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# Progress and prospect of ecological risks of land use change

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Ecological risks reflect the extent to which ecosystems are threatened by human activities and environmental changes. Changes in land use/land cover can have profound impacts on the regional ecological environment, such as land desertification, soil erosion, a sharp reduction in forest resources, and biodiversity loss. To objectively reveal the current research status, we conducted an econometric analysis of relevant research papers from 1991 to 2021, published in Web of Science. The results are as follows: 1) In the past 30 years, the number of publications in the field of ecological risks of land use change increased, and the period from 1991 to 2021 can be divided into three stages: the budding period from 1991 to 2008, the rising period from 2009 to 2015, and the high-yield period from 2016 to 2021. 2) Research in this field covered 104 countries or regions, mainly in Asia, the Americas, and Europe. The top three cited countries were the US, China, and the UK. 3) The high-frequency keywords of land use change in the field of ecological risks mainly included "land use", "management", "climate change", and "risk and ecology". Keywords frequently appeared in Tree Map, such as "dynamics", "framework", and "model", indicating the main research methods in this field. Based on the results, we suggest that for the future development of this research field, the evaluation method system should be improved and multidisciplinary research should be strengthened, ultimately exploring new ways to solve the current ecological problems.

KEYWORDS

**bibliometrix, bibliometrics, ecological risk, LUCC, cluster analysis**

## 1 Introduction

Human activities profoundly affect the Earth's surface (Turner et al., 2007). Changes in land use and management practices result in land use/land cover change (LUCC), which further have a range of environmental, ecological, and social impacts on land systems (Gong et al., 2015; Jin et al., 2019). In this context, LUCC reflects the interaction between natural factors and human activities in the regional ecological environment and has a profound impact on terrestrial ecosystems, global biodiversity, and regional ecological security (Sala et al., 2000; Xie et al., 2013). In the past few decades, the intensity of human land use has increased, with various negative impacts on the ecological

environment (Lu et al., 2018). For example, land desertification, soil erosion, a sharp reduction of forest resources and biodiversity loss (Valyaev et al., 2009; Song and Deng, 2017) seriously threaten the ecological security of humans (Song and Pijanowski, 2014; Zhang et al., 2014). In view of this, it is urgent to conduct in-depth research on the ecological risks caused by land use changes, promote ecological recovery and sustainable development, and provide a strong scientific basis for future studies on the harmonious relationship between human activities and the ecological environment (Liang et al., 2020).

Land use change is closely related to ecological risks, and the ecological impacts of different land use modes and intensities are regional and cumulative (Overmars et al., 2003). In recent years, land use intensity as increased, leading to the gradual destruction of the ecological environment. Land use change alters the structure and functions of ecosystems and affects a series of ecological processes in the atmosphere, soil, and water (Lambin, 1997). For example, the over-exploitation of land resources, large-scale deforestation, over-grazing, water pollution, and the over-population of cities pose regional ecological risks. Earlier studies on the ecological risks of land use mainly focused on the impacts of pollutants on ecosystems (Dale et al., 1998; Rand and Newman, 1998), whereas in recent years, more attention has been paid to the spatial distribution of ecological risks and the impact on ecosystem services (Bajocco et al., 2012; Li and Huang, 2015). With the deepening of the research on global change and ecological risks, the risks caused by land use change have attracted considerable attention. Consequently, the impact of land use change on regional and national ecological security has become an important factor (Wang et al., 2020).

Preventing ecological risks is crucial to environmental protection and sustainable land use (Guo et al., 2020). With the innovation and improvement of research methods and technologies, the ecological risks of land use change has gradually become a research hotspot in the fields of ecological risks and sustainable development. Currently, various organizations, research institutions, land management departments, and scientists are interested in the ecological risks of land use change. Some scientists used the existing model (Zhang et al., 2020) and the evaluation index (Karamesouti et al., 2015; Egidi et al., 2020) to assess the ecological risks of land use change by combining both to determine the impact of the land use structure change on the regional ecological risks (Li and Huang, 2015; Hua et al., 2018). In previous studies, the existing models based on model parameter simplification, Bayesian belief network, and GIS were improved, and new models and evaluation frameworks were developed and applied (Feng et al., 2017; Ran et al., 2022). For example, Mancino et al. (Mancino et al., 2016) proposed an improved USLE (Universal Soil Loss Equation) model to assess soil erosion risks. Liang and Song (Liang and Song, 2022) proposed a new framework for the ecological risk assessment of land use change and applied it to the Tibetan Plateau in China.

Recently, with the dramatic increase in the number of publications worldwide, it has become increasingly difficult for researchers to track relevant literature in their fields and to accurately grasp the status of research in various places. Using quantitative bibliometric methods, rich data (Silvente et al., 2018) can be processed, and this approach has been widely adopted in many disciplines. Bibliometrics is a quantitative analytical method that uses mathematical and statistical tools to measure the interrelationships and impacts of publications in a particular research field (Lee et al., 2020; Helha and Wang, 2022). Unlike other methods, bibliometric analysis tools not only visualize the connections among various pieces of information in the literature but also reveal more hidden structural features and trend (Caputo and Kargina, 2022). Based on the structured analysis of a data set, we can understand the changing trend of research in a certain field and obtain a deeper insight into the global research hotspot (Aria and Cuccurullo, 2017).

Several software packages and tools for bibliometrics have been developed, such as Bibexcel, SciMAT, bibliometrix, and citespace (Moral-Muñoz et al., 2020). For example, Guler et al. (Guler et al., 2016) discussed the specific functions of Taverna, using Taverna in the fields of bibliometrics and scientometrics. Cobo et al. (Cobo et al., 2012) proposed an open-source scientific mapping software tool, SciMAT (Scientific Cartographic Analysis Software Tool), which contains methods, algorithms, and metrics for all steps in the general scientific mapping workflow, from the pre-processing to the visualization of results. The software packages Bibliometrix and Biblioshiny (Aria and Cuccurullo, 2017), based on the R language and developed by Professor Massimo Aria in 2017, allows users to perform bibliometric and visual analysis on an interactive web interface that could be used for full bibliometric analysis and visual display. These bibliometric tools can provide technical support for relevant research.

