

# TWO DECADES OF GIS-MCDA IN AGRICULTURAL LAND SUITABILITY ASSESSMENT: A BIBLIOMETRIC ANALYSIS AND SYSTEMATIC REVIEW

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## ABSTRACT

This review examines two decades of Geographic Information System–Multi-Criteria Decision Analysis (GIS-MCDA) research in agricultural land suitability assessment by integrating bibliometric science mapping with a systematic thematic synthesis. The supplied Scopus screening workflow identified 740 records; 80 duplicate records were removed, leaving 660 records for screening. Of these, 246 records were excluded during screening, 246 full-text articles were assessed for eligibility, 114 were excluded after full-text assessment, and 132 studies were included in the qualitative synthesis. Keyword co-occurrence outputs place GIS, land suitability, analytical hierarchy process (AHP), multicriteria analysis, decision making, land use, and spatial analysis at the centre of the research field. The country collaboration outputs show an international network involving India, China, the United States, Saudi Arabia, Turkey, Ethiopia, Japan, Australia, and Iran, with India represented by the largest visible country node in the supplied map. The thematic map places geographic information system–land use–sustainable development and agricultural land–AHP–crop production in the motor-theme quadrant, while multicriteria analysis–decision making–spatial analysis appears as a basic theme. The overlay visualization indicates a temporal shift toward terms such as decision analysis, site selection, climate change, irrigation, watersheds, and related applied applications within the 2020–2023 scale shown in the VOSviewer output. The conceptual structure map obtained through multiple correspondence analysis (MCA) reports 43.08% inertia on Dimension 1 and 14.41% on Dimension 2, together accounting for 57.49% of the displayed two-dimensional structure. Together, these results show a field that is strongly centred on GIS-based suitability modelling and AHP/MCDA workflows while increasingly connecting them to land management, water-related applications, sustainability, and climate-related decision problems.

**KEYWORDS:** GIS; MCDA; AHP; land suitability; bibliometric analysis; systematic review

## 1. INTRODUCTION

Global agricultural systems face pressure from population growth, dietary change, climate change, and competition for land, water, and other natural resources (FAO, 2017; IPCC, 2019). Ensuring that agricultural production occurs on land that is appropriate for the intended use is a longstanding concern in land evaluation and is closely linked to food security and sustainable land management (FAO, 1976; FAO, 2017). Agricultural land suitability assessment the systematic evaluation of land parcels against crop- or land-use-specific requirements provides evidence for such decisions. Over the past two decades, the integration of Geographic Information Systems with Multi-Criteria Decision Analysis (GIS-MCDA) has become a widely used spatial decision-support approach in land-suitability research (Malczewski, 2006a; Shaloo et al., 2022). GIS-MCDA offers a structured framework for combining heterogeneous spatial data with explicit preferences and decision rules. Prior reviews have examined cropland-suitability assessment and geospatial multi-criteria methods; the present study combines bibliometric mapping with a workflow-oriented systematic synthesis of the same Scopus corpus (Shaloo et al., 2022). To address this objective, this paper combines quantitative bibliometric mapping with a qualitative systematic review of the same corpus. The remainder of this section establishes the background and rationale (Section 1.1), introduces GIS-MCDA as a suitability assessment framework (Section 1.2), justifies the combined bibliometric–systematic approach (Section 1.3), and presents the aim, objectives, and research questions (Section 1.4).

### 1.1 Background and Rationale

The application of multi-criteria methods to land evaluation has historical roots in the FAO land-evaluation framework of the 1970s, while the integration of GIS with multi-criteria evaluation was established in the 1990s and subsequently surveyed as a substantial research area (FAO, 1976; Carver, 1991; Jankowski, 1995; Malczewski, 2006a). Over the subsequent two decades, the field has matured along several trajectories. Methodologically, the portfolio of decision rules has diversified beyond simple weighted overlay to include the Analytic Hierarchy Process (AHP), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), fuzzy approaches, ordered weighted averaging (OWA), and hybrid formulations (Hwang & Yoon, 1981;

Malczewski, 2006a; Shaloo et al., 2022). The availability of remote-sensing products and global geospatial datasets has also expanded the data sources used in land-suitability assessment, while web-based platforms have enabled integrated online workflows (Yalew et al., 2016). In the present corpus, affiliations span Asia, Africa, the Middle East, Europe, North America, and Australia, indicating geographically distributed participation in the field. This combination of methodological diversification, expanding data sources, and geographic breadth has produced a literature large enough to merit systematic synthesis, yet heterogeneous enough that its findings benefit from explicit methodological coding rather than narrative review alone. Real-world decision challenges including agricultural land-use change, climate-related shifts in production conditions, and competition among alternative land uses further motivate a consolidated assessment of how GIS-MCDA has been operationalized and where methodological gaps remain.

### **1.2 GIS-MCDA as a Framework for Agricultural Land Suitability Assessment**

GIS-MCDA combines the spatial processing capabilities of GIS with the structured preference modelling of Multi-Criteria Decision Analysis, producing an integrated workflow for evaluating land suitability. The framework can be described through four core components. First, criteria selection involves identifying biophysical factors (e.g., soil, slope, climate, water availability) and, where relevant, socio-economic factors (e.g., accessibility, land value, tenure) that affect suitability for a specified crop or land use and can be represented as spatial criterion layers (FAO, 1976; Shaloo et al., 2022). Second, criteria weighting assigns relative importance to each criterion, commonly through expert-based methods such as AHP, while objective/data-driven approaches such as entropy- and CRITIC-based weighting are also available (Saaty, 1980; Hwang & Yoon, 1981; Diakoulaki et al., 1995). Third, spatial aggregation combines standardized criteria using decision rules ranging from weighted linear combination to TOPSIS, fuzzy decision approaches, or OWA; OWA provides a family of aggregation strategies controlled by order weights (Hwang & Yoon, 1981; Bellman & Zadeh, 1970; Yager, 1988; Malczewski, 2006b). Fourth, sensitivity analysis can include one-at-a-time perturbation, Monte Carlo-based approaches, or global methods such as Sobol sensitivity indices to test how outputs respond to changes in model inputs and assumptions (Saltelli et al., 2008; Sobol, 2001). This architecture is well suited to agricultural land suitability because the problem is inherently spatial, multi-dimensional, and preference-sensitive: it requires integrating heterogeneous data layers, accommodating trade-offs between competing objectives such as productivity and conservation, and making expert judgments explicit and auditable. GIS-MCDA can also make the decision chain inspectable, allowing stakeholders to examine and question the assumptions embedded in suitability outputs.

### **1.3 Rationale for a Combined Bibliometric and Systematic Review Approach**

Two review traditions provide complementary but different forms of evidence. Bibliometric analysis quantifies structural properties of a literature, including publication growth, productive authors, institutions and countries, citation networks, and conceptual patterns through techniques such as co-word analysis and bibliographic coupling, providing a macro-level view of the field (Donthu et al., 2021). Systematic review, by contrast, uses predefined methods to identify, select, and synthesize studies and to report how the evidence base was assembled (Page et al., 2021). Used in isolation, each approach leaves important questions unanswered: bibliometric studies can describe a field's structure without fully engaging study-level content, while systematic reviews can synthesize substantive findings without showing how those studies are distributed within the broader research landscape. Combining the two is useful here because the bibliometric component can reveal structural patterns in the corpus, while the systematic component can extract methodological and applied information that network mapping alone cannot surface. Previous reviews have examined cropland-suitability assessment and geospatial multi-criteria techniques (Shaloo et al., 2022). The contribution of the present study should therefore be understood as an integrated update that combines bibliometric science mapping with a workflow-oriented thematic synthesis of the Scopus corpus, with particular attention to criteria selection, weighting, decision rules, uncertainty, sensitivity analysis, validation, and emerging application contexts.

