# Theoretical and Methodological Basis of Mapping the Ecological State of Irrigated Lands in the Conditions of Climate Change: Bibliometric Analysis

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**Abstract**

The ecological state of irrigated lands is becoming increasingly complex under the influence of climate change and growing anthropogenic pressures. In this study, an integrated approach was applied to assess and map the ecological condition of irrigated lands by combining geographic information systems (GIS), remote sensing data, and field-based observations. Particular attention was paid to identifying and analyzing critical issues such as soil salinization, depletion of water resources, and overall agroecosystem degradation, which together threaten agricultural productivity and sustainability. The results of the research provide a scientific basis for identifying priority areas where ecological monitoring should be strengthened, while also highlighting opportunities for sustainable resource management. Based on these findings, practical recommendations were developed to optimize irrigation systems, improve water-use efficiency, and reduce environmental risks. These measures, grounded in modern geotechnologies, are expected to contribute to the long-term resilience of irrigated agriculture and the protection of fragile agroecosystems.

## 1. Introduction

In connection with climate change and increased human activity, consistent monitoring of the ecological state of irrigated agricultural lands is becoming increasingly important (Wang et al., 2021, Oymatov et.al., 2023). Modern satellite technologies and remote sensing methods have significantly expanded the possibilities for studying complex processes such as soil salinization, moisture deficiency, and vegetation cover degradation (Goldshleger et al., 2010). In recent years, studies on determining the soil salinity index (Land Degradation Index) in irrigated lands using Landsat-OLI and Sentinel-MSI data (Potential of land degradation index for soil salinity mapping) have shown that high spectral resolution satellite images are highly effective in detecting changes in soil salinity at the macro and micro levels .

Similarly, work on estimating evapotranspiration in southeastern Afghanistan using the GCOM-C algorithm highlights the importance of accurate data in optimizing irrigation regimes (Wali et al., 2024). A study on soil electrical conductivity estimation using Quantile Regression Forests using the LUCAS soil database in the European Union demonstrates the effectiveness of statistical modeling in estimating soil physicochemical properties at the macro level (Schillaci et al., 2025). A study on the dynamics of irrigated land in Nepal using MODIS NDVI data and Google Earth Engine platform confirms the importance of GIS in planning irrigation infrastructure at a regional scale (Ghimire et al., 2025). Studies on the spatiotemporal dynamics of irrigated lands in Inner Mongolia and their microclimatic impact aim to identify the positive effects of irrigation on the local climate (Li et al., 2024), while work on spring mapping in Argentina demonstrates the effectiveness of probabilistic approaches in ecosystem management (Navarro Rau et al., 2025). A framework developed to separate evapotranspiration processes in natural and agricultural landscapes using machine learning techniques allows for the individual assessment of the impact of climatic and anthropogenic factors (Liang et al., 2024). Studies on improving irrigation management within the framework of the European Water Framework Directive demonstrate the practical application of satellite models integrated with agrometeorological data (Longo-Minnolo et al., 2024). A study on the assessment of soil organic carbon content in Mediterranean climate regions, taking into account long-term climate conditions, provides a deeper understanding of the role of climate factors in maintaining soil fertility (Fernandes et al., 2019). Overall, these studies demonstrate the importance of modern geoinformation technologies, satellite data, and statistical analysis methods in assessing and optimizing the ecological status of irrigated lands, creating a solid theoretical foundation for future scientific research in environmental protection and sustainable agricultural development.

## 2. Research methodology

This systematic literature review was conducted to provide a comprehensive analysis of scientific articles published in Scopus-indexed journals from 2000 to 2024 on the theoretical and methodological foundations of mapping the ecological status of irrigated lands under climate change. The analysis was conducted on a total of 83 articles in April 2024. The articles were downloaded as CSV and RIS format files and analyzed using Microsoft Excel, VOSviewer, and MapChart.