Recently, LUCC has attracted considerable attention in the field of global ecological risks and sustainable development. Researchers from various fields have recognized LUCC as one of the main driving forces of changes in the global environment (Veldkamp and Verburg, 2004; Xie et al., 2013). However, there is still a lack of relevant macro-reviews. Whilst most recent studies focus on keyword co-occurrence analysis, journal source, and author publications, only few studies take into account the historical citation context, high-frequency keyword clustering analysis, subject evolution, future development, and direction prediction. Therefore, this paper used the Bibliometrix series to analyze and visualize the literature related to the ecological risks of land use change, considering studies published in the Web of Science from 1991 to 2021. The literature was comprehensively quantitatively analyzed and evaluated, and future development directions are proposed to provide a scientific basis for the improvement of ecological risk research in this field. The following research questions are answered: 1) how is the introduction of literature and history developing in the field

TABLE 1 Search terms in Ecological Risks of Land Use Change. LUCC = land use/land cover change.

| Order | Search terms | Order | Search terms |
|---|---|---|---|
| TS1 | Ecological risk of land use change | TS8 | Ecological environment risks of land use change |
| TS2 | Ecological risk of land cover change | TS9 | Ecological environment risks of land cover change |
| TS3 | Ecological risk of land use/cover change | TS10 | Ecological environment risks of land use/cover change |
| TS4 | Ecological risk of land use | TS11 | Ecological environment risks of land use |
| TS5 | Ecological risk of land cover | TS12 | Ecological environment risks of land cover |
| TS6 | Ecological risk of LUCC | TS13 | Ecological environment risks of LUCC |
| TS7 | Ecological risk of land use and land cover change | TS14 | Ecological environment risks of land use and land cover change |

of ecological risks of land use change? 2) Which countries have performed more research in this field? 3) What are the focus and direction of future research in this field?

# 2 Data sources and research methods

## 2.1 Data sources

In the data collection, the database containing the bibliometric data was selected, the core document was filtered, and the data were exported from the selected database. Web of Science was the citation index database in the ISI database, comprising more than 8,000 of the world's most influential, peer-reviewed, high-quality journals and containing the world's largest and most comprehensive collection of information resources. It includes more than 11,000 authoritative and high-influence academic journals in natural science, engineering, and biomedicine. This paper used the core collection in the Web of Science database as the data source. The retrieve term was "ecological risks of land use change", and we used 14 expressions (Table 1). The retrieve period was from 1991 to 2021.

First, the retrieved data were filtered, and the categories that were not related to this topic, such as medicine, chemical science, physics, and zoology, were excluded. After preprocessing, such as data deduplication and irrelevant data removal, a total of 4,044 papers in the field of ecological risks of land use change were obtained. The downloaded data were saved in text format, and each document contained several elements, such as the author's name, title, keywords, and other information that constituted the bibliographic properties of the document.

## 2.2 Research methods

### 2.2.1 Research framework

The bibliometric analysis using R-Tool facilitated more complete description, evaluation, and monitoring (Garfield et al., 1964) of the published studies. The Bibliometrix R-package (http://www.bibliometrix.org) provides a set of tools for quantitative bibliometric studies. Written in the R language, it is an open-source environment. There is a large number of efficient statistical algorithms with high-quality numerical routines and integrated data visualization (Rodríguez-Soler et al., 2020). The standard bibliometric analysis process includes five steps: study design, data collection, data analysis, data visualization, and interpretation (Silvente et al., 2018). The results can be visualized through the Bibliometrix software, which helps to quickly understand the literature in the relevant fields.

Combining the standard bibliometric analysis and the Bibliometrix software, we proposed a research framework and clarified the ideas and methods of bibliometric analysis (Figure 1). The specific steps were as follows: 1) data set collection and preprocessing, exporting the data from the selected database (Web of Science), and cleaning up the data; 2) building the operating environment required for the Bibliometrix software (Aria and Cuccurullo, 2017); 3) selecting suitable data statistical analysis methods according to the research content, such as cited paper analysis and keyword analysis; 4) visualizing the analysis results, deep data digging, and conducting comprehensive quantitative analysis and evaluation.

### 2.2.2 Analysis method

We used the Bibliometrix software package to analyze and visualize the current research status and trends in the field of ecological risks of land use change. Using coupling analysis, cluster analysis, co-citation analysis, and other methods, this paper illustrates the basic situation of ecological risks of land use change from the aspects of annual literature, research forces (countries, authors, journals), research hotspots, and topics. The current situation in the field of ecological risks of land use change was analyzed from multiple perspectives (historical citation, disciplinary evolution, and coupling analysis) to provide a reference for future research.

Coupling analysis (Kessler, 1963) measures the similarity of literature by the number of the same references cited. For example, if the same references are cited in literature A and B, a coupling relationship is formed between them, and the number of the same references they contain is called "coupling strength".

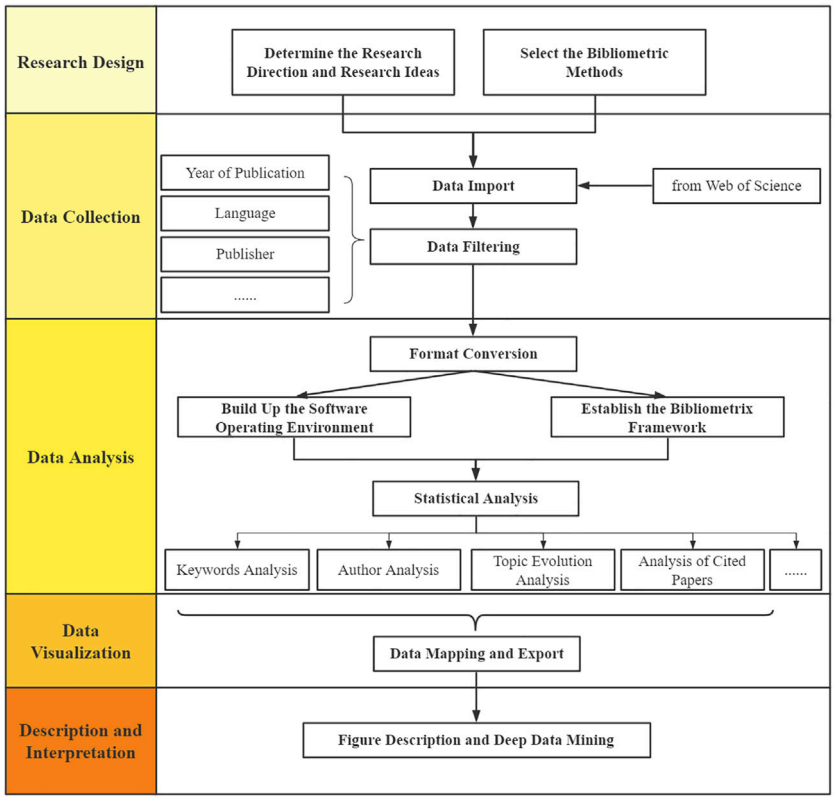


FIGURE 1
Bibliometric analysis process of the bibliometrix software.