### **1.4 Aim, Objectives and Research Questions**

The overall aim of this review is to provide a comprehensive, evidence-based synthesis of two decades of GIS-MCDA research applied to agricultural land suitability assessment, identifying both the structural dynamics of the field and the substantive methodological and applied findings that have accumulated. To realise this aim, the review pursues the following specific objectives: (i) to map the bibliometric landscape of the field, including publication trends, influential contributors, outlets, and collaborative networks; (ii) to identify the dominant methodological approaches — decision rules, weighting techniques, and sensitivity analysis practices — and their evolution over time; (iii) to examine the thematic and application clusters that have emerged through co-occurrence and bibliographic coupling analysis; (iv) to synthesise the substantive findings regarding criteria selection, validation practices, and the treatment of uncertainty; and (v) to identify persistent gaps, emerging trends, and priorities for future research. Based on the stated objectives, the review addresses the following research questions: RQ1: How has GIS-MCDA research in agricultural land suitability assessment evolved in terms of publication output, sources, authorship, countries and collaboration patterns? RQ2: Which MCDA methods, weighting techniques, aggregation rules and GIS-integration approaches dominate the literature, and how have these approaches evolved over the review period? RQ3: Which biophysical, environmental, hydrological and socio-economic criteria and data sources are most frequently represented in GIS-MCDA agricultural land suitability studies? RQ4: To what extent do the reviewed studies report sensitivity analysis,

uncertainty assessment, validation and stakeholder participation? RQ5: What emerging themes, methodological limitations and research priorities can be identified from the combined bibliometric and thematic evidence?

## **2. Conceptual and Theoretical Background**

### **2.1 Foundations of Multi-Criteria Decision Analysis**

Multi-criteria decision analysis is concerned with structuring and supporting decision problems in which alternatives are evaluated against multiple, generally conflicting, criteria (Hwang & Yoon, 1981; Malczewski, 2006a). Its central premise is that decision problems may involve multiple objectives whose performances are expressed in different units and whose relative importance must be represented explicitly. MCDA therefore provides procedures for representing preferences and making trade-offs explicit rather than assuming that a single criterion can adequately describe the decision problem. Rather than prescribing what is optimal independently of preferences, MCDA provides disciplined procedures for making the trade-offs embedded in a decision explicit, comparable, and contestable.

An MCDA problem is conventionally specified through a set of alternatives, a set of criteria or attributes, preference parameters such as criterion weights, and an aggregation or decision procedure that combines evaluations with those preference parameters to produce a value, ranking, classification, or other decision output (Hwang & Yoon, 1981). A further constitutive element is the decision maker — individual or collective — whose preferences the model represents; preference elicitation and trade-off assessment are therefore integral to many value- and utility-based MCDA approaches (Keeney & Raiffa, 1976).

Several families of methods compete within this common specification. The multi-attribute value and utility tradition associated with Keeney and Raiffa constructs value or utility functions from explicitly elicited preferences and trade-offs (Keeney & Raiffa, 1976). The European outranking tradition, associated with the ELECTRE family and later methods such as PROMETHEE, evaluates alternatives through pairwise preference relations and can accommodate incomparability within the decision structure (Roy, 1968; Brans & Vincke, 1985). The Analytic Hierarchy Process introduced by Saaty derives priorities from structured pairwise comparisons and includes consistency diagnostics for the comparison matrix (Saaty, 1980). Fuzzy-set and fuzzy-decision formulations extend MCDA to settings in which criteria, preferences, or decision information are represented with graded rather than strictly crisp membership or preference values (Zadeh, 1965; Bellman & Zadeh, 1970). Across these families, a fundamental distinction separates compensatory methods, which permit strong performance on one criterion to offset weakness on another, from non-compensatory approaches that limit such trade-offs through thresholds or preference conditions (Hwang & Yoon, 1981; Malczewski, 2006a).

A major operational choice in applied MCDA is the weighting technique. Direct rating, ranking, point allocation, pairwise comparison, and trade-off procedures represent alternative ways of eliciting relative importance, while data-driven procedures derive weights from properties of the criterion data (Hwang & Yoon, 1981). In particular, entropy-based weighting uses information content as a basis for discrimination among criteria, whereas the CRITIC method derives objective weights from contrast intensity and conflict among criteria (Zeleny, 1982; Diakoulaki et al., 1995). In spatial applications, the large number of decision units means that preferences are usually elicited at the criterion level rather than separately for each pixel or polygon, after which the resulting weights and standardization functions are applied across the mapped decision space. This design supports computational reproducibility but may also encode a single preference structure into areas where stakeholder priorities differ.

### **2.2 Integration of GIS and MCDA for Spatial Decision-Making**

Spatial decision problems differ from generic MCDA problems in that both alternatives and criteria are geographically referenced, and the output of the evaluation is itself a spatial object. GIS-MCDA emerged in part from the complementary capabilities of GIS and MCDA: GIS provides storage, spatial transformation, analysis, and visualization of geographic data, whereas MCDA provides structured decision logic for combining criteria and preferences (Carver, 1991; Jankowski, 1995; Malczewski, 2006a).

Two directions of integration are commonly described in the GIS-MCDA literature: GIS can provide the data and spatial-analysis environment within which an MCDA model is evaluated, or MCDA can provide the decision rules used to guide the combination and interpretation of spatial criteria (Jankowski, 1995; Malczewski, 2006a). With respect to implementation, GIS-MCDA systems have also been described in terms of loose coupling, tight coupling, and full or embedded integration, differing in how data, models, and user interfaces are connected (Malczewski, 2006a). The present review examines how those integration choices are represented in the included agricultural land-suitability studies.

Operationally, GIS-MCDA studies in land suitability commonly proceed through problem definition; identification of the goal and criteria; acquisition and preprocessing of criterion data; standardization to a common scale; derivation of criterion weights; aggregation of standardized criteria; classification of the resulting suitability surface; and, where reported, sensitivity analysis, uncertainty assessment, validation, and cartographic representation (Carver, 1991; Malczewski, 2006a; Shaloo et al., 2022). Each stage embeds choices — which criteria to admit, which standardization or value functions to apply, whose weights to represent, and which aggregation rule to adopt — that affect the final suitability map. The product is a decision map whose interpretability depends on the transparency with which the analytical chain is reported. This pipeline constitutes the backbone of the data-extraction scheme used in the thematic synthesis of the present review (Section 3.4).

## 2.3 Land Suitability Assessment: Concepts and Evaluation Standards

Land suitability assessment belongs to the broader tradition of land evaluation, defined as the assessment of land performance for a specified use. Within this tradition, land capability and land suitability are distinguished: capability concerns broader, relatively persistent patterns of land use potential, whereas suitability is use-specific and evaluates land relative to a defined land utilization type (FAO, 1976; Rossiter, 1996). The conceptual apparatus of much suitability work was codified in the FAO Framework for Land Evaluation, which introduced land utilization types, land characteristics and land qualities, diagnostic criteria, and a hierarchical classification into suitability orders, classes, subclasses, and units (FAO, 1976). A later FAO discussion document revisited the framework in light of evolving land-resource management concepts and additional tools and procedures (FAO, 2007). The framework's core logic is to relate the requirements of a specified land use to the qualities and characteristics of the land.

Alongside the FAO tradition, earlier and parallel systems shaped land-evaluation practice, including categorical land-capability schemes and parametric approaches for combining ratings of individual land characteristics (Klingebiel & Montgomery, 1961; Rossiter, 1996). These systems share a classificatory ambition: they assign land units to a limited number of classes whose meanings and boundaries are defined by the evaluation framework or study. GIS-MCDA differs in that standardized criteria can first be aggregated into a continuous composite suitability score and only subsequently classified for reporting. Classification thresholds may therefore be study-specific and should be reported explicitly rather than assumed to have a uniform agronomic basis across studies. Modern land-suitability assessment can draw on increasingly diverse spatial data sources, including digital elevation and soil information, remote-sensing products, climate datasets, and web-accessible geospatial resources; recent web-based frameworks demonstrate the use of multiple global datasets within integrated GIS-MCDA workflows (Yalew et al., 2016). The original FAO framework predates many current quantitative approaches to sensitivity analysis, uncertainty analysis, and empirical validation, while the later FAO discussion of a revised framework explicitly considers additional concepts and tools for land evaluation (FAO, 1976, 2007). Consequently, the treatment of uncertainty, sensitivity, and validation in continuous GIS-MCDA suitability models remains an important methodological issue for contemporary reviews rather than a question that can be resolved solely from the 1976 framework.