### 2.1 Criteria for Reviewing and Selecting Articles

The search process was carried out in the following stages: first, articles published in English in the Scopus database using the keywords “climate change” and “irrigated land” were selected and entered into a spreadsheet. The selection criteria were set as the time period 2000–2024, and the fields of study were environmental sciences, earth and planetary sciences, and

agricultural sciences. The analysis was carried out in May 2025 (Figure 1).

The following exclusion criteria were used in the screening process:

- The title and annotation of the article are in English, but the full text is written in another language;
- Articles on scientific fields that are not related to the research topic;
- The specified keywords (Irrigation, mapping, climate) are not present in the article;
- Articles that do not have a DOI number and are difficult to find the full text.

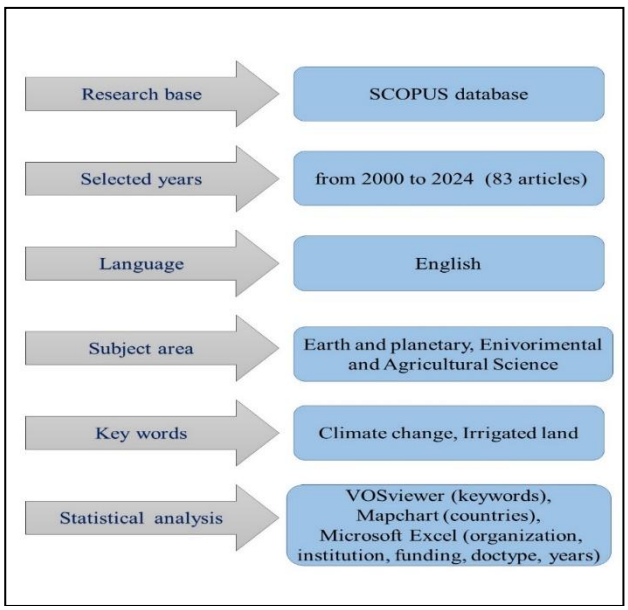


Figure 1. Scheme of the research methodology

### 2.2 Bibliometric analysis

The downloaded bibliographic data in CSV format was first imported into Microsoft Excel and prepared for analysis. At this stage, the data was carefully reviewed, and incorrect entries, duplicate data, empty cells, and values in inconsistent formats were identified, corrected, or removed. Excel served as the main tool for sorting, cleaning, and preparing the data for analysis. Then, an analysis based on the frequency of co-authorship of authors was performed using VOSviewer. This allowed the connections between scientific topics to be identified and the authors of the most relevant articles to be grouped into clusters. VOSviewer allowed for the graphical representation and analysis of bibliometric networks. As a result, the main areas and topics that researchers are focusing on were identified, and important conclusions were drawn about the internal structure of the scientific field.

## 3. Results

A total of 83 publications were analyzed within the framework of this study. This analysis clearly demonstrated the diversity of scientific work on the topic in terms of form and content. As shown in Figure 2, journal articles occupy the largest share, reaching 65. This indicates that scientific research on the topic is mainly published in scientific journals. Conference proceedings are also noteworthy as an important source, with 12 articles falling into this category. In addition, 3 studies were published as literature reviews, and 1 as a book chapter. 1 revised edition and 1 note were also included in the analysis. These data confirm that the theoretical and practical aspects of research on the topic are widely discussed, and at the same time, the leading role of scientific journals. There are 3 articles devoted to literature reviews, which are important in identifying the development trends of the topic and existing gaps in the knowledge base.

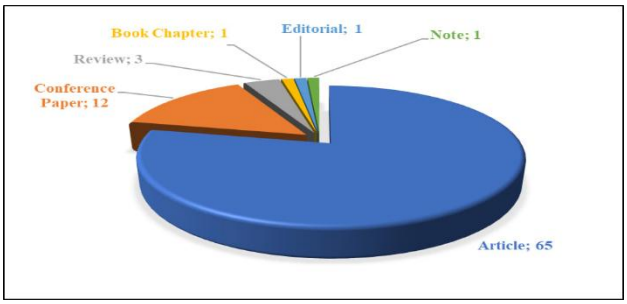


Figure 2. Distribution of document types in the years analyzed.