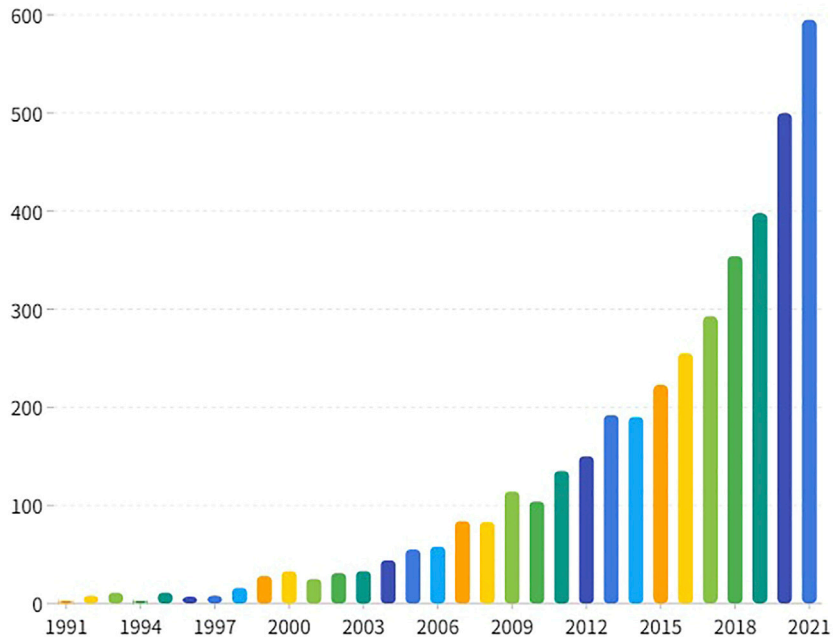


FIGURE 2
Annual scientific results output in the field of ecological risks of land use change.

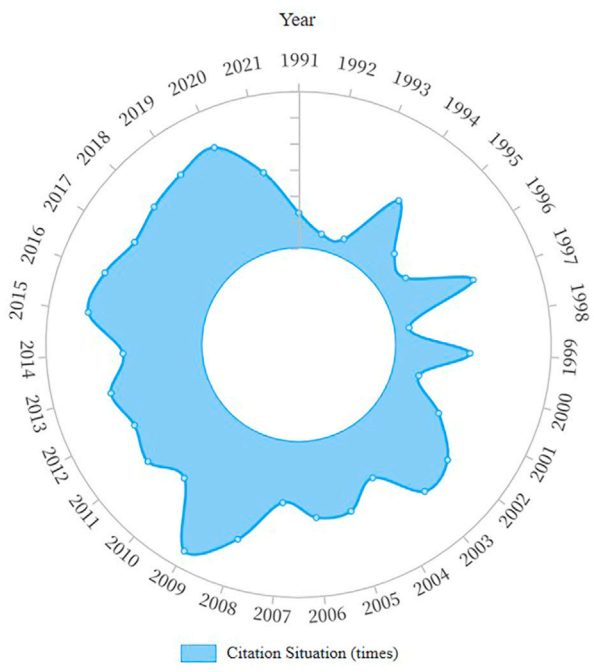


FIGURE 3
Annual cited trends of papers in the field of ecological risks of land use change.

The more similar the subject or professional content of the paper, the more likely it is that their references contain the same amount of literature. Cluster analysis (de Bem Machado et al., 2022) refers to the analytical process of grouping a collection of physical or abstract objects into multiple classes composed of similar objects, with the aim to collect data on a similar basis to categorize. Clustering is performed in many fields, including mathematics, computer science, statistics, biology, and economics. In various applications, many clustering techniques have been developed to describe data, measure the similarity between different data sources, and classify data sources into different clusters.

Co-citation analysis (Peters and Van Raan, 1991) uses co-citation counting to construct similarity measures among documents, authors, or journals. A basic assumption of co-citation analysis is that the more two items are cited together, the more likely it is that their content is related. According to different analysis units, different types of co-citation can be used: literature co-citation, author co-citation, and journal co-citation analysis (McCain, 1990). A co-citation network can be formed by co-citation relationships among a group of publications, and the distance between nodes in the network can reflect the affinity and disaffinity of their subject content. This analysis can not only be used to reveal the development status and changes of the scientific structure but also to perform Frontier analysis, field analysis, scientific research evaluation, among others, with the aim to provide advanced support for the macro-science and technology decision-making and to offer a basis for scientific planning and evaluation.

# 3 Results

## 3.1 Annual output analysis of scientific results

The number of publications derived from the time series analysis reflected the trends of the study (Figure 2). The number of papers published in the land use change ecological risk area fluctuated slightly from 1991 to 2021, albeit with an overall increase. Based on the time-series characteristics, this period was divided into three research stages: 1991–2008, 2009–2015, and 2016–2021. The period 1991 to 2008 was the budding period of the research on ecological risks of land use change, with a small number of annual publications; in some years, even less than 10 articles were published. The period from 2009 to 2015 was the rising period of research on the ecological risks of land use change, with a steadily increasing number of publications, indicating that this issue had attracted widespread attention from researchers. In the period from 2016 to 2021, the number of publications increased dramatically, reaching 595 in 2021.