## 2.4 Theoretical Positioning of the Present Review

The present review is positioned at the intersection of three bodies of scholarship. The first is the methodological literature on MCDA and its spatial integration, which supplies the technical vocabulary in which the reviewed studies are written and against which their choices can be evaluated. The second is the land-science and land-evaluation tradition, which defines the object of the assessments under review suitability for agricultural use and the normative standards to which such assessments have historically been held (FAO, 1976; Rossiter, 1996). The third is meta-research: the study of research itself through evidence synthesis and quantitative science studies, from which the review draws its two instruments, the systematic review protocol and bibliometric science mapping (Page et al., 2021; Donthu et al., 2021).

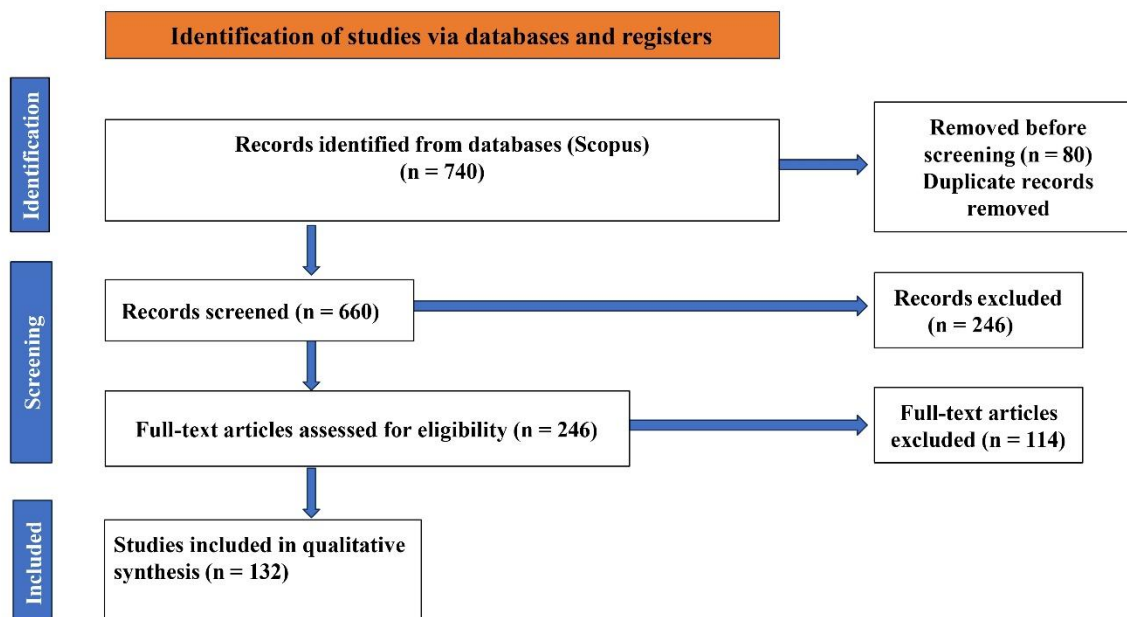
Within this triple anchoring, the review adopts a deliberately practice-oriented epistemology. Its unit of analysis is not the decision problem but the published study, and its analytical question is not which method is theoretically superior but how the GIS-MCDA framework is actually operationalized in the agricultural suitability literature, with what degree of transparency, uncertainty handling and validation, and with what consequences for the credibility of the resulting suitability claims. To make such claims auditable, the review employs a workflow-stage model of the GIS-MCDA process — from data and criteria through standardization, weighting, aggregation and integration architecture to output representation and validation as its coding and synthesis framework. This model is introduced operationally in Section 3.4 and structures Section 6; it also underpins the quality dimensions that recur throughout the discussion in Section 7: transparency of reported choices, reproducibility of the analytical chain, treatment of uncertainty and preference subjectivity, and empirical validation of outputs.

The scope of the review is correspondingly bounded. It covers studies that apply GIS-MCDA to the suitability of land for agricultural production systems, including crop-specific and farming-system-specific assessments; it excludes applications of the same analytical machinery to non-agricultural spatial decisions such as industrial siting, landfill location or urban growth modelling, except where such studies serve as methodological precedents explicitly cited by the reviewed literature. This boundary respects the domain-specific character of suitability reasoning its criteria, standards and decision stakes are specific to agriculture while acknowledging that methodological innovations often migrate across application domains. How this positioning translates into concrete review procedures is the subject of Section 3.

## 3. MATERIALS AND METHODS

### 3.1 Review Protocol and Reporting Standards

The supplied PRISMA workflow reports 740 records identified from Scopus, 80 duplicate records removed before screening, 660 records screened, 246 records excluded at screening, 246 full-text articles assessed for eligibility, 114 full-text articles excluded, and 132 studies included in the qualitative synthesis. These figures form the numerical basis used in the present manuscript.



**Fig.1 PRISMA Flowchart**

The review uses a combined bibliometric and systematic-review design. The bibliometric component maps the structure, conceptual organization, geographic collaboration, and temporal development of the literature, whereas the systematic component provides a study-level synthesis of GIS-MCDA applications in agricultural land suitability assessment. The supplied PRISMA workflow was used as the reporting basis for identification, screening, eligibility assessment, and inclusion, consistent with the PRISMA 2020 reporting framework (Page et al., 2021).

### 3.2 Search Strategy and Data Sources

A systematic literature search was conducted using the Scopus database to identify studies addressing land suitability and land evaluation using geographic information systems (GIS) and multi-criteria decision-making (MCDM) techniques. The search strategy was designed to capture studies combining land suitability-related concepts, geospatial/GIS methods, and MCDM approaches. The Scopus search expression was:

*TITLE-ABS-KEY ("land suitability" OR "land evaluation" OR "agricultural suitability") AND (GIS OR geospatial OR "geographic information system") AND ("multi-criteria decision making" OR MCDA OR MCDM OR AHP OR TOPSIS)*

The initial Scopus search identified 740 records. The retrieved records were subsequently screened using predefined eligibility criteria. First, the publication-year filter was applied to retain studies published between 2005 and 2025, resulting in 660 records after excluding 80 records outside the specified period. The document-type filter was then applied, retaining 605 journal articles and excluding 55 records of other document types.

Next, the records were restricted to the Environmental Sciences and Agricultural and Biological Sciences subject categories, resulting in 359 records after the exclusion of 246 records from other subject categories. A language filter was subsequently applied to retain English-language publications, reducing the dataset to 347 records. An additional thematic/relevance filter was applied to retain studies related to GIS, land suitability, multi-criteria analysis, geographic information systems, land-use planning, remote sensing, agriculture, and sustainable development, resulting in 295 records. Finally, the Open Access criterion was applied, leaving 132 studies for the final bibliometric analysis.

The resulting dataset therefore comprised 132 studies and was used for the subsequent bibliometric analyses. The exported records were analysed using VOSviewer and Bibliometrix/Biblioshiny to examine publication trends, country collaboration, keyword co-occurrence, keyword overlay and density, thematic evolution/mapping, author or keyword clustering, dendrogram structures, and conceptual structure through multiple correspondence analysis (MCA). VOSviewer is a software environment for constructing and visualizing bibliometric maps, including co-occurrence networks (van Eck & Waltman, 2010), while bibliometrix provides a framework for science mapping and bibliometric analysis in R (Aria & Cuccurullo, 2017).

Methodological details requiring confirmation: the supplied Scopus export contains the final 132 records and does not retain the original search timestamp or the complete 740-record retrieval set. Therefore, the exact Scopus search date/time and database-access details should be inserted from the original search record before submission. The database, search string, publication period (2005–2025), document type (Article), language (English), subject-category restrictions, thematic filtering, and Open Access criterion are supported by the supplied PRISMA diagram and export.

### 3.3 Eligibility Criteria and Study Selection Process

The supplied PRISMA diagram should be retained as the definitive numerical record for the identification and screening stages because its counts are internally consistent: 740 identified – 80 duplicates = 660 screened; 660 – 246 excluded = 414 records moving forward, represented by 246 full-text articles assessed after the documented screening workflow; 246 assessed – 114 excluded = 132 included studies. The manuscript should reproduce the figure exactly as supplied and avoid introducing additional counts that are not present in the source files.

