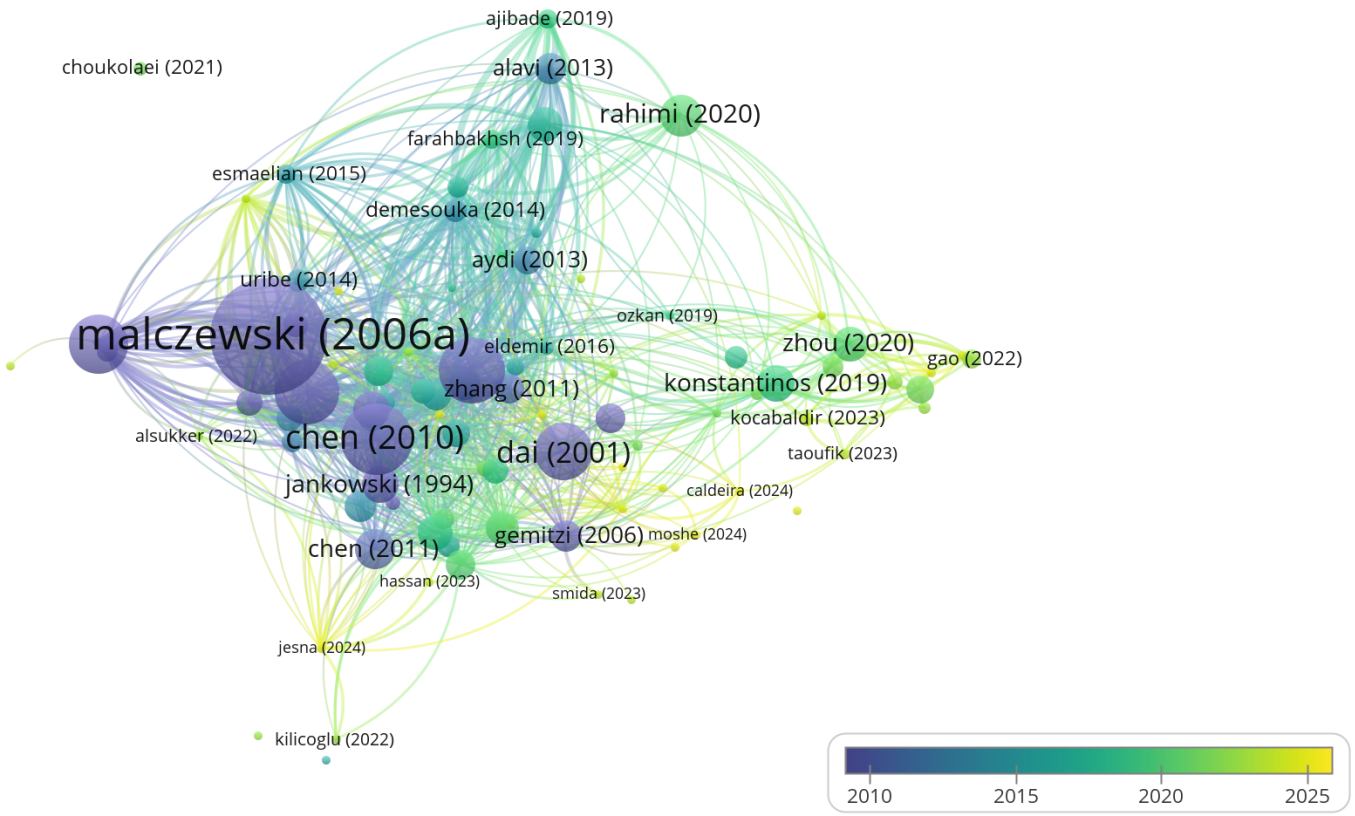

Fig. 6. Network map of the most cited documents in the field. Larger nodes represent publications with higher citation counts, while the connections illustrate co-citation relationships. The color gradient reflects the average year of citation, ranging from earlier (blue) to more recent (yellow) studies.

such as Waste Management & Research and Journal of Cleaner Production, emerge as the main dissemination vehicles, reinforcing their position as prominent platforms in the environmental field. The dense connections between the columns demonstrate that influential authors have contributed to interdisciplinary themes, disseminating relevant research in renowned journals. This analysis highlights not only the predominant thematic areas but also the importance of scientific collaboration and interdisciplinarity as essential drivers for addressing complex environmental problems, reaffirming the role of highly relevant journals in the dissemination of knowledge.

In addition to the quantitative bibliometric outputs, this study acknowledges the importance of critically assessing the methodological rigor of the most cited and representative works. While techniques such as the Analytic Hierarchy Process (AHP) are frequently employed, several studies fail to report the use of sensitivity or uncertainty analyses, which limits the transparency and robustness of their findings. However, a subset of high-impact contributions has addressed these issues in greater depth. For instance, [48] proposed a spatial framework for weight sensitivity analysis in GIS-based land suitability evaluation, emphasizing how weight variations influence final decisions. Similarly, [52], developed GIS-based methodologies that integrate spatially explicit sensitivity and uncertainty analyses for landslide susceptibility mapping and broader multi-criteria decision contexts. These studies underscore the importance of incorporating robustness checks to assess the stability of results under varying assumptions. Nonetheless, the majority of the literature reviewed tends to rely heavily on AHP without performing such validation procedures.

Moreover, despite the increasing availability and sophistication of geospatial data, relatively few studies engage in a detailed discussion of the computational challenges involved in processing raster data within GIS-MCDM/A frameworks. These gaps point to important directions for future research: strengthening methodological rigor through validation techniques such as sensitivity and uncertainty analyses, and addressing technical barriers to the integration of raster-based information in decision models. By reflecting on these limitations, this study encourages a more critical and comprehensive application of GIS-based multicriteria methods, especially in complex domains—such as corporate and strategic planning—where reliable decision support is essential.