Also, 1 article was rejected from publication, which also reflects the rigor of the selection process by scientific journals. In general, the analysis of these publications shows that research on the theoretical and methodological foundations of mapping the ecological state of irrigated lands under climate change has become more active in recent years, and various forms of scientific work are being carried out in this direction (Figure 2).

### 3.1 Distribution of literature review by year

During the period 2000–2024, the number of published articles using the theoretical and methodological foundations of mapping the ecological state of irrigated lands under climate change conditions has steadily increased. In particular, the publication of 17 articles in 2021 and 7 in 2023 indicates an increasing interest in the topic. This may be due to global climate change, the depletion of freshwater resources and the need for their effective management. In 2024, attention to this topic remains high and amounted to 12 (Figure 3).

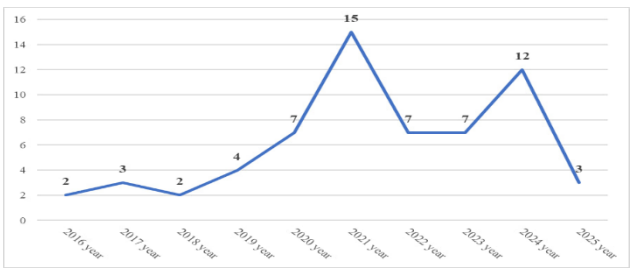


Figure 3. Scientific publications in the last 10 years.

### 3.2 Distribution of literature review by country

According to the results of the analysis, the largest number of scientific works on cassava cultivation and production were published in China (24 articles) and the United States (17 articles). It was also observed that active scientific activity on this topic is being carried out in countries such as Italy (10), India (6), Spain (5), Germany (4), Iran (4), the Netherlands (4), the United Kingdom (4) and Canada (3). Most of these countries are developed in the agricultural sector and are leaders in the development and application of cassava cultivation technologies adapted to climatic conditions (Figure 4).

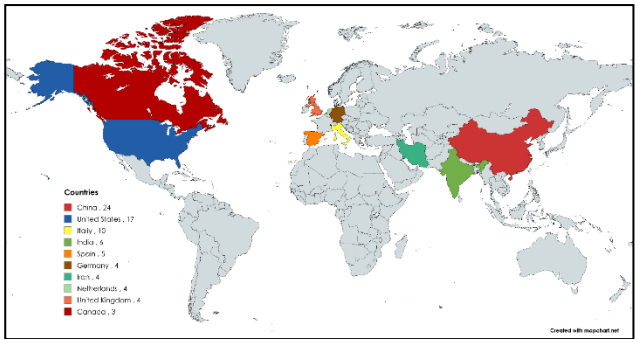


Figure 4. Top 10 countries active in article authorship.

### 3.3 Most cited articles in Scopus database

According to the results of bibliometric analysis, there are a number of authoritative articles among the scientific research conducted on mapping and monitoring of irrigated lands. Among the 10 articles listed in the table, the most cited is the article by BD Wardlow and co-authors entitled “Large-area crop mapping using time-series MODIS 250 m NDVI data: An assessment for the US Central Great Plains”, published in the journal Remote Sensing of Environment in 2008. This article has received 698 citations to date, which indicates the relevance of the topic and the effectiveness of the authors' methodological approach. Also, the article by C. Milesi et al. (2005) published in the journal “Environmental Management” also occupies one of the top places with 570 citations. This article is a major work on mapping the biogeochemical cycle of turf grasses in the United States, and is also one of the main works related to the monitoring of irrigated lands. In terms of journals, Remote Sensing of Environment contains three of the most cited articles, all of which are among the scientific works with a high impact factor.
When viewed by publication year, the majority of the articles fall into the period 2005–2012. This confirms that it was during this period that technologies such as MODIS, Landsat, and Google Earth Engine began to be actively used in the scientific community.