The review scope covers research addressing agricultural land suitability or land evaluation where GIS/geospatial techniques are integrated with multi-criteria decision analysis. The conceptual framing of the manuscript indicates inclusion of crop-specific and farming-system-specific suitability assessments and exclusion of non-agricultural spatial applications unless they serve as explicit methodological precedents. The supplied screening record results in 132 studies included in the qualitative synthesis after full-text assessment.

| Criterion           | Inclusion                                                                       | Exclusion                                                                               |
|---------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| Publication period  | 2005–2025                                                                       | Outside period                                                                          |
| Document type       | Journal article                                                                 | Conference paper, book, review, editorial, etc.                                         |
| Language            | English                                                                         | Other languages                                                                         |
| Subject area        | Environmental Sciences; Agricultural & Biological Sciences                      | Other subject categories                                                                |
| Analytical approach | GIS/geospatial + MCDA/MCDM                                                      | GIS-only or non-MCDA studies                                                            |
| Application         | Agricultural land suitability, land evaluation, crop/farming-system suitability | Urban, industrial, waste, energy, healthcare, tourism and other non-agricultural siting |
| Accessibility       | Open Access, according to the applied search filter                             | Non-open-access records                                                                 |

Title and abstract screening was subsequently required to ensure that the retained records corresponded to the agricultural scope of the review. Non-agricultural applications of GIS-MCDA, even when methodologically relevant, were excluded from the agricultural evidence synthesis.

### 3.4 Data Extraction and Classification Scheme

The country collaboration map was interpreted qualitatively from node size and visible connecting lines. For the systematic synthesis, each study should be coded against the GIS-MCDA workflow described in the manuscript: study objective and land-utilization context; criterion selection and data sources; spatial preprocessing; criterion standardization; weighting; aggregation/decision rule; output classification; sensitivity and uncertainty analysis; and validation. Additional descriptors visible in the supplied bibliometric outputs include crop and application terms, water- and watershed-related themes, climate change, land use, sustainability, and site selection.

### 3.5 Bibliometric Analytical Framework and Tools

Bibliographic records retrieved from Scopus were used as the primary data source for the bibliometric analysis. The dataset was examined with respect to publication characteristics and thematic information, including authorship, country/affiliation information, publication year, keywords, citation-related information, and subject or application terms available in the Scopus records. The bibliometric outputs were generated using VOSviewer and Bibliometrix/Biblioshiny, software packages designed for bibliometric mapping and science-mapping workflows (van Eck & Waltman, 2010; Aria & Cuccurullo, 2017). Country collaboration was interpreted qualitatively from the relative size of nodes and the presence and density of connecting links in the collaboration network. Because the supplied visualization files do not contain the underlying country-by-country collaboration matrix or numerical edge-weight data, exact link strengths, collaboration frequencies between individual countries, and network-weight statistics were not inferred from the graphical representation. The classification framework was used to facilitate comparison of methodological choices across the included studies and to identify recurring patterns, methodological gaps, and emerging application areas within GIS-based land suitability and MCDA research. Bibliometric preprocessing and mapping. The Scopus records were exported in CSV format and processed before science mapping. The analysis should report the software versions, keyword field used, counting method, minimum occurrence threshold, normalization procedure, clustering settings, and any thesaurus or synonym-merging procedure. For VOSviewer, the manuscript should specify whether full or fractional counting was used and the minimum number of occurrences required for inclusion. For Bibliometrix/Biblioshiny, the manuscript should report the analysis parameters used for thematic mapping, conceptual-structure analysis and hierarchical clustering. These settings are necessary to ensure reproducibility of the reported network structures (Donthu et al., 2021). Keyword normalization should be performed before network construction by harmonizing abbreviations, spelling variants and synonymous expressions. In particular, GIS/geographic information system(s), AHP/analytic hierarchy process/analytical hierarchy process, and MCDA/MCDM/multi-criteria decision analysis should be evaluated for consolidation. The final thesaurus or normalization rules should be reported as supplementary methodological information.

## 4. Bibliometric Performance Analysis

### 4.1 Publication Growth and Temporal Trends

The temporal distribution of the 132 studies was derived directly from the Year field in the Scopus export. The retrieved literature spans 2006–2025, although publications were not evenly distributed across the period.

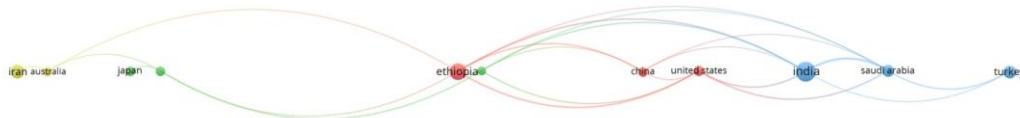
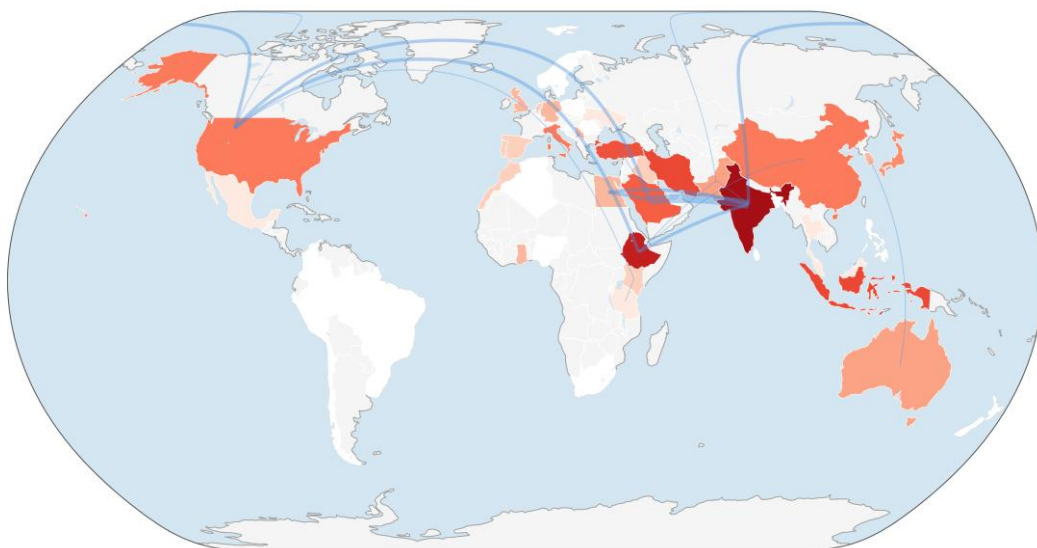
**Table.1 Number of Publications per year (2006-2025)**

| Year      | Publications |
|-----------|--------------|
| 2006      | 1            |
| 2007–2013 | 0            |
| 2014      | 4            |
| 2015      | 3            |
| 2016      | 7            |
| 2017      | 3            |
| 2018      | 8            |
| 2019      | 6            |
| 2020      | 12           |
| 2021      | 13           |
| 2022      | 12           |
| 2023      | 14           |
| 2024      | 21           |
| 2025      | 28           |
| Total     | 132          |

The distribution indicates a marked increase in research output during the later part of the study period. In particular, 100 of the 132 included studies (75.8%) were published between 2020 and 2025, while 49 studies (37.1%) were published in 2024–2025 alone. The highest number of publications in the dataset occurred in 2025 ( $n = 28$ ), followed by 2024 ( $n = 21$ ) and 2023 ( $n = 14$ ). Thus, the bibliographic record indicates a substantial expansion of research activity in recent years.

The VOSviewer overlay visualization provides a complementary temporal perspective at the keyword level rather than at the publication-count level. The overlay suggests that the more recent literature increasingly incorporates terms associated with decision analysis, site selection, climate change, irrigation, watersheds, sustainability, and related applied themes, alongside the established GIS, AHP, and land-suitability terminology. These observations should be interpreted as changes in the thematic vocabulary of the field and should not be treated as direct measures of publication growth.