4) Research Domains: In addition to considering the representativeness of journals and their relationship with authors, it is important to analyze how these interactions are established in the different areas of knowledge. To this

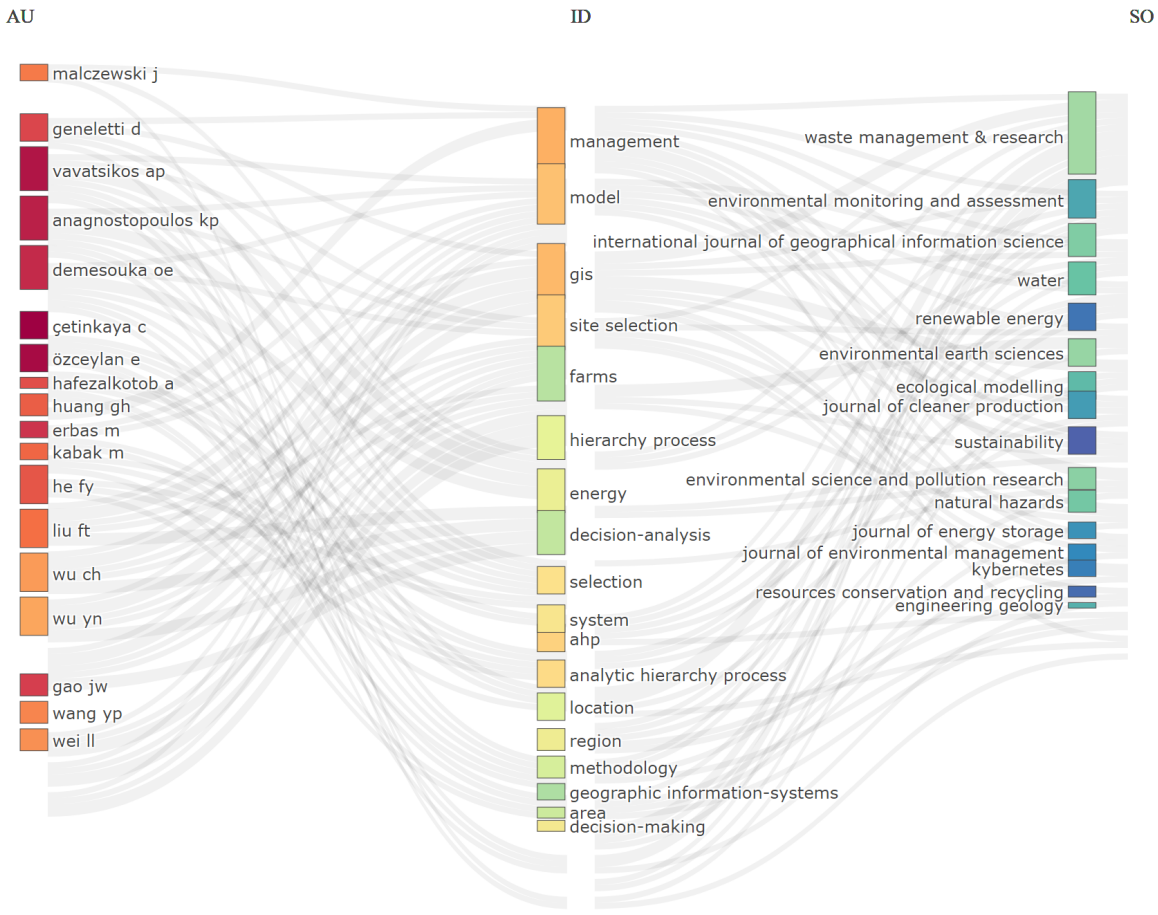

Fig. 7. Visualization of the relationships among authors, keywords, and journals through a three-field plot. The diagram highlights how leading authors are associated with specific research themes and publication outlets.

end, the "JCR Journal Maps" function of CiteSpace was used to create a double map overlay that covers the main areas of knowledge. This technique enables a comprehensive analysis of citation dynamics, identifying both the specific origin of citations and their destination, revealing areas of expertise and patterns of knowledge flow [53]. Fig. 8 presents a visual panorama in which citing journals appear on the left and cited journals on the right, connected by trajectories that reflect the exchange of information. The density and thickness of these trajectories are directly proportional to the frequency and intensity of knowledge flow between journals, indicating the relevance and mutual influence between the different research domains [54]. This approach allows not only for the identification of patterns of collaboration and impact but also for the mapping of the movement of knowledge between disciplines, promoting a more integrated and strategic vision of scientific production. In the analysis presented in Fig. 8, four main citation flows were identified that connect different research domains, revealing significant patterns of interdependence between the areas. Studies published in journals in the fields of “ecology, land, and marine” frequently cite works from the domains of “land, geology, and geophysics,” “systems, computing, and computers,” and “economics, economics, and politics.”. Similarly, research in journals of “mathematics, systems, and mathematics” shows a strong tendency to cite studies from the domains of “systems, computing, and computers” and “economics, economics, and politics”. On the other hand, publications in the area of “economics, economics, politics” demonstrate a predominant self-citation pattern while also drawing on works in “systems, computing, computer” and “earth, geology, and geophysics.”. This mapping reveals that the citing literature is predominantly concentrated in three major areas: “ecology, land and marine,” “mathematics, systems, and mathematical,” and “economics, economic, and political,” highlighting the interdisciplinary interaction and the importance of these areas as centers of highly referenced scientific production. The analysis of the connections between domains reflects the complexity and convergence of approaches at the frontiers of scientific knowledge.

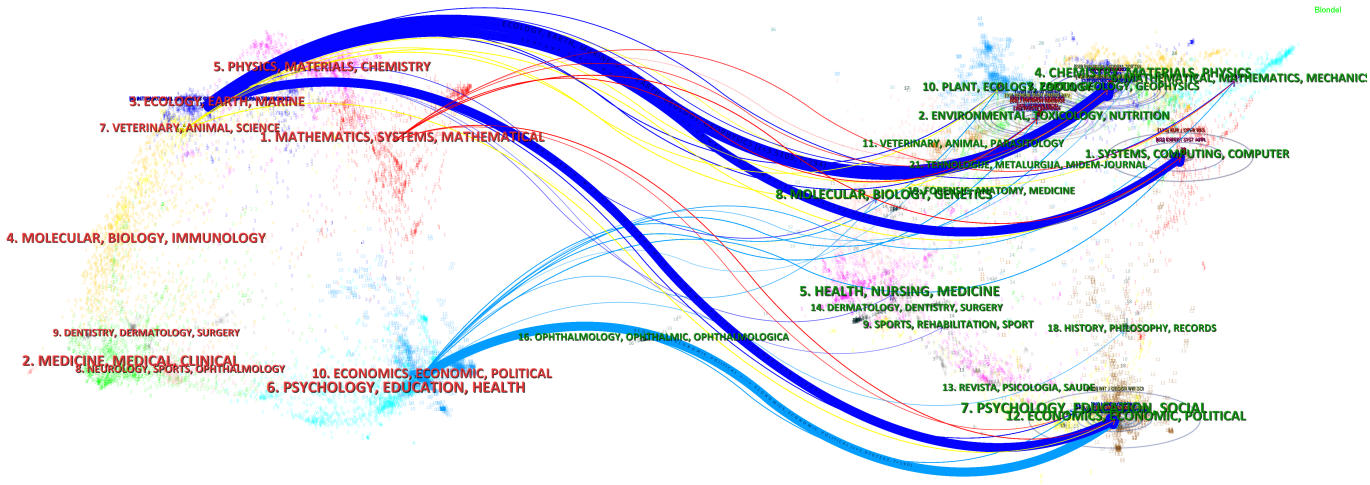

Fig. 8. Double map overlay of research domains, showing citation relationships between citing and cited disciplines.