| № | Article name | Authors | Public year | Journal name | Volume | Total citations |
|---|---|---|---|---|---|---|
| 1 | Large-area crop mapping using time-series MODIS 250B m NDVI data: An assessment for the U.S. Central Great Plains | BD Wardlow and et.al (Wardlow and Egbert, 2008) | 2008 | Remote Sensing of Environment | 112 | 698 |
| 2 | Mapping and modeling the biogeochemical cycling of turf grasses in the United States | C Milesi and et.al (Milesi et al., 2005) | 2005 | Environmental Management | 36 | 570 |
| 3 | Genetic approaches to crop improvement: Responding to environmental and population changes | S Takeda and et.al (Takeda and Matsuoka, 2008) | 2008 | Nature Reviews Genetics | 9 | 342 |
| 4 | Soil Salinity and Sodicity in Drylands: A Review of Causes, Effects, Monitoring, and Restoration Measures | I Stavi and et.al (Stavi et al., 2021) | 2021 | Frontiers in Environmental Science | 9 | 245 |
| 5 | Mapping three decades of annual irrigation across the US High Plains Aquifer using Landsat and Google Earth Engine | JM Deines and et.al (Deines et al., 2019) | 2019 | Remote Sensing of Environment | 233 | 146 |
| 6 | Soil surface moisture estimation over a semi-arid region using ENVISAT ASAR radar data for soil evaporation evaluation | M Zribi and et.al (Zribi et al., 2011) | 2011 | Hydrology and Earth System Sciences | 15 | 130 |
| 7 | Merging remote sensing data and national agricultural statistics to model change in irrigated agriculture | JF Brown and et.al (Brown and Pervez, 2014) | 2014 | Agricultural Systems | 127 | 116 |
| 8 | Mapping irrigated cropland extent across the conterminous United States at 30mBm resolution using a semi-automatic training approach on Google Earth Engine | Y Xie and et.al (Xie et al., 2019) | 2019 | ISPRS Journal of Photogrammetry and Remote Sensing | 155 | 109 |
| 9 | Assessing water availability in a semi-arid watershed of southern India using a semi-distributed model | J Perrin and et.al (Perrin et al., 2012) | 2012 | Journal of Hydrology | 460-461 | 95 |
| 10 | Water management problems in the Ethiopian rift: Challenges for development | T Ayenew and et.al (Ayenew, 2007) | 2007 | Journal of African Earth Sciences | 48 | 92 |

Table 1. List of most cited scientific articles on irrigated land mapping

### 3.4 Distribution of literature review by field

Mapping and analysis of irrigated lands under climate change has been widely used in various scientific fields. According to the results of bibliometric analysis, the largest share falls on environmental sciences (41) and earth and planetary sciences (35). These fields mainly focus on monitoring the ecological state of irrigated lands and assessing the impact of climate change. Also, research in this area has been conducted in such fields as agricultural and biological sciences (32), engineering (9), computer sciences (6), biochemistry (6), physics and astronomy (5), medicine (3) and energy (2). In these fields, issues of irrigated lands, natural resources and sustainable development have been studied, playing an important role in creating a reliable database for scientific analysis (Figure 5).

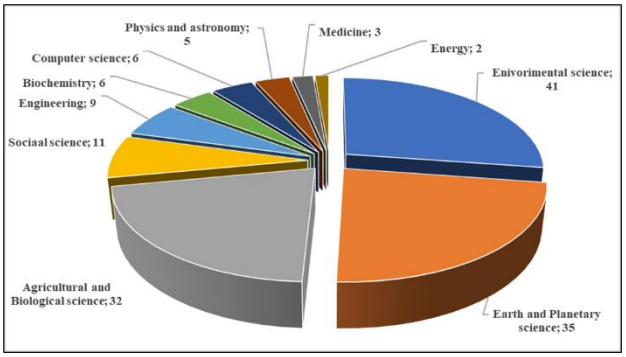


Figure 5. Most common scientific fields in irrigated land mapping studies.