## 3.2 Literature citation analysis

### 3.2.1 Analysis of annual citation trends

Based on the average citation distribution per year (Figure 3), the average annual citation number from 1991 to 2000 was low. In 1992, 1993, and 1998, the average annual citation numbers were 0.73, 0.82, and 0.68, respectively, indicating that at this stage, research on the risks of land use change was still in its infancy and that the field was not well known to the public. After 2000, the average annual number of citations fluctuated, peaking in 2009 (6.22). To some extent, the average number of annual citations was closely related to the development stage of the research. Overall, the average annual number of citations increased, with some fluctuations, indicating that the influence of related research had increased.

### 3.2.2 Citation source analysis

Using the citation source analysis in the Bibliometrix installation package, we selected 20 nodes and determined the most cited journals in this field. Based on the number of citations (Figure 4, Table 2), *Science of the total environment, Science, Nature, Proceedings of the national academy of sciences of the united states of America, and Conservation biology* were the most influential journals in the field of ecological risks of land use change, among which Science of the total environment was the most cited journal, with a total of 4,918 articles cited

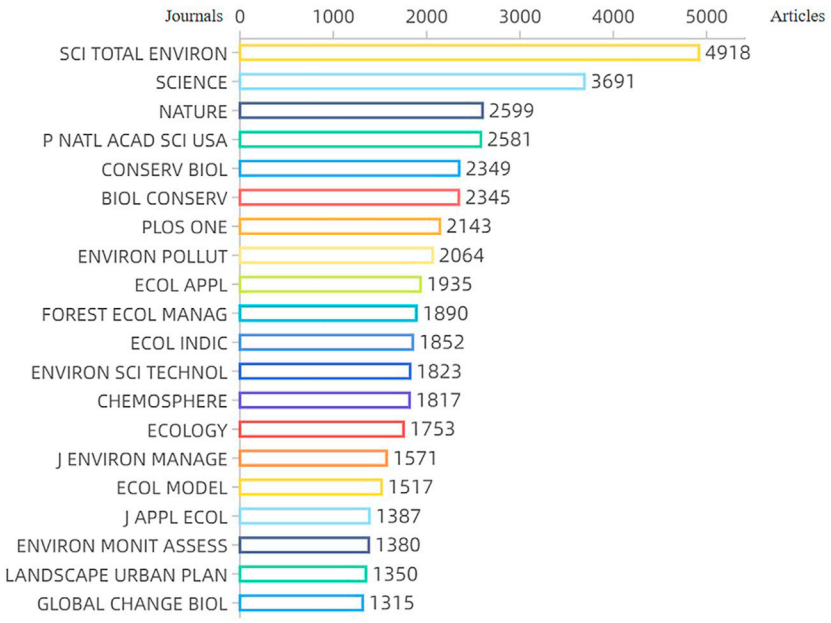


FIGURE 4
Number of cited journal papers in the field of ecological risks of land use change (Top 20).

TABLE 2 Journal Names (abbreviated—full name).

| Abbreviated journal name | Full journal name | Abbreviated journal name | Full journal name |
|---|---|---|---|
| Sci. Total Environ. Sci | Science of the Total Environment | P. Natl. Acad. Sci. USA. | Proceedings of the National Academy of Sciences of the United States of America |
| Science | Science | Conserv. Biol. | Conservation Biology |
| Nature | Nature | Biol. Conserv. | Biological Conservation |
| Plos. One | PLoS One | Environ. Pollut. | Environmental Pollution |
| Ecol. appl. | Ecological Applications | Forest. Ecol. Manag. | Forest Ecology and Management |
| Ecol. Indic. | Ecological Indicators | Environ. Sci. Technol. | Environmental Science & Technology |
| Chemosphere | Chemosphere | Ecology | Ecology |
| J. Environ. manage. | Journal of Environmental Management | Ecol. Model. | Ecological Modelling |
| J. Appl. Ecol. | Journal of Applied Ecology | Environ. Monit assess | Environmental Monitoring and Assessment |
| Landscape. Urban. Plan. | Landscape and Urban Planning | Global. Change. Biol. | Global Change Biology |

from 1991 to 2021. Science, Nature, Proceedings of the national academy of sciences of the United States were cited in more than 2,500 articles, with 3,691, 2,599, and 2,581 articles, respectively.

### 3.2.3 Analysis of highly cited papers

Using the historical citation visualization analysis in the Bibliometrix installation package, we selected 10 nodes and found some classical studies in the field. Several classical articles appeared from 2000 to 2014 (Table 3). For example, in 2013, Xie (Xie et al., 2013) published "Ecological Risk Assessment of Land Use Change in the Poyang Lake Eco-economic Zone, China" in the International Journal of Environmental Research and Public Health. To explore the ecological risk characteristics of land use change in this zone, the authors combined the landscape disturbance index with the landscape fragmentation index and constructed the ecological risk index of land use change. According to the authors, areas with high ecological risk values in the future should strengthen land use management. These results could provide a reference for

TABLE 3 Classical Studies in Ecological Risks of Land Use Change (Top 10). LC/GC = local citation/global citation.

| Doi | Year | LCS | GCS | LC/GC ratio (%) |
|---|---|---|---|---|
| 10.3390/ijerph10010328 | 2013 | 47 | 84 | 55.95 |
| 10.1016/j.scitotenv.2014.12.100 | 2015 | 33 | 152 | 21.71 |
| 10.1007/s10653-007-9115-z | 2007 | 30 | 116 | 25.86 |
| 10.1016/j.scitotenv.2016.09.048 | 2017 | 28 | 74 | 37.84 |
| 10.1016/j.ecolind.2018.12.050 | 2019 | 26 | 64 | 40.63 |
| 10.2307/1941812 | 1991 | 25 | 98 | 25.51 |
| 10.3390/su8060536 | 2016 | 24 | 44 | 54.55 |
| 10.1016/j.scitotenv.2011.04.020 | 2012 | 23 | 401 | 5.74 |
| 10.3390/ijerph121114192 | 2015 | 23 | 36 | 63.89 |
| 10.1080/20018091094439 | 2001 | 20 | 58 | 34.48 |