#### 4.2 Geographic and Institutional Distribution

**Fig.2 Country collaboration network****Fig.3 Country collaboration map**

The separate country-network plot presents the same countries along a collaboration structure in which India, China, the United States, Saudi Arabia, Turkey, and Ethiopia occupy central or strongly connected positions, with Japan, Australia, and Iran connected through additional network pathways.

The country collaboration outputs reveal a geographically distributed research community with a prominent set of connected national nodes. India has the largest visible node in the supplied country collaboration map, followed by other clearly represented nodes including China and the United States. Saudi Arabia and Turkey are also

prominent on the right side of the network, while Ethiopia acts as a visible connecting node between groups. Japan, Australia, and Iran are represented as additional participating countries. The connecting arcs demonstrate that collaboration is not restricted to one region and that Asian, African, Middle Eastern, European, North American, and Australian researchers appear within the same network.

| Country        | Records with affiliation |
|----------------|--------------------------|
| India          | 24                       |
| Ethiopia       | 18                       |
| Indonesia      | 11                       |
| Iran           | 11                       |
| Türkiye/Turkey | 10                       |
| Saudi Arabia   | 9                        |
| United States  | 7                        |
| Italy          | 7                        |
| China          | 6                        |
| Japan          | 6                        |
| United Kingdom | 6                        |
| Vietnam        | 6                        |

**Table 2. Countries represented in the Scopus corpus based on author-affiliation records**

Country frequencies represent the number of records containing at least one author affiliation from the respective country. Because individual publications may contain authors from multiple countries, these frequencies are not mutually exclusive and should not be interpreted as collaboration-edge strengths or as a substitute for the VOSviewer network statistics.

#### 4.3 Journal and Source Analysis

The Scopus export contains 132 bibliographic records published between 2006 and 2025 across 83 unique source titles. This allows journal/source productivity and citation patterns to be examined directly from the available data. Overall, the source distribution is relatively dispersed, although a small number of journals account for a noticeable share of the retrieved literature.

**Table.3 Most productive publication sources**

| Rank | Source title                                | Documents | Total citations | Mean citations/document |
|------|---------------------------------------------|-----------|-----------------|-------------------------|
| 1    | Sustainability (Switzerland)                | 14        | 639             | 45.64                   |
| 2    | Land                                        | 5         | 251             | 50.20                   |
| 3    | Cogent Food and Agriculture                 | 5         | 208             | 41.60                   |
| 4    | Modeling Earth Systems and Environment      | 4         | 538             | 134.50                  |
| 5    | Land Use Policy                             | 3         | 142             | 47.33                   |
| 6    | Agriculture (Switzerland)                   | 3         | 121             | 40.33                   |
| 7    | Environment, Development and Sustainability | 3         | 80              | 26.67                   |
| 8    | Environmental and Sustainability Indicators | 3         | 50              | 16.67                   |
| 9    | Discover Sustainability                     | 3         | 38              | 12.67                   |
| 10   | Smart Agricultural Technology               | 3         | 34              | 11.33                   |

The publication record shows a clear increase in output over time. Only one document was indexed in 2006, whereas annual production reached 12 documents in 2020, 13 in 2021, 12 in 2022, 14 in 2023, 21 in 2024, and 28 in 2025. Thus, 49 of the 132 records (37.1%) were published during 2024–2025 alone, indicating a marked recent expansion of research activity in the field. The 132 records accumulated 4,927 citations in the supplied export, equivalent to an average of 37.3 citations per document, with a median of 17 citations. Citation concentration is uneven across sources. Sustainability (Switzerland) has the largest number of publications (14) and also the highest aggregate citation count (639). In contrast, Modeling Earth Systems and Environment produced only four documents but accumulated 538 citations, giving it a substantially higher mean citation count per document (134.5). Other sources with relatively high aggregate citation counts include Land (251), Cogent Food and Agriculture (208), and Land Use Policy (142). The source profile therefore indicates a growing and increasingly diversified literature, with Sustainability (Switzerland) serving as the most productive publication venue in the dataset, while several lower-volume journals have generated comparatively high citation visibility. These differences suggest that publication productivity and citation influence are not distributed uniformly across sources and should therefore be interpreted using both document counts and citation indicators rather than a single measure.

#### 4.4 Citation Structure and Influential Publications

The Scopus export contains citation information for all 132 publications included in the dataset. Collectively, these publications received 4,927 citations, with an average of 37.33 citations per document and a median of 17 citations. A total of 126 publications had received at least one citation, whereas only 6 publications were uncited

at the time of data export. The citation distribution is highly uneven, indicating that a relatively small group of publications accounts for a substantial share of the field's accumulated citations. The 10 most-cited publications alone account for approximately 39.9% of all citations in the dataset, while the 15 most-cited publications account for approximately 49.3%.

The most highly cited publication is *Comparison of Fuzzy-AHP and AHP in a spatial multi-criteria decision making model for urban land-use planning* by Mosadeghi et al. (2015), with 384 citations. It is followed by Zolekar and Bhagat (2015), *Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach*, with 289 citations, and Pramanik (2016), *Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques*, with 245 citations. Other highly cited contributions include Gigović et al. (2016), with 204 citations; Seyedmohammadi et al. (2019), with 195 citations; and Yalew et al. (2016), with 184 citations. These publications represent the most frequently cited contributions within the present dataset and therefore provide an empirical basis for identifying influential literature.

| Rank | Publication                                                                                                                                         | Year | Citations |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------|------|-----------|
| 1    | Mosadeghi et al., <i>Comparison of Fuzzy-AHP and AHP in a spatial multi-criteria decision making model for urban land-use planning</i>              | 2015 | 384       |
| 2    | Zolekar & Bhagat, <i>Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach</i>                    | 2015 | 289       |
| 3    | Pramanik, <i>Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques</i>                            | 2016 | 245       |
| 4    | Gigović et al., <i>The combination of expert judgment and GIS-MAIRCA analysis for the selection of sites for ammunition depots</i>                  | 2016 | 204       |
| 5    | Seyedmohammadi et al., <i>Development of a model using matter element, AHP and GIS techniques to assess the suitability of land for agriculture</i> | 2019 | 195       |
| 6    | Yalew et al., <i>Land suitability analysis for agriculture in the Abbay basin using remote sensing, GIS and AHP techniques</i>                      | 2016 | 184       |
| 7    | Salmon Mahini & Gholamalifard, <i>Siting MSW landfills with a weighted linear combination methodology in a GIS environment</i>                      | 2006 | 144       |
| 8    | Yalew et al., <i>AgriSuit: A web-based GIS-MCDA framework for agricultural land suitability assessment</i>                                          | 2016 | 117       |
| 9    | Tashayo et al., <i>Land suitability assessment for maize farming using a GIS-AHP method for a semi-arid region, Iran</i>                            | 2020 | 103       |
| 10   | Silva et al., <i>Biogas plants site selection integrating Multicriteria Decision Aid methods and GIS techniques</i>                                 | 2014 | 100       |

The dataset has an h-index of 40, meaning that 40 publications had received at least 40 citations each. Because citation counts are cumulative and strongly influenced by publication age, the identification of influential publications should be interpreted as a citation-based description of prominence within the retrieved Scopus dataset rather than as a measure of intrinsic research quality or impact.

#### 4.5 Author Productivity Patterns

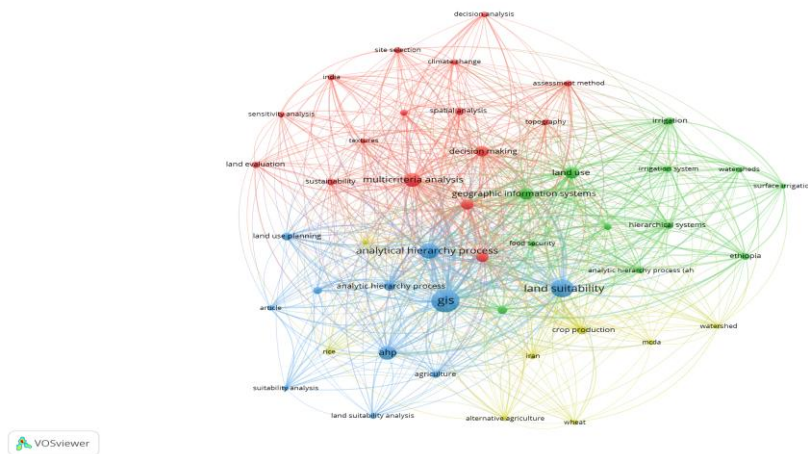
The author-level information in the Scopus export permits a direct assessment of publication productivity. The dataset contains 569 distinct author records identified through Scopus author identifiers. Author productivity is strongly concentrated at the single-publication level: 543 authors (95.4%) contributed to only one publication, 22 authors (3.9%) contributed to two publications, 3 authors (0.5%) contributed to three publications, and 1 author (0.2%) contributed to four publications. Overall, only 26 authors (4.6%) contributed to two or more publications in the retrieved dataset.