### 3.5 Researchers who have conducted the most scientific research

In the scientific research on the ecological status of irrigated lands, Brown, J.F. stands out as the leading author - he actively participated in research in this direction with a total of 4 articles. This shows that he occupies a leading position in analytical work on the assessment of land resources under climate change. Xie, Y. took second place with 3 articles, and his work is probably focused on vegetation indices or soil moisture monitoring. Authors such as Amyay, M., Deines, J.M., Pervez, M.S., Lahrach, A., Lark, T.J., and Zhu, X. were active on this topic with 2 articles each. These authors probably developed a methodology for ecological monitoring and mapping of irrigated lands using Landsat or Sentinel data. At the same time, Abdou, A. and Aalami, M.T. Researchers such as participated with 1 article each, which indicates that they are conducting research in a new or unique direction in this field (Figure 6).

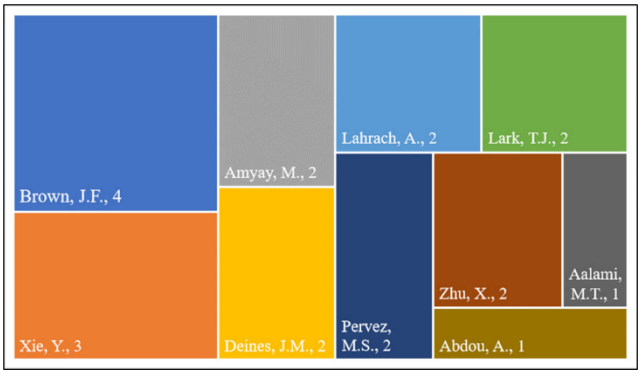


Figure 6. Most active authors.

### 3.6 Distribution of literature review by institutions that conducted the most research

In recent years, the Chinese Academy of Sciences has been the most active organization in scientific research on the ecological status assessment and mapping of irrigated lands, taking the lead in this area with 12 articles. This institute is noteworthy as a center for comprehensive research on remote sensing, ecological analysis, and land resource management under climate change.

The University of the Chinese Academy of Sciences has also actively participated with 5 articles, which indicates a high level of coordination of scientific research activities in China. In addition, the Ministry of Education of the People's Republic of China and Beijing Normal University have made significant contributions in this area with 4 articles each. Prestigious scientific centers such as the United States Geological Survey, Université Toulouse III-Paul Sabatier, University of Wisconsin-Madison, and State Key Laboratory of Remote Sensing Science have participated in international research with 3 articles each. All this indicates the strengthening of knowledge exchange and transnational scientific cooperation in this area. The Northeast Institute of Geography and Agroecology and the Universiteit Utrecht each complete the list with 2 articles, demonstrating the relevance of the topic in different regions (Figure 7).

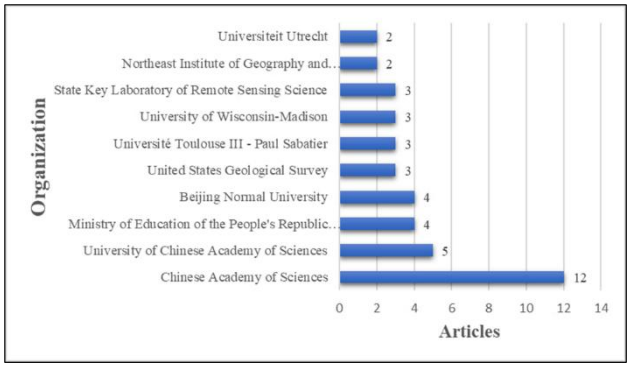


Figure 7. Leading scientific organizations in terms of research.

### 3.7 Distribution of literature review by funding sources

In recent years, the organization that has funded the most research on the ecological status of irrigated lands under climate change is the National Natural Science Foundation of China, which has supported 8 articles. The China Ministry of Science and Technology (6) and the Chinese Academy of Sciences (5) have also actively participated. Organizations such as the U.S. Geological Survey and the Department of the Interior of the United States are also among the leading funders in this field, with 4–5 articles. Major scientific centers such as NASA, the European Commission, and the European Space Agency have also contributed. This shows that the issue of mapping the ecological status of irrigated lands is relevant on a global scale. (Figure 8).