B. Content Analysis

Keywords play a very important role in summarizing the main topics discussed in articles. Their co-occurrence can effectively reflect research hotspots in different areas of knowledge, providing support for scientific research [55]. Fig. 9 shows the distribution of keywords and their connections.

Fig. 9 presents a network visualization illustrating the relationships between keywords used in the research portfolio, with a central emphasis on Geographic Information Systems (GIS). The term 'GIS' stands out as the most prominent node, reflecting its critical role and interconnectedness across various research domains. The network is organized into color-coded thematic clusters, each representing distinct areas of application and study. The green cluster focuses on environmental and risk-related themes, including terms such as 'climate change', 'vulnerability', and 'land use'. This cluster underscores a longstanding research interest in environmental risk management and climate change adaptation, key areas where GIS tools are increasingly applied. The red cluster highlights management, decision-making, and methodologies like multi-criteria analysis (MCA), reinforcing the foundational role of decision-support systems in GIS research. The blue cluster, associated with energy applications, includes terms like 'renewable energy', 'wind farms', and 'site selection', reflecting a growing shift in the field toward integrating GIS in energy planning and sustainable development. The purple cluster, which is linked to conservation and ecological concerns, includes terms like 'biodiversity' and 'landscapes', signaling a broader focus on the intersection of GIS and environmental conservation. Finally, the yellow cluster groups decision-support methodologies such as 'ranked weighting' and 'multi-criteria evaluation', highlighting the continued reliance on advanced analytical tools for site assessment and decision-making.

A closer examination of the connections between these clusters reveals not only the diversity of GIS applications but also its evolution over time. Initially, GIS research was predominantly centered on management and risk analysis (as shown in the green and red clusters), with methodologies like multi-criteria analysis being heavily utilized for evaluating environmental issues. However, over time, there has been a marked shift toward energy sustainability and ecological conservation, as evidenced by the increasing prominence of the blue and purple clusters. This transition mirrors broader societal and scientific concerns, as the field adapts to global challenges such as the climate crisis and the growing need for clean energy solutions.

Moreover, the integration of methodologies such as AHP (Analytic Hierarchy Process), fuzzy logic, and MCDM/A (Multi-Criteria Decision Making) demonstrates how GIS is increasingly used in complex decision-making contexts, ranging from climate risk analysis to energy planning and environmental management. This visualization not only reinforces the central role of GIS in multiple academic and applied fields but also highlights the field's dynamic evolution, with a clear shift toward more interdisciplinary approaches, particularly those focused on sustainability and environmental stewardship.

1) Analysis of Terms from Article Titles: Title search is an approach that can be used to identify trends, map central themes, and track the evolution of research topics. Titles condense the main concepts of articles, reducing noise and providing an accurate representation of the content [56]. This analysis is particularly useful for detecting emerging topics and exploring connections between knowledge areas [40]. To investigate the origins and evolution of these terms, the clustering and timeline visualization function of CiteSpace was used.

By considering the time in which these words emerged, a concise picture of the production of scientific knowledge in terms of patterns, relationships, and intellectual organization of the topics covered is obtained. This allows us to observe trends that can help us understand the structures of a knowledge domain [45]. This visualization model highlights when certain terms emerge, their relevance over time, and how they connect to other concepts, providing a clear view of the dynamics of the development of ideas and research topics. The main

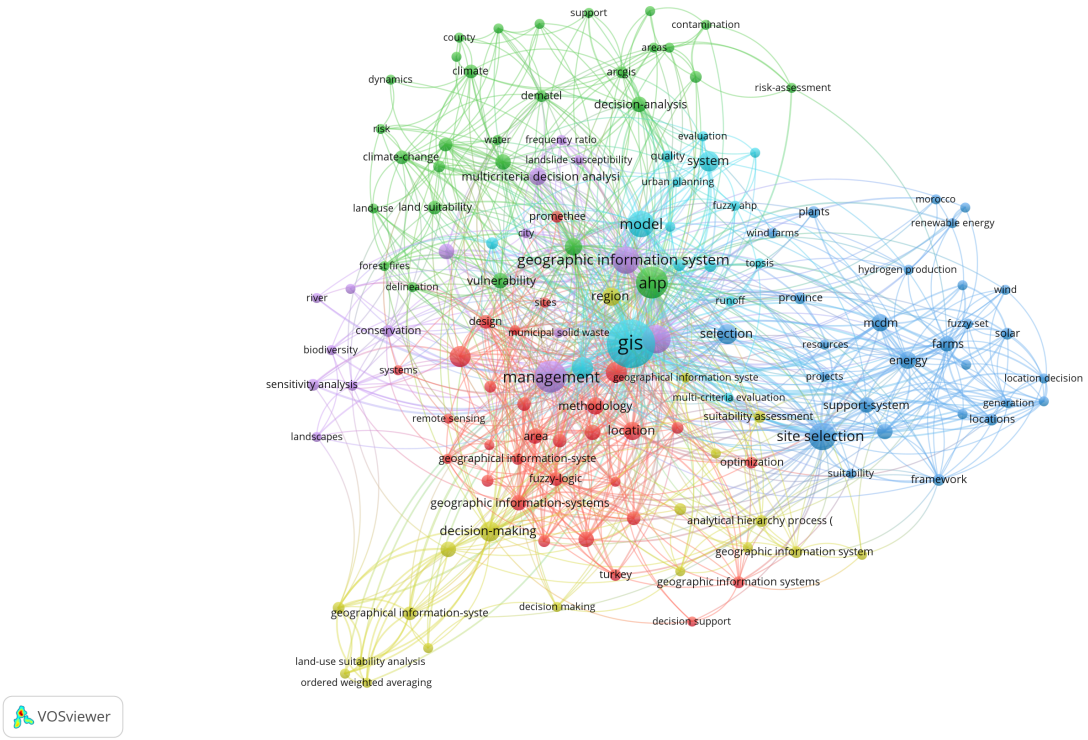

Fig. 9. Co-occurrence network of keywords visualized with VOSviewer. The size of each node reflects the frequency of keyword occurrence, while the links indicate co-occurrence relationships. Different colors denote clusters of related research themes.

advantage of Timeline View is its ability to integrate temporal and structural aspects, allowing the identification of emerging topics, peaks of interest, and areas of convergence over specific periods. Through this feature, it is possible to track the evolution of central ideas and identify the most influential works in each period, establishing historical and contextual connections between them [57].