land ecological management, environmental management, and restoration. In 2015, Islam (Islam et al., 2015) published an article in Science of the Total Environment, titled "Potential Ecological Risk of Hazardous Elements in Different Land-use Urban Soils of Bangladesh". The authors assumed that soil pollution was influenced by both natural and man-made factors. By assessing some of the harmful elements in urban soils from 12 different land use types in Bangladesh, they found that, judging from the potential ecological risk (PER), all soils showed a considerable to very high potential ecological risk. In 2007, Luo et al. (Luo et al., 2007) selected regional surface soil samples of cultivated land, woodland, bare land, and orchards to study and evaluate the impacts of land use methods around reservoirs on heavy metal concentration and analyzed the ecological risk of metals according to the ecological index proposed by Hakanson. In 2017, Mo et al. (Mo et al., 2017) published an article in Science of the Total Environment, titled "Impacts of Road Network Expansion on Landscape Ecological Risk in a Megacity, China: A Case Study of Beijing." With the support of GIS technology, the authors applied a variety of spatial analysis methods to investigate the spatial and temporal changes of road network and landscape ecological risks in Beijing and discussed the impacts of road network expansion on urban landscape ecological risks. Based on their results, the landscape index varied significantly among different landscape types. Moreover, there were obvious spatial differences in the impacts of road network expansion on the ecological risks in the research area. In 2019, Jin et al. (Jin et al., 2019) conducted an ecological risk assessment of Delingha, a city on the Qinghai-Tibet Plateau. The authors stated that changes in land use/land cover affected regional ecological processes, and RS (remote sensing) and GIS (geographic information system) methods were adopted to evaluate the ecological risk in Delingha, which provided a scientific basis for urban ecological protection on the Qinghai-Tibet Plateau.

Based on historical citation visualization analysis, we found that the eighth-ranked local reference had a GCS (global citation score) over 400 and an LC/GC (local citation/global citation) ratio of 5.74. This indicated that this article was more cited in other areas and that this reference was not only a classic reference in the field of ecological risks of land use change but also frequently cited by many authors in other fields, with a strong intersection with other disciplines.

TABLE 4 Number of Local Citations of Authors in the Field of Ecological Risks of Land Use Change (Top 10). LCS = local citations score.

| Author | LCS | Author | LCS |
|---|---|---|---|
| Wang Y. | 83 | Wang P. | 52 |
| Landis W. G. | 76 | Xie H. L. | 51 |
| Burger J. | 63 | Huang H. S. | 47 |
| Ager A. A. | 59 | Ahmed M. K. | 40 |
| Finney M. A. | 55 | Islam M. S. | 40 |

## 3.3 Author analysis

In dataset, Wang, Landis, and Burger were the authors with the greatest LCS(local citations score) in the field, with values of 83, 76, and 63, respectively (Table 4). For example, "Impacts of Road Network Expansion on Landscape Ecological Risk in a Megacity, China: A Case Study of Beijing", published in Science of the Total Environment by Wang and Mo in 2017, was cited 81 times (Mo et al., 2017). Burger's paper "Landscapes, Tourism, and Conservation", published in Science of the Total Environment in 2000, was cited 42 times (Burger, 2000). This article argued that ecological integrity declines with the development of more landscapes. Moreover, an increasing population and changes in population distribution can affect land use, with significant impacts on biodiversity and the ecological environment. The author provided three examples of strengthening land conservation at landscape scale and, thus, promoting habitat and biodiversity conservation.

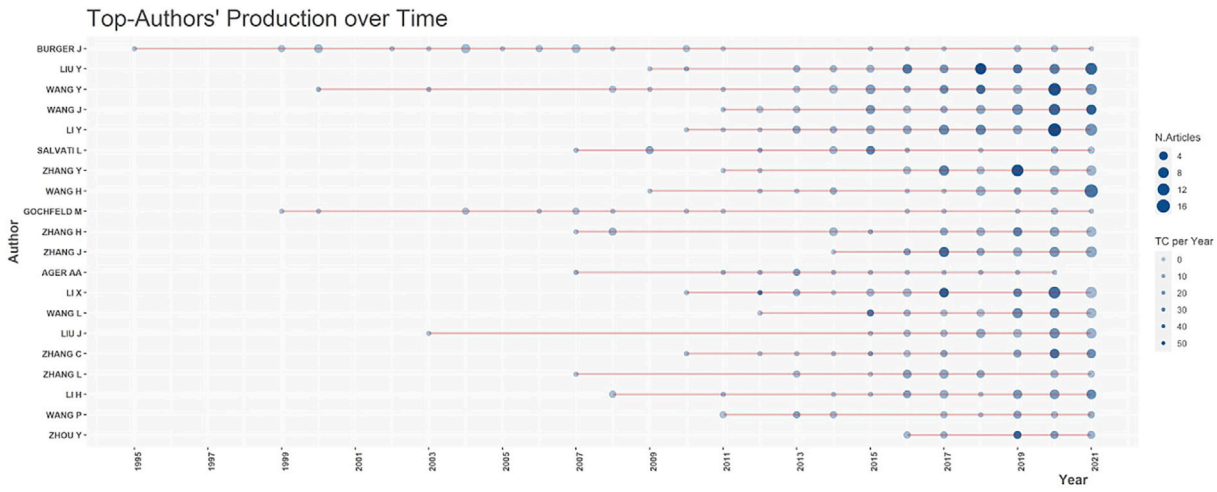


FIGURE 5
Published trends of some authors in the field of ecological risks of land use change.

When considering the change in studies over time (Figure 5), Burger and Gochfel conducted a long-term study in the field of ecological risks of land use change. Burger published articles in the Journal of Toxicology and Environmental Health as early as 1995: "Risk Assessment, Life History Strategies, and Turtles: Could Declines Be Prevented or Predicted (Burger and Garber, 1995)?" Burger and Garber argued that the ecological risk assessment process should include the ability to predict the adverse consequences of specific environmental pollutants or of human invasion. In 1199, Gochfel co-published with Burger et al. "Attitudes and Perceptions about Ecological Resources and Hazards of People Living around the Savannah River Site" in the journal Environmental Monitoring and Assessment. The authors highlighted that risk assessment is increasingly being used as a basis for environmental decisions and regulations, and the process should be transparent. In many cases, evaluation involved the selection of indicators that measured both cultural benefits and ecosystem health.

Teng et al.'s publication "Current and Future Assessments of Soil Erosion by Water on the Tibetan Plateau based on Rusle and Cmip5 Climate Models" had the highest total citation number per year, with 56.4 citations in 2018 (Teng et al., 2018). The total numbers of annual citations for Wang, Li, and Li in 2020 were also relatively high, with 53, 56.33, and 39, respectively.