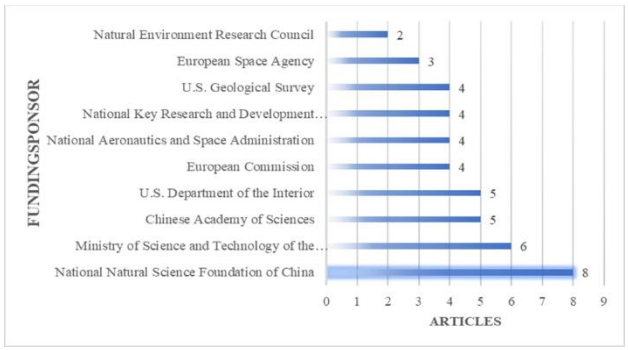


Figure 8. The most research-funded foundations.

### 3.8 Keyword analysis of literature review

As a result of the analysis carried out using the VOSviewer program, a network of scientific collaboration between authors working on the topic of irrigated land mapping was identified. According to the results of the visualization, 1 cluster consisting of 17 authors was observed. This cluster indicates the existence of close scientific collaboration between the authors. The following authors stand out in this cluster: Panagos P., Montanarella L., Schillaci C., and Balog K. They are known as the authors of influential scientific works on irrigated land, soil degradation, land resource monitoring, and the practical application of GIS/remote sensing technologies. Within this network, authors such as Panagos P. and Montanarella L. are particularly central, and it is determined that they worked in numerous collaborations with other authors. This allows them to be described as the “node point” of the cluster. Their scientific activity and collaboration on several articles played an important role in the formation of the scientific network in this area.

Other authors in the network, such as Kargas G., Kaya F., Jones A., and Scarpa S., although with relatively few collaborations, have also contributed to the research on the topic and are an integral part of the scientific network. The presence of these authors demonstrates the multidisciplinary and international relevance of the topic. Overall, the formation of the cluster as a whole and the existence of strong connections indicate that there is a well-established scientific community among researchers working in this area. This serves as a solid basis for future collaborations on irrigated land mapping.

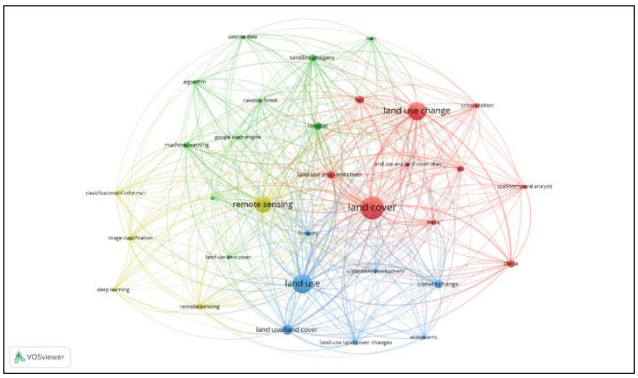


Figure 9. Most frequently used keywords in land cover research.

## 4. Discussion

Irrigated land mapping and related scientific research have become significantly more active in recent years. The relevance of this area is directly related to global climate change, water resource constraints, agricultural intensification, and food security. The analysis of the research shows that the most cited articles in this area were created mainly by scientists from the USA, the European Union, and other developed countries. The methods developed by them, in particular, advanced methodologies used in irrigated land mapping based on open satellite platforms such as MODIS, Landsat, ENVISAT, and Google Earth Engine, also serve as the main theoretical and practical direction for other researchers. Among the 10 analyzed articles, the study by BD Wardlow (2008) on mapping large-scale cropland in the central region of the USA based on MODIS NDVI data received the most citations (698). This article has also served as a basis for many other works. Similar leading articles have also used modern remote sensing technologies, radar and multispectral imagery, statistical models and cloud computing platforms such as GEE as the main tools.