To determine clusters, CiteSpace uses three text mining algorithms available in CiteSpace: latent semantic indexing (LSI), logarithmic likelihood ratio (LLR), and mutual information (MI) [53]. In addition to the visual aspect, the software presents two important factors for understanding networks, namely modularity (Q) and silhouette. Modularity refers to the connections between nodes, that is, to what extent a network can be divided into independent modules [58]. The modularity score ranges from 0 to 1, with low modularity suggesting a network that cannot be reduced to clusters with clear boundaries, while high modularity consists of a well-structured network [59]. Silhouette measures the homogeneity of networks [53] and ranges from -1 to 1, with the value closest to 1 indicating that the cluster is more homogeneous and, therefore, more isolated. This technique organizes the data into a structured timeline, where nodes represent terms extracted from the titles and are connected by edges that reflect co-citations or thematic relationships [40]. With a modularity of 0.6158 and an average silhouette value of 0.864, Fig. 10 shows a network with good clustering capacity and homogeneity.

The CiteSpace timeline analysis reveals the evolutionary trajectory of GIS and MCDM/A integration research through a chronological mapping of research themes. Diamond-shaped nodes represent key terms, with size indicating impact and color gradient (purple to red) showing temporal progression from early to recent studies.

The visualization in Fig. 10 illustrates the evolution of key research themes in GIS and decision-making over time, with a clear transition in focus from early methodological applications to more contemporary concerns with sustainability and environmental risk. In the early 2000s, research predominantly centered around multi-criteria decision-making (MCDM) methods, such as Analytic Hierarchy Process (AHP) and fuzzy logic, applied to problems like emergency service station location and municipal solid waste management. From 2006 onwards, the focus shifted towards more participatory processes and flood vulnerability analysis, reflecting an increasing interest in risk assessment and stakeholder involvement. By the 2010s, GIS integration with decision models, such as the fuzzy AHP, became prominent, alongside research into renewable energy planning and site selection. The most recent trends from 2016 onward highlight a strong emphasis on ecological risk assessment and climate change, signaling a growing priority in addressing global sustainability challenges. This evolution reflects the broader shift in GIS research from technical decision support systems to more interdisciplinary approaches, integrating environmental and energy concerns, and adapting to the pressing issues of climate change and sustainable

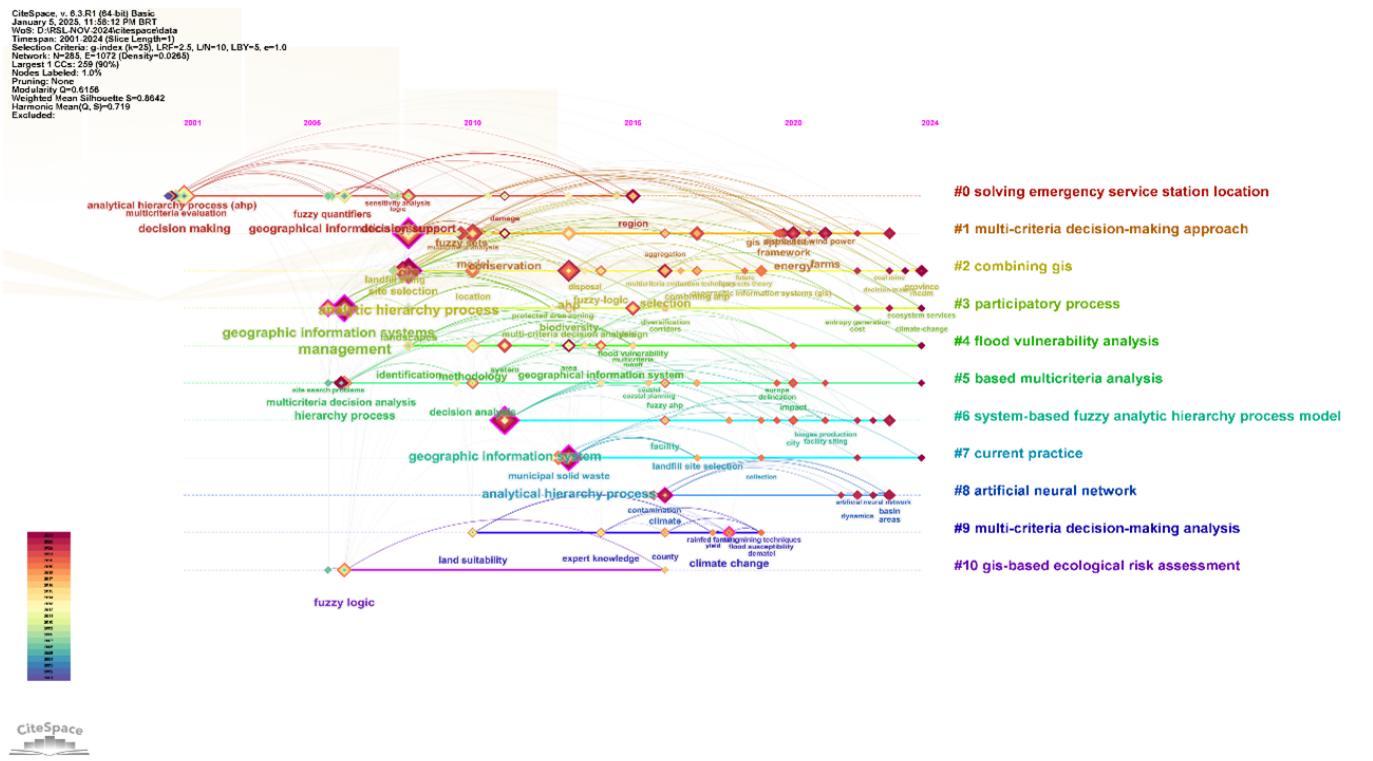

Fig. 10. Timeline visualization of title terms produced with CiteSpace. The figure illustrates the evolution of research themes over time, where each color corresponds to a distinct cluster, and the connecting lines represent the development and persistence of keywords across periods.

development.