## 3.4 Distribution characteristics analysis of major countries/regions

The distribution characteristics of the main study countries/regions reflected the influence of various countries in the field of ecological risks of land use change. The dataset used in this paper was published in 104 countries or regions, and the top 20 countries were as follows: 3 Asian countries (China, India, Iran), 4 American countries (United States, Canada, Brazil, Mexico), 9 European countries (UK, Spain, Italy, Germany, Sweden, Netherlands, France, Portugal, Europe), 1 Oceanian country (Australia), 1 African country (South Africa), and Turkey and Russia across Asia and Europe. Papers on the ecological risks of land use change have mainly been published in Asia, the Americas, and Europe (Figure 6).

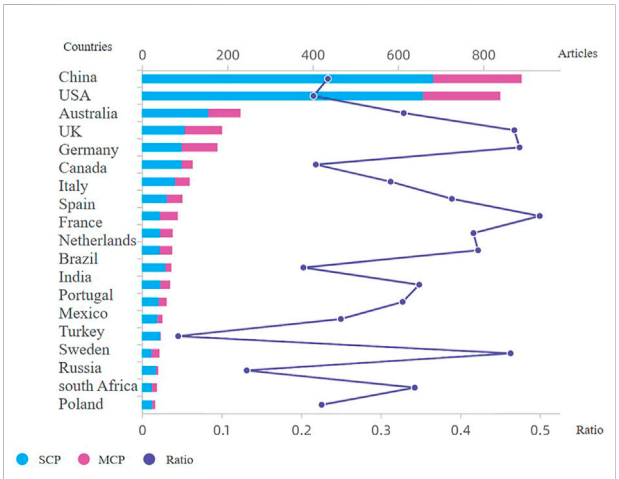


FIGURE 6
Published papers in some countries in the field of ecological risks of land use change. Note: SCP is the number of papers published independently in the country; MCP is the number of papers published jointly in the country; Ratio represents the proportion of papers jointly published in the total publication.

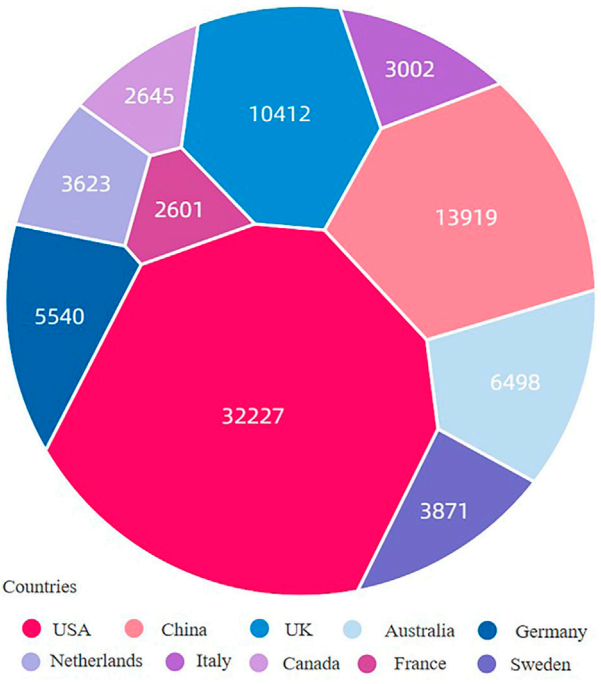


FIGURE 7
Cited times of some national papers in the field of ecological risks of land use change.

Specifically, China was the only developing country among the top three countries, with several times the number of studies than other countries, except the US. The reason for the high output may be that China was paying increasing attention to the research and assessment of the ecological risks of land use changes. Respective papers were mainly published in some developed countries, indicating that such countries have a dominant position in this research field. Among the counties mentioned above, France, Germany, Sweden, and the UK had relatively close cooperations with other countries, with ratios (cooperation accounting for total publications) of 0.5, 0.47, 0.46, and 0.46, respectively. Although the total number of papers published in China and the US was far higher than those published in other countries, the ratios were 0.23 and 0.21, respectively. Turkey's ratio was only 0.04, indicating that this country needs to strengthen its cooperation with other countries in this research field.

The top three countries regarding citations were the US, China, and the UK, with 32, 227, 13,919 and 10,412 references, respectively (Figure 7). The more productive countries also received a corresponding number of citations. However, the numbers of publications and citations in the US and China far exceeded those of the other countries, indicating that these two countries significantly influenced the field of ecological risks of land use change. In many less developed countries, especially in most countries in Asia, Africa and Latin America, a low number of publications in this field was published. This is related to many factors, such as the relatively low level of technology and the shortage of funds.

## 3.5 Keyword analysis

### 3.5.1 High-frequency keywords

High-frequency keyword analysis reflected the hot spots in the research field in an intuitive way. We used the Biblioshiny software for data mining and the statistical analysis of the high-frequency keywords and plotted the Tree Map of the top 50 keywords in the field (Figure 8). Keywords such as "land use", "management", "climate change", "risk", and "conservation" appeared more frequently, 534,399,392,307, and 302 times, respectively, accounting for 28% of the total keywords. Keywords frequently appearing in Tree Map were "dynamics", "framework", and "model", indicating the main research methods in the field of ecological risks of land use change. Keywords such as "land", "vegetation", "climate", "river", and "urbanization" in Tree Map indicated that these were the key factors in the research process.

### 3.5.2 Cluster analysis and multiple correspondence analysis of high-frequency keywords

Cluster analysis in Bibliometrics was based on the simultaneous frequency of two keywords, using statistical methods to simplify complex keywords, which were divided into several small class groups according to the mesh relationship (Madani and Weber, 2016). This study used hierarchical clustering, treating the keywords of each cluster as a category and merging them into high-level clusters based on similarity, grouping all individuals into one category and displaying them. Finally, the entire classification system formed a tree graph, showing the close or alienated relationships among the keywords.

Multiple correspondence analysis (MCA) is a commonly used sociological method. In this study, it was applied to analyze the associations among variables in large taxonomic datasets and to explore their relationships, resulting in an intuitive two-dimensional (or three-dimensional) diagram reflecting the similarity among keywords (Figure 9).