Widiatmaka is the most productive author, with four publications. Everest, Timuçin; Bagherzadeh, Ali; and Karuppannan, Shankar each contributed three publications. Several other authors, including Negese, Ajanaw; Yalew, S.G.; van Griensven, A.; Mul, M.L.; van der Zaag, P.; Ambarwulan, Wiwin; and Honarbakhsh, Afshin, contributed to two publications. The relatively small number of repeatedly publishing authors, together with the large proportion of one-time contributors, indicates a broad author base with limited repeated authorship within the retrieved publication set.

Collaboration is also prominent at the document level. Of the 132 publications, 126 (95.5%) were co-authored, while only 6 publications were single-authored. The mean number of authors per publication was 4.55, with a median of four authors and a maximum of 12 authors on a single publication. The export records 1,405 unique co-author pairs, demonstrating a substantial network of collaborative relationships. These findings indicate that the literature is predominantly collaborative, although repeated publication by individual authors is relatively limited. Author productivity and collaboration should therefore be interpreted separately: the field demonstrates extensive co-authorship across publications, while only a small proportion of authors appear repeatedly in the dataset.

## 5. Science Mapping and Network Analysis

### 5.1 Keyword Co-occurrence and Thematic Clustering



**Figure 4. Keyword co-occurrence network of GIS-MCDA**

The visible network can be interpreted into broad thematic groupings. One group links GIS, land suitability, AHP, and suitability analysis; a second connects MCDA/decision making with land evaluation, sustainability, spatial analysis, and land-use planning; a third connects GIS-MCDA with irrigation, watersheds, water availability, and hierarchical systems; and a fourth includes crop-oriented applications such as crop production, rice, wheat, and alternative agriculture. These groupings should be described as thematic patterns in the network rather than as formally named clusters unless the underlying cluster export provides cluster numbers and membership.

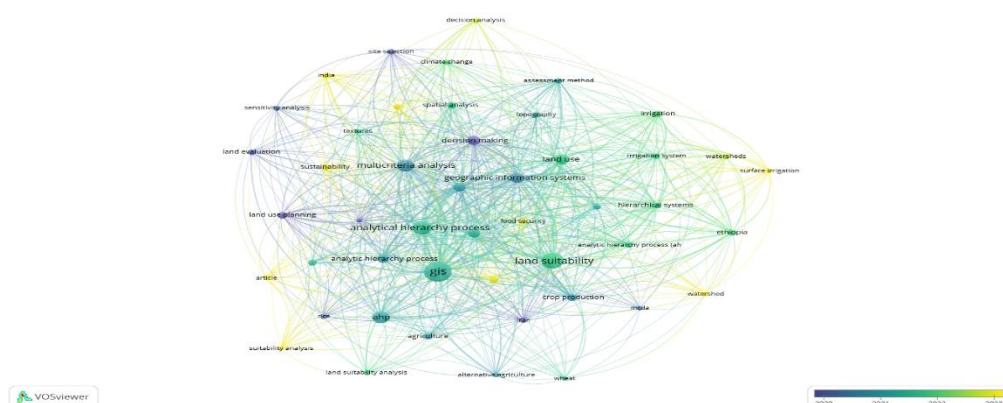
The keyword co-occurrence network is densely connected, indicating substantial conceptual overlap among GIS, land suitability, MCDA, AHP, decision making, land use, and spatial analysis. GIS and land suitability are large, centrally positioned nodes, while analytical hierarchy process/AHP also occupies a prominent position. Additional connected terms include land evaluation, sustainability, climate change, site selection, irrigation, watersheds, crop production, agriculture, rice, wheat, soil, textures, topography, and sensitivity analysis. The network therefore represents GIS-MCDA as an applied analytical framework rather than a narrowly technical GIS topic.

The density visualization identifies the highest concentration of terms around GIS, land suitability, analytical hierarchy process/AHP and multicriteria analysis. A second concentration is associated with decision making, land use, spatial analysis and land evaluation. More peripheral but clearly visible areas include irrigation, watersheds, climate change, site selection, sensitivity analysis and crop production. The density pattern reinforces the interpretation that GIS, land suitability and AHP constitute the central methodological core of the research field, while water management, climate-related assessment and application-specific planning represent expanding thematic areas.

### 5.2 Co-authorship and Collaboration Networks

At the country level, the collaboration network is structured around a visible central group of India, China, and the United States, with Saudi Arabia, Turkey, and Ethiopia forming additional strongly connected nodes. Japan, Australia, and Iran are linked into the network through visible pathways. The network suggests that GIS-MCDA land-suitability research has developed through cross-country collaboration rather than through isolated national literatures. The prominence of India is consistent across the map and the country network output, but this visual prominence should not be translated into a numerical productivity ranking without the underlying counts.

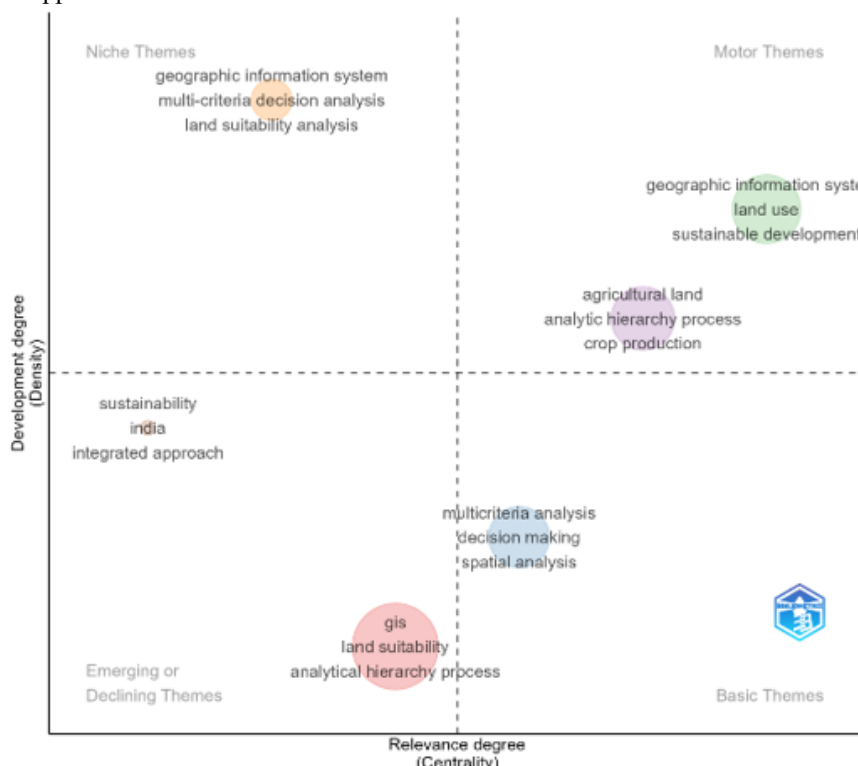
### 5.3 Thematic Evolution over Two Decades



**Figure 5. Overlay visualization of keyword co-occurrence**

The overlay visualization adds a temporal perspective. The 2020–2023 colour scale shows newer-looking terms such as decision analysis, site selection, climate change, irrigation, surface irrigation, watersheds, alternative agriculture, and wheat toward the later end of the scale. Earlier or more established central terms include GIS, Genetics and Molecular Research 25 (20s): 2026

AHP, land suitability, analytical hierarchy process, and multicriteria analysis. The result is consistent with a field that retains a stable methodological core while expanding toward specific planning, water-management, climate, and agricultural applications.