This visualization approach effectively captures knowledge diffusion across application domains, providing valuable insights for identifying research gaps and anticipating future directions in this interdisciplinary field. The temporal mapping of thematic clusters highlights the dynamic interconnections between different research areas while demonstrating clear paradigm shifts in research focus.

2) Summary of Content and Overview: As seen in the previous section, the studies included in the portfolio present numerous distinct approaches to GIS-MCDM/A combinations. Although the variety of this compilation shows the great capacity for integration of these areas, it is possible to identify the persistence of some components. To illustrate the general overview of the portfolio content and based on the classification proposed by Malczewski (2006), who made important contributions in this area, some components are distributed into three main aspects: GIS, multicriteria, and the type of problem addressed. Fig. 11 shows the arrangement of these elements.

Fig. 11 shows the main common aspects in the articles and the classification of their components. The numbers in parentheses refer to the mentions in the portfolio. Regarding GIS, concerning the type of data, three components were used: raster, vector, and the use of both. A raster image consists of colored or black-and-white points called pixels (pixels—image elements), and a vector image is created by defining the X and Y coordinates of a point in a coordinate system [60]. Raster data was used in 75 papers, vector data in 4, and the combination of both in 18. With regard to the multicriteria part, the context of spatial multicriteria problems is a set of factors (or characteristics) of an individual agent or group of agents that have the potential to change preferences regarding decision alternatives [34]. In this sense, the decision-making process carried out by a group was considered in 89 papers, which corresponds to 91.75% of the portfolio. The individual decision appeared in 3 papers, and 5 did not specify the form of decision. As for the methods used, around 17 different methods were used. AHP was the most used. However, much of its application was combined with other methods, which was found in 36 papers, around 37.11% of the portfolio. Generally used to calculate the weights of criteria, such as Ramya & Devadas (2019), who used AHP to calculate the weights of the criteria considered and the TOPSIS method to select the most suitable locations for industrial development in India. And [61], in which AHP was also implemented in the weighting of criteria and the PROMETHEE and VIKOR methods were used to classify the alternatives for installing electric vehicle charging stations. The participation of fuzzy logic, present in four variations of multicriteria methods, is also noteworthy. What is clear is that this implementation arose with the objective of assisting in the issue of uncertainty in multicriteria methods ([52], [62], [63]). In particular, the AHP pairwise comparison is the most widely used technique for weighting criteria in MCDM/A processes. However, since the pairwise comparison of criteria is based on expert opinions, it is open to subjectivity when making comparison judgments [52]. In this sense,

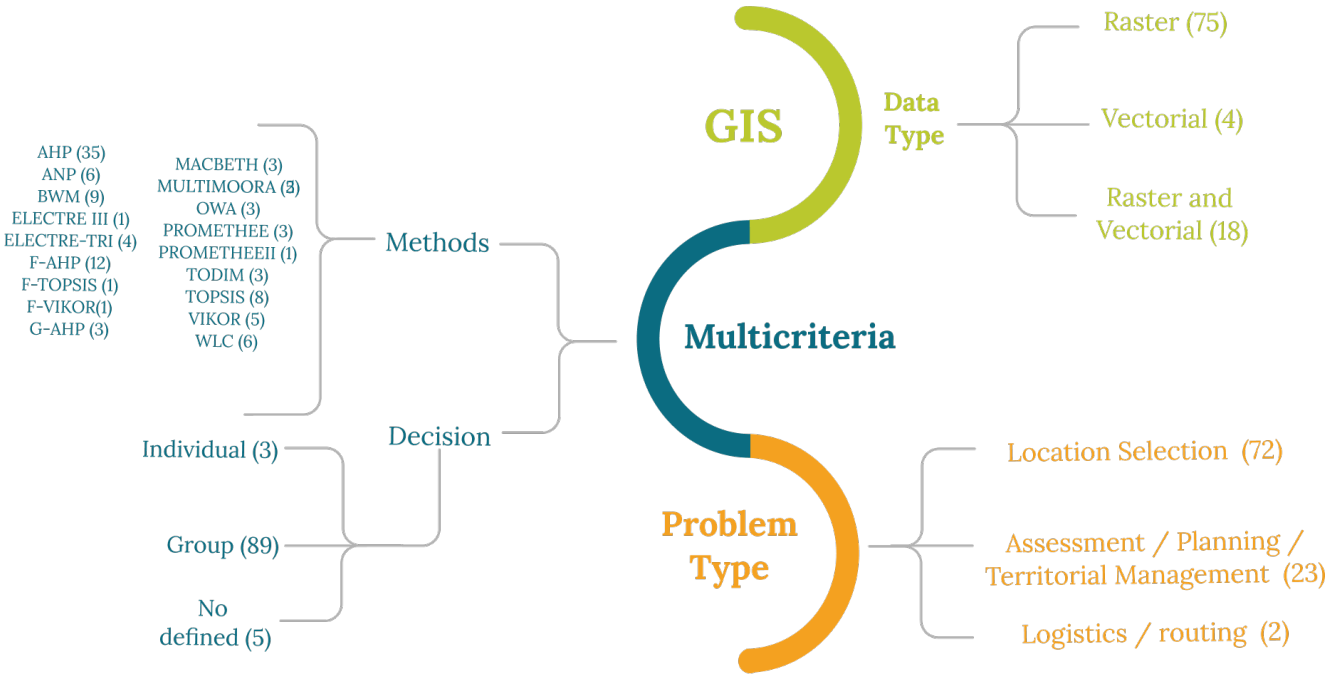

Fig. 11. Systematic classification of GIS–multicriteria applications, organizing studies by methods, decision type, data type, and problem type.

using the fuzzy concept, decision-makers are more flexible in expressing their judgments, applying different degrees of fuzzification or uncertainty. According to [64], the results with the application of fuzzy logic were more accurate. Finally, the problems addressed in the portfolio were classified into three types: site selection, site assessment (comprising mapping studies, resource and material allocation), and logistics (routes and emergency logistics). Site selection problems were the most addressed, with 72 articles, representing 74.23% of the portfolio.