The analysis of the author network identified using the VOSviewer program during the bibliometric analysis shows that authors such as Panagos, P. , Montanarella, L. , Schillaci, C. , Szatmári, G. have been highly active and collaborative in

research on irrigated lands and soil degradation. A single cluster of 17 scientists indicates the existence of strong scientific ties between the authors. This indicates a certain regional and thematic consolidation in this field. In particular, research conducted in the European Union countries shows a high level of international scientific networks and institutional cooperation. In addition, many articles mention climate change, land degradation, soil salinity, water supply and irrigation efficiency as important topics. These aspects indicate that research is not only of scientific but also practical importance. In particular, such developments play a key role in water resource conservation, sustainable management of cropland and agro-ecological monitoring. Overall, this bibliometric analysis confirms that the topic of irrigated land mapping is one of the broadest and most relevant areas in the global scientific space. In the future, research in this area is expected to develop further through technological integration, international cooperation and the effective use of open source data. In particular, by strengthening cooperation between scientific networks and authors, the quality of scientific results and their practical utility will increase.

#### 4.1.1 Limitations

Since this literature review was conducted only on articles published in English in Scopus between 2000 and 2024, important scientific works published in other years or in other languages may have been excluded from the analysis. Also, since the bibliometric analysis was conducted only based on available data and keywords, it is possible that some relevant but rare studies or studies expressed in other terms may have been missed. The results of the analysis are limited by the capabilities of VOSviewer and Microsoft Excel, which do not allow for deep semantic analysis.

## 5. Conclusion

In recent years, scientific research on the assessment and mapping of the ecological state of irrigated lands under climate change has become significantly more active worldwide. The growing number of studies in this area indicates not only the global relevance of the problems, but also the development of solutions based on modern technological approaches - remote sensing, GIS, satellite data and machine learning. The results of the bibliometric analysis showed that organizations such as the National Natural Science Foundation of China, the Chinese Ministry of Science and Technology, and the Chinese Academy of Sciences are leading in funding research on this topic. This indicates that the Chinese science system provides a strategic priority in this area. Also, the participation of major organizations such as the US Geological Survey, NASA, the European Commission and the European Space Agency indicates that this topic has gained wide attention in the international scientific community. According to the results of the analysis by scientific institutions, the Chinese Academy of Sciences stands out as the most active organization with 12 articles. The scientific activities of this institute are significant not only in terms of the number of articles, but also in terms of their technological approach and comprehensive scope. Higher education institutions such as the University of Chinese Academy of Sciences and Beijing Normal University are also actively participating, indicating that research is being conducted in a coordinated and systematic manner in China.

Among the authors, Brown, JF stands out as a leading scientist. His work is probably related to long-term monitoring work based on Landsat data. Xie, Y. , Deines, JM , Pervez, MS , Zhu, X. Although these authors work in different regions, their common goal is to identify environmental risks early and develop sustainable management measures.

Most of the articles analyzed in the field were conducted in the fields of environmental sciences, earth and planetary sciences, agriculture, biology, engineering, and computer sciences. This means that the topic is multidisciplinary and complex, requiring the joint study of technical, environmental and economic factors. When analyzed over the years, a gradual increase in the number of articles is observed from 2000 to 2024. In particular, the increase in the number of articles published in 2021–2024 indicates an increased attention to the problems of climate change and water resources in the scientific community. These studies serve as an important source for identifying and predicting factors affecting water scarcity, land degradation and food security at the global level.

In general, the results of the bibliometric analysis show that scientific research on the assessment of the ecological state of irrigated lands is being conducted by an increasing number of countries, institutions and authors. This contributes to the strengthening of transnational scientific cooperation, the popularization of open platforms and the expansion of innovative approaches to combating environmental problems. In the future, research in this area is expected to take on a more integrated form and play an important role in the formation of climate-adapted land resource management strategies

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