**Figure 6. Thematic map generated from the supplied Bibliometrix/Biblioshiny output.**

The thematic map classifies the field into niche, motor, basic, and emerging/declining themes. The upper-right motor-theme quadrant contains a geographic information system–land use–sustainable development cluster and an agricultural land–analytical hierarchy process–crop production cluster, indicating themes that combine comparatively high centrality and density in the supplied analysis. The basic-theme quadrant contains multicriteria analysis, decision making, and spatial analysis, showing concepts that are strongly connected to the field but comparatively less developed internally. The niche quadrant contains geographic information system, multi-criteria decision analysis, and land suitability analysis, while the emerging-or-declining quadrant contains a GIS–land suitability–analytical hierarchy process grouping together with sustainability, India, and integrated approach.

#### 5.4 Conceptual Structure and Hierarchical Clustering

The conceptual structure analysis based on multiple correspondence analysis (MCA) explains 43.08% of the displayed inertia on Dimension 1 and 14.41% on Dimension 2, representing 57.49% cumulatively. The map indicates a conceptual separation between water- and irrigation-oriented applications and crop/land-suitability-oriented applications. Terms such as surface irrigation, river basins, watersheds, water availability and irrigation systems occupy the upper portion of the map, while GIS, AHP, land suitability, agricultural land, crop production, rice, wheat and land-use planning occupy more central or lower positions. Fuzzy mathematics and fuzzy AHP are positioned closer to the water/resource-management side of the conceptual structure. This indicates that the field is not conceptually homogeneous: a stable GIS-AHP suitability core is connected to more specialized water-management, climate, resource-management and planning applications.

#### 6. Thematic Synthesis of GIS-MCDA Applications in Agricultural Land Suitability Assessment

**Table 4. Metadata-supported methodological patterns in the 132-record Scopus export**

Counts represent records containing the specified terms in the title, abstract or author-keyword fields; they should not be interpreted as verified full-text method-use frequencies.

| Indicator                           | Records | %    |
|-------------------------------------|---------|------|
| AHP-related terminology             | 109     | 82.6 |
| MCDA/MCDM terminology               | 66      | 50.0 |
| Weighted overlay/linear combination | 26      | 19.7 |
| Fuzzy methods                       | 15      | 11.4 |
| Fuzzy AHP                           | 12      | 9.1  |
| Parametric approach                 | 7       | 5.3  |
| TOPSIS                              | 5       | 3.8  |
| OWA                                 | 3       | 2.3  |
| Stakeholder/expert participation    | 36      | 27.3 |

|                                   |    |      |
|-----------------------------------|----|------|
| Climate change/scenario terms     | 19 | 14.4 |
| Validation/accuracy-related terms | 17 | 12.9 |
| Sensitivity-analysis terms        | 9  | 6.8  |
| Uncertainty-related terms         | 2  | 1.5  |

### 6.1 Overview of Included Studies

The qualitative synthesis comprises 132 studies according to the supplied PRISMA workflow. Across the supplied science-mapping outputs, the corpus is characterized by strong recurrence of GIS, land suitability, AHP, multicriteria analysis, decision making, land use, spatial analysis, and crop-oriented applications. The network structure also shows substantial linkage with irrigation, watersheds, water availability, climate change, sustainability, and land-use planning.

### 6.2 GIS Datasets and Suitability Criteria

The keyword network indicates that published suitability studies integrate a wide range of spatially represented criteria. Visible terms include topography, textures, soils, climate change, rainfall, water availability, irrigation, watersheds, land use, land-use planning, and crop production. This pattern is consistent with the manuscript's conceptual description of GIS-MCDA as a framework for integrating heterogeneous spatial criteria. The supplied MCA map further links soils, textures, rain, groundwater, river basins, watersheds, irrigation systems, and land management within the same conceptual structure. Metadata-supported coding indicates particularly frequent representation of soil-related variables (119 records; 90.2%), slope/topography/elevation (95; 72.0%), rainfall/climate variables (60; 45.5%), land-use/land-cover variables (60; 45.5%), socio-economic terms (60; 45.5%), water/irrigation variables (37; 28.0%), distance/accessibility variables (35; 26.5%), and remote-sensing/vegetation variables (29; 22.0%). These figures describe term occurrence rather than a standardized inventory of the actual criteria used in each full-text study.

### 6.3 Criteria Standardization and Weighting Techniques

AHP is one of the most visible methodological terms in the supplied maps. The co-occurrence network repeatedly displays analytical hierarchy process/AHP close to GIS and land suitability, and the thematic map places agricultural land–AHP–crop production among the motor themes. The outputs also contain terms associated with fuzzy AHP and fuzzy mathematics in the MCA plot, indicating that fuzzy extensions form part of the conceptual landscape. The supplied figures do not provide enough information to calculate the frequency of each weighting technique, so the manuscript should describe these as visible methodological patterns rather than report method percentages. The metadata-supported synthesis shows a strong concentration of AHP-related terminology, appearing in 109 of the 132 records (82.6%). Weighted overlay or linear-combination terminology occurs in 26 records (19.7%), while fuzzy methods occur in 15 records (11.4%). TOPSIS and OWA are less frequently represented, occurring in five and three records, respectively. These results suggest that AHP remains the dominant methodological vocabulary in the current corpus, although several alternative decision rules and fuzzy extensions are present.

### 6.4 MCDA Methods and Decision-Making Approaches

The central methodological vocabulary is dominated by multicriteria analysis, MCDA, AHP, analytical hierarchy process, decision making, and decision analysis. The network links these methods directly with land suitability, GIS, land evaluation, land-use planning, irrigation, and crop production. This indicates that MCDA is being used primarily as an aggregation and decision-support layer within spatial agricultural assessment rather than as a standalone theoretical topic. The presence of fuzzy AHP and fuzzy mathematics in the MCA output indicates methodological diversification beyond a single deterministic AHP formulation.

### 6.5 Approaches to GIS-MCDA Integration

GIS and MCDA appear as a tightly integrated conceptual pair throughout the supplied maps. GIS is positioned as a major central node, while AHP/MCDA and land suitability form closely connected methodological and application nodes. The overlay and thematic maps further connect this integration to land use, sustainable development, crop production, water management, and site-selection problems. The present evidence therefore supports describing GIS-MCDA as the principal integrated analytical framework represented in the corpus.

### 6.6 Suitability Modelling and Output Representation

The visible application vocabulary includes land suitability, suitability analysis, land evaluation, site selection, land-use planning, crop production, wheat, rice, irrigation, watersheds, urban area, and alternative agriculture. This suggests that suitability outputs are applied to both crop-production and broader land-management or site-selection questions. The MCA map additionally positions urban planning, semi-arid region, watershed, soil erosion, vulnerability, and agricultural land as related application contexts.

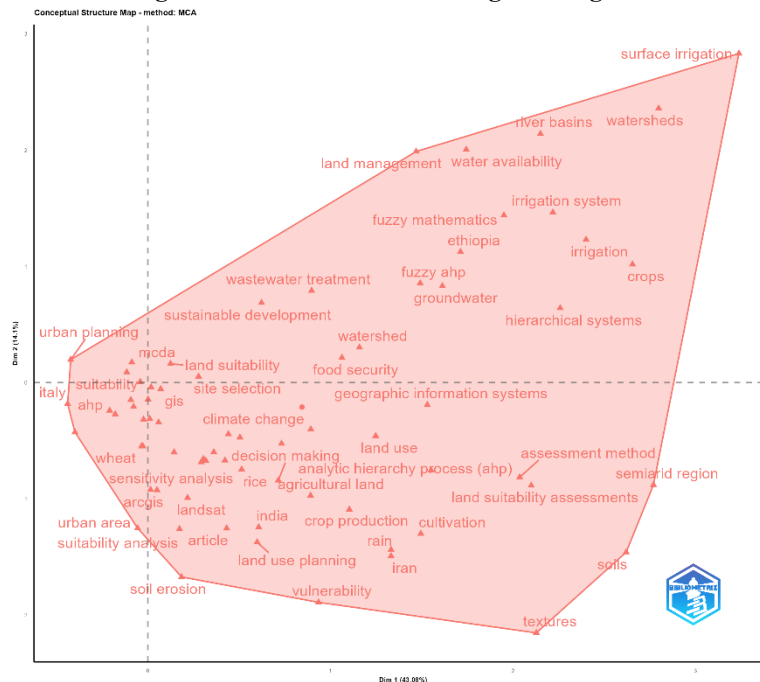
### 6.7 Uncertainty, Sensitivity and Validation Practices