3) Concept Tree and Research Challenges: In addition to the overview provided by the analysis of contributions between countries, authors, institutions, and keywords, much is discussed within the texts of the articles, such as research gaps. In practice, these research "gaps" can be identified as pairs of topics that are separated within the corpus, both in terms of their thematic content and the articles in which they appear [65]. Therefore, the objective of this analysis was to seek the main elements of the body of the texts of the portfolio articles and their contexts. In this regard, the CiteSpace software has a function (concept tree) that can assist in the investigation of possible research gaps. This function consists of a hierarchical representation of natural relationships between various types of words found in the original text sources. A concept tree represents the groupings of words that surround nouns [66]. Given a set of text documents, such as titles, abstracts, and citation contexts, constructing a concept tree in CiteSpace consists of the following steps [67]: 1. Extracting noun phrases from the preprocessed text with part-of-speech tagging; 2. Derive the hierarchical relations between phrases at the sentence level so that if a noun phrase nA co-occurs with noun phrases nB and nC, then nA is considered as a top-level concept in the hierarchical structure. 3. Create a visualization of the hierarchical structure as a concept tree. The display window (Fig. 12) has two panels: a) the relevant articles and b) displays the created tree together with the context in which the concept is arranged in the text of its respective articles (in blue).

In the example shown in Fig. 12, the CiteSpace visualization highlights the evolution of research in MCDM-GIS integration. In Section a), the list of relevant articles emphasizes key terms such as Weighted Linear Combination (WLC), fuzzy AHP, and GIS-based statistical methods, reflecting the growing use of hybrid approaches that integrate traditional MCDM techniques with fuzzy logic and spatial analysis. This trend indicates a shift towards more sophisticated models capable of handling data uncertainty and spatial variables. Section b) presents a network tree that connects central themes like decision-making, stakeholders, and research, signaling a shift towards participatory processes and collaborative decision-making. This evolving focus shows the increasing importance of multidisciplinary decision support systems that integrate technical, social, and environmental factors. The tree also reveals that the research scope has broadened, with terms like site selection, land use, and environmental management emphasizing the field's shift towards addressing sustainability and complex environmental issues. While fuzzy logic and AHP remain central, the integration of multiple methodologies is becoming more common to tackle complex decision-making challenges. The visualization also identifies research gaps, especially in areas like integrating spatial data, managing uncertainty, and participatory decision-making, suggesting the need for more integrated models combining quantitative and qualitative data. This shift reflects the demand for robust decision support systems that can address both technical and social complexities in contemporary urban and

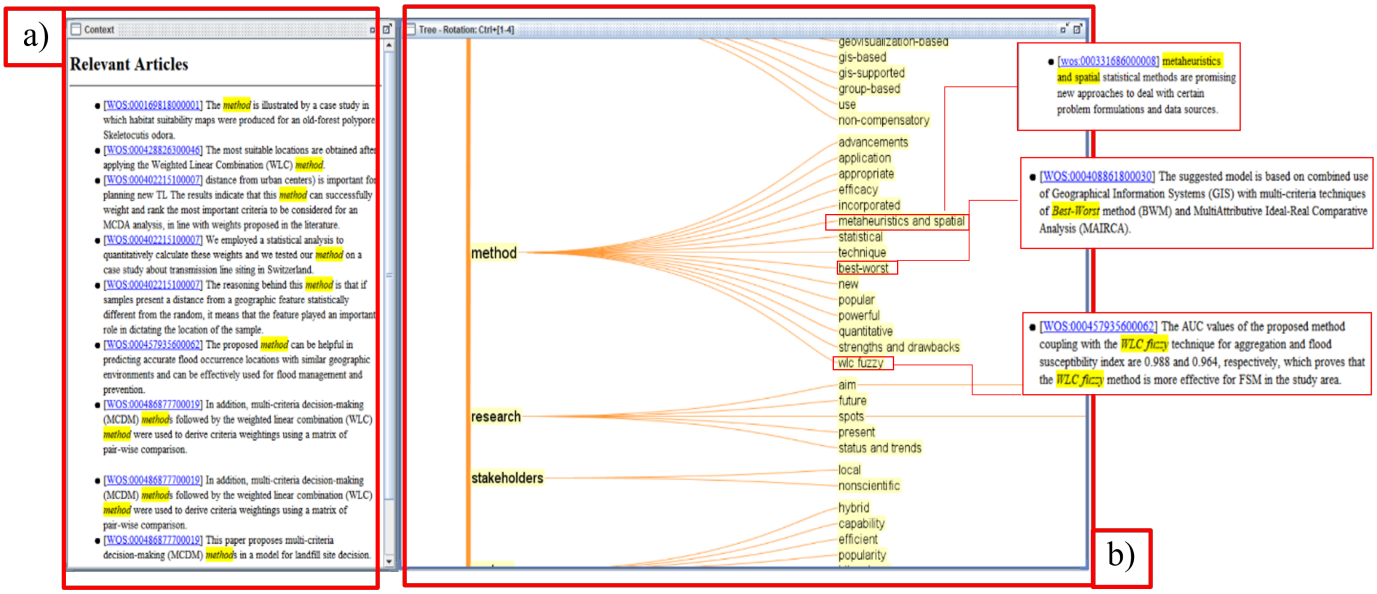

Fig. 12. Concept tree generated with CiteSpace, illustrating hierarchical connections between terms extracted from the full text of articles.