1) First category of cluster analysis: this category was mainly related to pollution, heavy metals, and sediments. For example, Qian et al. (Qian et al., 2022) argued that rapid urbanization changed land use and landscape patterns in watersheds, reduced ecosystem services and habitat quality, and thus caused adverse ecological impacts, such as the spread of non-point-source pollution. The authors used the export coefficient model to construct exposure-response relationships between land use


FIGURE 8
Keywords in the field of ecological risks of land use change.

and NPS pollution, with the aim to investigate the risk of the degradation of water purification services provided by aquatic ecosystems. Zhang et al. (Zhang et al., 2017) noted that the accumulation of heavy metals in agricultural soils is a subject great concern. They assessed the characteristics and ecological risks of heavy metal pollution in the three land-use types on the southern Loess Plateau of China and noted that more soil samples were needed to assess the ecological risks of heavy metals in a larger study area.

2) Second category of cluster analysis: this category was mainly related to models, frames, and systems. For example, Mancino et al. (Mancino et al., 2016) proposed an improved USLE model to assess the soil erosion risk based on the simplification of the model parameters and the use of the spatial resolution dataset and analyzed the spatial and temporal variability of the model results in the Mediterranean region (Matera, southern Italy) for the basic land use class. Bartolo et al. (Bartolo et al., 2012) used a relative risk model (RRM) for a regional ecological risk assessment of the 1.1 million km of Northern Tropical River (NTR) areas in Australia. With the help of the classic framework in the field of disaster risk assessment, Liang et al. (Liang and Song, 2022) proposed a new framework for the ecological risk assessment of land use change and applied it to the Qinghai-Tibetan Plateau in China.
3) Third category of cluster analysis: this category was mainly related to water, soil, river basins, and regions. For example, Zhu et al. (Zhu et al., 2022) used the principles of landscape ecology to construct a 20-year landscape ecological risk assessment model of river basins. The authors studied the spatial and temporal evolution and the spatial autocorrelation characteristics of landscape ecological risks in the Yellow River Basin in Shaanxi Province, providing theoretical support for administrative policies, such as future ecological risk assessment and protection, restoration measures, and control.
4) Fourth category of cluster analysis: this category was mainly related to ecology, climate, forest, and biodiversity. For example, Hansen et al. (Hansen et al., 2014) assessed the climate, land use change, and impacts on vegetation communities in US national parks. Based on the results, the cumulative and synergistic effects of land use and climate changes greatly affect ecosystem functions and biodiversity of national parks.
5) Fifth category of cluster analysis: This category was mainly related to habitat and diversity. For example, Wang et al. (Wang et al., 2021) evaluated the landscape ecological risks of Baishuijiang National Nature Reserve based on different management zones from 1986 to 2015. According to the authors, human activities led to significant changes in land

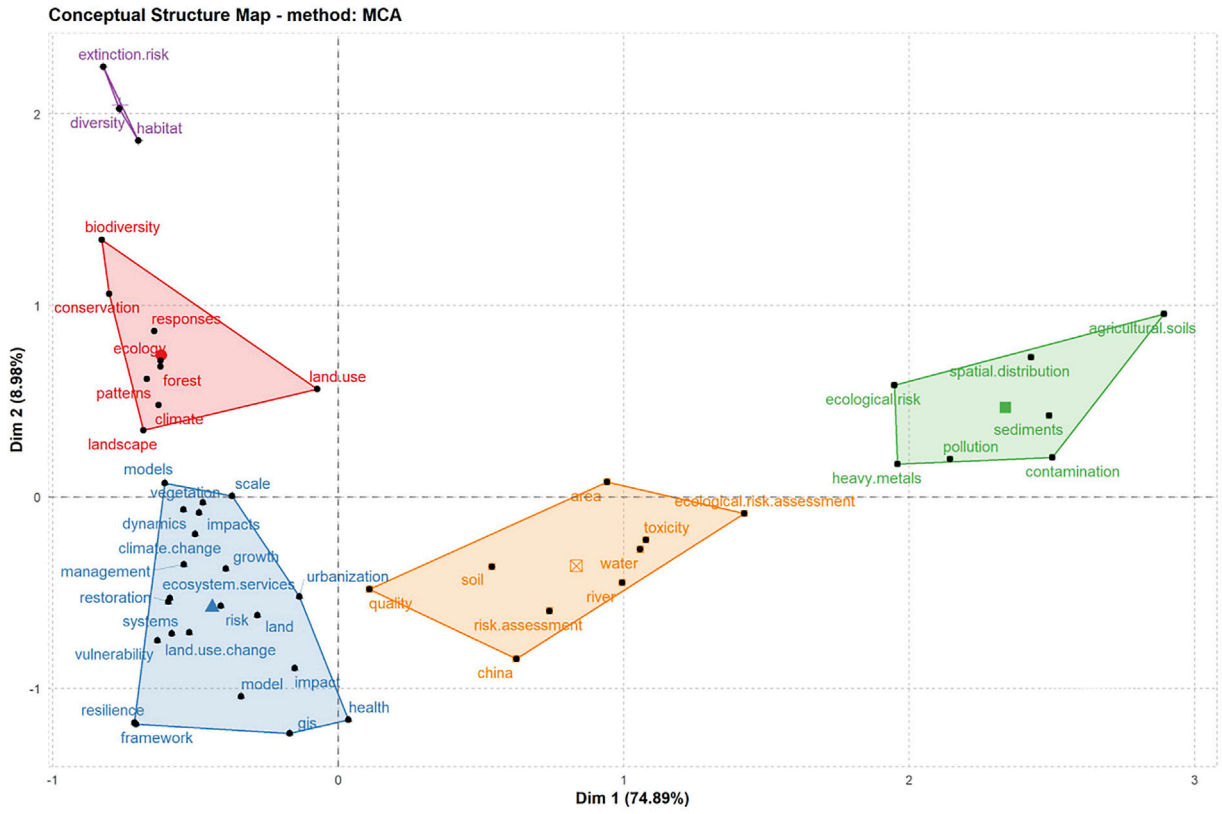


FIGURE 9
Multiple correspondence analysis in the field of ecological risks of land use change.

use/land cover (LULC), further affecting the ecological balance of the habitats of endangered wildlife species.