Sensitivity analysis is an explicit keyword in the supplied co-occurrence and conceptual-structure outputs, indicating that robustness testing is represented in the literature. However, the available files do not contain study-level extraction counts for sensitivity analysis, uncertainty analysis, or independent validation. The review should therefore distinguish between the presence of these concepts in the bibliometric corpus and the actual proportion of included studies applying each practice. Sensitivity-analysis terminology is present in nine records (6.8%), uncertainty-related terminology in two records (1.5%), and validation or accuracy-related terminology in 17 records (12.9%). These figures are based on title, abstract and author-keyword evidence and therefore cannot establish whether an independent validation, formal uncertainty analysis or quantitative sensitivity procedure was

actually implemented. Nevertheless, the relatively limited visibility of these terms provides a clear reporting priority for future GIS-MCDA land-suitability studies.

## 6.8 Crop-, Region-, and Application-Specific Patterns

**Figure 7. Hierarchical clustering dendrogram**



**Figure 8. Conceptual structure map based on multiple correspondence analysis (MCA). Dimension 1 explains 43.08% and Dimension 2 explains 14.14% of the displayed inertia**

The hierarchical clustering dendrogram further indicates several related thematic groups rather than a single homogeneous research stream. Because exact cluster membership is sensitive to the clustering parameters and the supplied output does not report a preferred cut level, the dendrogram is interpreted as evidence of thematic relatedness rather than as a definitive set of named clusters. Crop-specific terms include rice, wheat, crop production, crops, agriculture, and cultivation. Water-related applications are also prominent, with irrigation, irrigation system, surface irrigation, groundwater, river basins, watersheds, and water availability visible in the network and MCA plots. Geographic/application terms include India, Ethiopia, Iran, semi-arid region, urban planning, urban area, and land-use planning. The combined pattern indicates that GIS-MCDA research is applied across crop, water, regional planning, and resource-management contexts rather than being confined to a single crop or geographic setting.

## 7. DISCUSSION

### 7.1 Convergence of Bibliometric and Thematic Findings

The bibliometric outputs converge on a clear central structure: GIS, land suitability, AHP/analytical hierarchy process, multicriteria analysis, and decision making are repeatedly prominent across co-occurrence, density, overlay, thematic, and conceptual-structure maps. The country maps add a geographic dimension to this structure by showing an international collaboration network with India as the largest visible node and strong representation from China, the United States, Saudi Arabia, Turkey, and Ethiopia. The field therefore shows convergence between a stable analytical core and a geographically distributed research community.

### 7.2 Methodological Evolution of GIS-MCDA over Two Decades

The temporal overlay suggests that the methodological core remains stable while the application vocabulary has broadened. GIS, AHP, and land suitability remain central, whereas later-looking terms on the 2020–2023 scale include decision analysis, site selection, climate change, irrigation, watersheds, and related applied topics. The thematic map similarly places land use, sustainable development, agricultural land, and crop production in the motor-theme quadrant. These outputs collectively indicate expansion of application domains around an established GIS-MCDA core.

### 7.3 Strengths and Limitations of Existing Approaches

The principal strength visible in the corpus is methodological integration: GIS provides the spatial environment while MCDA/AHP supplies explicit multi-criteria decision logic. The network also shows applications to diverse agricultural and resource-management problems. At the same time, the supplied outputs do not permit a quantitative assessment of how often studies perform independent validation, uncertainty analysis, or sensitivity testing. Those issues therefore remain important targets for the systematic study-level synthesis rather than conclusions to be quantified from the current maps alone.

### 7.4 Research Gaps

The available science maps highlight several areas for closer study. First, the strong concentration of GIS–AHP–land suitability terms suggests a need to determine whether methodological choices are diversifying sufficiently

beyond established AHP workflows. Second, the overlay map indicates expanding attention to climate change, decision analysis, site selection, and water-related applications; the substantive review should determine whether these applications change the underlying modelling practice or mainly change the application context. Third, the presence of sensitivity analysis and uncertainty-related terms should be followed by study-level coding to determine how systematically these practices are implemented. Finally, the country network demonstrates international collaboration, but the supplied outputs do not reveal whether collaboration intensity is evenly distributed across regions. The strong concentration of AHP-related terminology indicates that the field remains heavily anchored in pairwise-comparison weighting. Future research should therefore emphasize transparent comparison of alternative weighting and aggregation strategies, rather than simply combining additional criteria within conventional AHP workflows. Sensitivity, uncertainty and validation are much less visible in the metadata than GIS, land suitability and AHP. Future studies should report how changes in criteria, weights, standardization functions and decision rules affect the final suitability map. Climate change and scenario-related terms are increasingly visible in the later literature, but greater integration of current and projected climate conditions is needed to move from static suitability mapping toward temporally explicit suitability assessment. Socio-economic variables and stakeholder/expert participation occur less consistently than physical environmental criteria. Future suitability frameworks should make stakeholder preferences, accessibility, land tenure, economic feasibility and implementation constraints more explicit. A stronger reporting standard is required for criterion selection, weight elicitation, standardization functions, class thresholds, sensitivity analysis, uncertainty treatment and independent validation. Without this information, technically sophisticated suitability maps remain difficult to reproduce or compare across regions.

### **7.5 Future Research Directions**

Future work indicated by the supplied corpus includes stronger treatment of uncertainty and validation; wider comparison of alternative weighting and aggregation approaches; integration of climate-change variables, water availability and watershed processes; and continued development of GIS-MCDA applications for land-use planning and crop-production decisions. The thematic and overlay outputs also indicate scope for research that connects methodological development with sustainability and integrated land-management objectives.

### **7.6 Limitations of the Review**

Additional limitations arise from the construction of the Scopus corpus. The search was restricted to English-language, open-access journal articles and therefore may exclude relevant studies published in other languages, document types or subscription-only journals. The Open Access filter reduced the thematically filtered dataset from 295 to 132 records and may therefore introduce accessibility-related selection bias. In addition, the supplied export contains some GIS-MCDA studies whose applications are outside agricultural land suitability, indicating that an additional title/abstract scope-screening step is necessary before agriculture-specific conclusions are generalized. Bibliometric results are also sensitive to keyword normalization, counting method and inclusion thresholds, which should therefore be reported explicitly. Finally, citation counts are cumulative and favour older publications, while recent publications may be underrepresented in citation-based indicators.

## **8. CONCLUSION**

This review demonstrates that GIS-MCDA research in land-suitability assessment has expanded substantially over the 2006–2025 period, with particularly strong publication growth after 2020. The bibliometric structure is centred on GIS, land suitability, AHP/analytical hierarchy process, multicriteria analysis and decision making, while newer applications increasingly connect these methods with irrigation, watersheds, climate change, land-use planning and sustainable development. The keyword-density and co-occurrence results confirm the central role of GIS and AHP, while the MCA results indicate a broader conceptual structure linking crop production, agricultural land, water management, irrigation and regional planning. The metadata-supported synthesis further indicates a strong methodological concentration on AHP, with weighted overlay and fuzzy approaches forming important secondary approaches. At the same time, sensitivity analysis, uncertainty assessment and validation are less visible within the available metadata and therefore represent important priorities for improved methodological reporting and reproducibility. The field is consequently characterized by a relatively stable GIS-MCDA methodological core accompanied by expanding application contexts. Future progress will depend on more transparent criteria selection, improved comparison of weighting and aggregation methods, stronger uncertainty and sensitivity assessment, independent validation, greater inclusion of socio-economic and stakeholder dimensions, and stronger integration of climate and water-resource dynamics. The final agriculture-specific corpus should also be established through explicit scope screening so that non-agricultural GIS-MCDA applications do not influence conclusions intended specifically for agricultural land suitability.

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