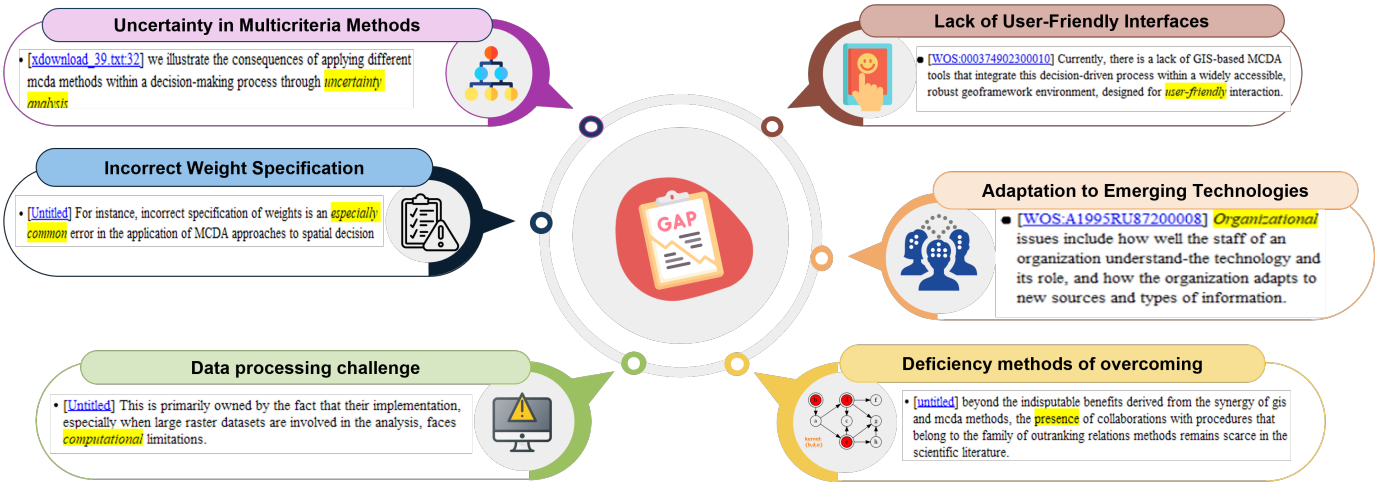

Fig. 13. Main research gaps identified through concept tree analysis, including methodological uncertainties, data challenges, and technological limitations.

environmental planning. The analysis also identifies research gaps in integrated modeling approaches that bridge scientific rigor with practical implementation needs (Fig. 13) [67]. This visualization effectively captures the field's progression toward more robust decision-support systems capable of addressing complex real-world challenges. Another contribution is the possibility of identifying some gaps in the exploration of the topic, as shown in Fig. 13.

Fig. 13 highlights some results obtained through concept tree analysis. When applied to the portfolio, the main challenges and potential gaps in research involving GIS-MCDM/A can be summarized in Table IV, which organizes the information in a comprehensive and accessible way. The table presents the identified gaps, categorized by the type of problem (such as site selection, logistics, and site assessment), methods used in the studies, and their respective bibliographic sources.

Table IV highlights the main challenges in using GIS combined with MCDM/A, such as lack of user-friendly interfaces, data quality and accuracy, uncertainties in judgments, and computational challenges, impacting areas such as site selection, logistics, planning, and land management. Methods such as AHP, BWM, PROMETHEE, and VIKOR are widely applied to address these limitations, while recent studies point to advances in data integration, fuzzy modeling, and computational optimization to overcome these barriers. Despite the progress, technical complexity and subjectivity in analyses remain significant obstacles, demanding continuous innovation in the field.

4) Thematic Analysis of Relevance and Development: Finally, identifying trends and advances in the development of the area is essential to understanding the state of the art, allowing a comprehensive view of the main developments, gaps, and future directions of the field of study. In this context, the analysis presented here uses Bibliometrix to build a thematic map that was generated based on a clustering

TABLE IV
LIMITATIONS AND CHALLENGES

Limitations Challenges	Problem Type	Methods Used	Sources
Lack of user-friendly interfaces in GIS-MCDA tools	Site Selection	AHP, F-AHP, WLC, BWM	[68], [69], [70], [71]
Data quality accuracy and access	Site Selection	AHP, TOPSIS, PROMETHEE, MULTIMOORA, BWM	[72], [73], [74], [75], [76]
	Assessment, planning, territorial Management	AHP, ANP, BWM, VIKOR	[77], [78], [79], [80], [48]
	Logistics, routing	AHP	[81]
Computational challenges	Site Selection	AHP, ANP, WLC, BWM, ELECTRE-TRI	[82], [83], [84], [85]
	Assessment, planning, territorial Management	ELECTRE III, AHP	[86], [87]
Uncertainty of judgments	Site Selection	AHP, TOPSIS, TODIM, MULTIMOORA, BWM	[88], [89], [90], [91], [92]
	Assessment, planning, territorial Management	AHP, PROMETHEE, VIKOR	[62], [93], [94], [95], [96]
	Logistics, routing	OWA	[97]

approach, using centrality and density indices to categorize themes into four quadrants: Motor Themes (high centrality and density), Niche Themes (high density and low centrality), Basic Themes (high centrality and low density), and Emerging or Declining Themes (low centrality and density) [98]–[100]. The authors' keywords were used for the analysis. General keywords, assigned by indexing systems or publishers, classify articles in databases with broad terms, based on the title, abstract, or content, while author keywords are selected by the authors themselves to highlight the central topics of their research [101].

As shown in Fig. 14, the Motor Themes, located in the upper right quadrant, represent central and well-developed topics that are essential to the structure of the research field. In the case of analysis, they include themes such as "analytic hierarchy process" and "decision-making," which play critical and strategic roles. The basic themes, in the lower right quadrant, such as "site selection" and "geographic information systems," are fundamental topics but still under development, indicating the need for further exploration. The niche themes, in the upper left quadrant, are more specialized, such as "climate" and "areas," demonstrating limited relevance to specific applications. On the other hand, the Emerging or Declining Themes, located in the lower left quadrant, represent areas with potential for growth or decline, such as the theme "support.". This approach is especially useful because it provides a clear visualization of the status of topics in the field of study, allowing prioritization of efforts to consolidate fundamental areas or explore new directions. The use of bibliometrics guarantees methodological rigor by integrating advanced quantitative methods for the analysis of thematic networks and bibliometric trends.

C. Future Research Directions

Building upon the identified gaps through concept tree and thematic mapping analyses, it is evident that the field of GIS-MCDM/A continues to face methodological and technological challenges that hinder its full potential in complex decision environments. While recent studies have advanced techniques such as fuzzy modeling, data fusion, and computational optimization, further developments are required to enhance usability, adaptability, and real-world applicability. The following research directions are proposed to guide future efforts:

Toward Hybrid GIS-MCDM/A-DSS Platforms: There is a critical need for the development of hybrid platforms that integrate the spatial analytical capabilities of GIS, the structured evaluation processes of MCDM/A methods, and the interactive, modular architecture of Decision Support Systems (DSS). Such platforms would enable more dynamic and context-aware decision-making by supporting model management, scenario testing, and real-time data interpretation across various domains, including corporate strategy, land-use planning, and logistics.

Integration of Artificial Intelligence and Machine Learning: The incorporation of AI and ML into GIS-MCDM/A frameworks presents a promising frontier. These technologies can facilitate the automation of criteria weighting, enhance predictive analytics, and support adaptive decision models capable of learning from evolving spatial data streams. In dynamic environments characterized by uncertainty and complexity, such integration can significantly improve the robustness and responsiveness of spatial decision-making systems.

Cross-Sectoral Comparative Research Frameworks: Despite the increasing volume of GIS-MCDM/A applications, there is a lack of systematic comparative analysis across sectors. Future research should focus on developing frameworks that evaluate methodological transferability, performance, and contextual constraints in different organizational settings—such as public policy, environmental governance, and private enterprise. This would contribute to the standardization and refinement of GIS-MCDM/A approaches and help establish best practices.

Enhanced Participatory and Real-Time Spatial Decision Tools: To address the demand for transparency and inclusiveness in decision-making, further advancements are required in participatory GIS and real-time decision environments. Incorporating stakeholder inputs through intuitive interfaces, mobile integration, and collaborative criteria definition mechanisms can strengthen user engagement and the legitimacy of outcomes. Additionally, real-time geospatial processing will be essential to support decisions

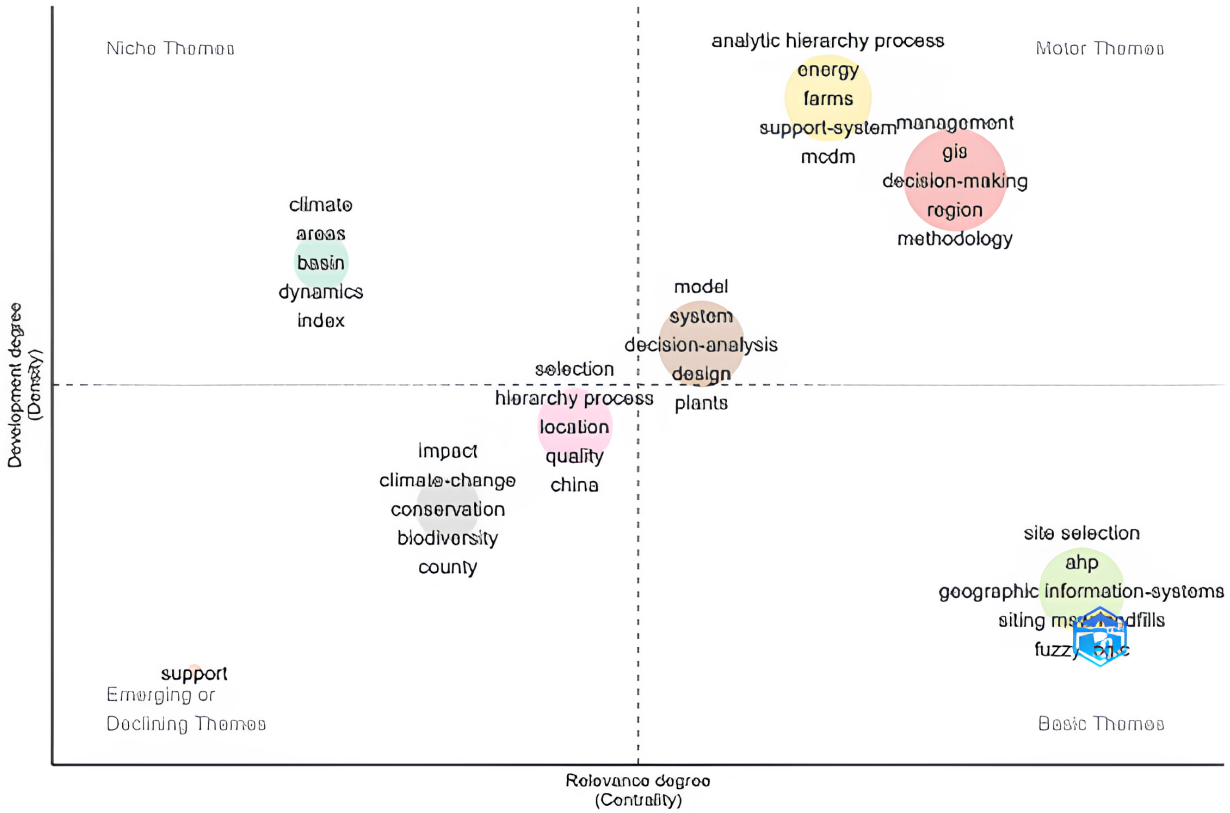

Fig. 14. Thematic map illustrating the distribution of research topics across four quadrants: motor themes (well-developed and central), niche themes (specialized but peripheral), basic themes (fundamental but underdeveloped), and emerging or declining themes.

in rapidly changing scenarios, such as crisis management and smart city operations.

In conclusion, advancing GIS-MCDM/A research necessitates a multi-dimensional effort that bridges theoretical rigor with technological innovation. By addressing these prospective directions, future studies can contribute to the evolution of spatial decision systems that are not only analytically robust, but also adaptable, user-centered, and sector-responsive.

IV. Conclusions

In this study, an analysis of scientific production on the topic of the multicriteria approach and geographic information systems was conducted. The PRISMA protocol checklist effectively contributed to the synthesis of the literature in a portfolio composed of 97 articles aligned with the context. Additionally, with the support of bibliometric analysis tools such as CiteSpace, VOSviewer, and Bibliometrix, development of the topic, were observed, along with statistical information on various items, including the production of countries, institutions, and authors.

During the content investigation, the development of elements over time was observed. With the support of VOSviewer, the visualization of clusters that brought together the main connections between keywords allowed for an understanding of the main themes highlighted in this study. The analysis of terms in the body of the text of articles through a concept tree complemented the research with greater detail on the gaps, such as the lack of more user-friendly interfaces, the importance of adaptation of management teams to new technologies, the scarcity of procedures belonging to the family of overcoming relationship methods, and the computational difficulty in dealing with raster data.

Importantly, the study underscores the growing need for systems that offer greater flexibility, not only in terms of methodological adaptability but also in their usability by diverse stakeholders. This includes the development of more intuitive interfaces, robust training and capacity-building programs, and platforms capable of supporting decision-makers in operational environments. These challenges, highlighted in both the abstract and the body of the work, represent critical areas for improvement in the design and implementation of GIS-MCDM/A systems.

In conclusion, the effectiveness of bibliographic software with its network representations and visual elements, is highlighted, as they contributed to the interpretation and understanding of the development of the topics addressed.

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