## 3.6 Analysis of research topic evolution

Topic evolution analysis included the law of subject content, intensity, and structure over time, as well as evolutionary relationships, paths, and trends. This analysis played an important role in showing the development of the field, grasping the development direction, and predicting the future trends (Xie et al., 2020). The Sankey diagram, as a typical flow chart (Figure 10), was commonly used for data visualization analysis. This paper visualized the evolution of topics in the field of land use change from 1991 to 2021, which facilitated the analysis of the flow of different themes in the field of ecological risks of land use change. The different widths of the lines in the Sankey diagram represent different flow shunts, and the width of the lines indicates the flow rate occupied by this branch proportionally. Colors could help to distinguish among the different research topics.

From the perspective of the evolution path map and the evolution state of each period, the research topics in different periods were diverse, and the topic evolution relationship in different periods was more complex. In the embryonic and initial stage of the research, the proportion of different topics was different. At this time, the research was exploratory and mainly started from several general directions. During this period, GIS and model simulation methods were mostly used for risk assessment. Over time, authors focused on specific topics but also expanded their focus on various other topics. Obviously, the emergence of themes such as “climate change”, “monitoring”, and “pesticides” showed that the academic community more clearly recognized the factors affecting the ecological risks of land use change and that this issue was more deeply studied through certain methods and means. Later, research mainly focused on topics such as “ecosystem services”, “water quality”, “land use”, and “climate change”, which occupied a considerable proportion, indicating that the academic research on the ecological risks of land use change had gradually deepened.

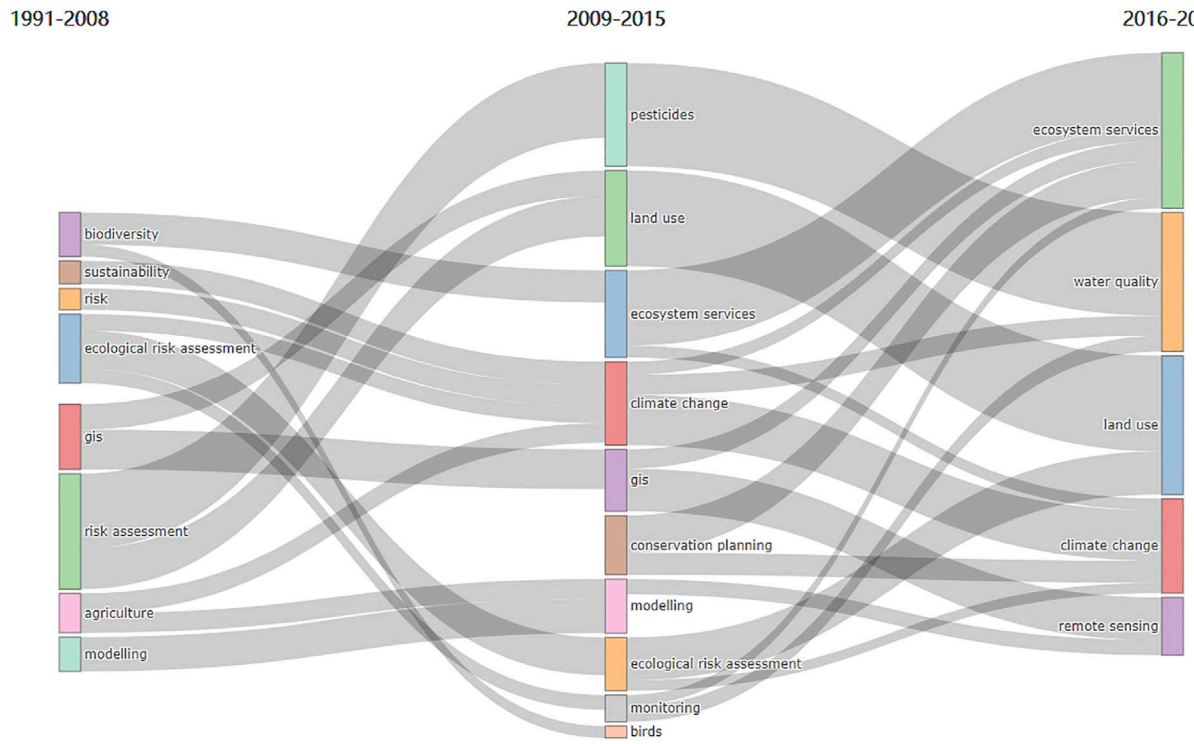


FIGURE 10
Research topic evolution in the field of ecological risks of land use change.

## 4 Discussion

Based on the results of our literature analysis, the issue of the ecological risks of land use change has gradually become an important branch of ecological risk research and assessment, and research in this field has attracted considerable attention form the scientific community. Currently, respective research mainly focuses on ecological functions and regional ecological risk assessment, with various research methods. According to the differences among the research objects, different ecological risk assessment systems and models have been developed. However, in many studies, the specific outstanding problems are as follows: 1) The establishment standard of the ecological risk comprehensive assessment model needs to be studied. The selection and combination of indicators of the model are often affected by human subjectivity (knowledge system, personal experience, hardware conditions, among others) and have obvious regional characteristics. Therefore, the results are often different. In addition, the portability of the model is a considerable challenge. 2) At present, there is no unified standard for the classification of ecological risk, and the land risk status varies greatly in different regions. In addition, there is no recognized and accurate evaluation threshold, which impedes the grading of quantitative data of ecosystem risks and therefore impacts the accurate evaluation of the reginal risk degree. 3) The method system and evaluation index of land use ecological risk management need to be improved. At present, the research on the ecological risks of land use change is still in the stage of qualitative description, and the selection of evaluation indicators in each case is also different due to the differences in the selected research areas and objects. Therefore, the results of ecological risk assessment in different regions are not comparable.

As a source of anthropogenic disturbance of ecosystems, land use change plays an important role in regional ecological risks. With the deepening of relevant research, future studies can be based on the following aspects:

1) Strengthening the theoretical research on the ecological risks of land use change. The scientific output in this research field is still on the rise, but it should not only be satisfied with the number of papers but also pay attention to its innovative and guiding role in the field, with the aim to make long-term and sustainable contributions. At present, respective research involves natural resources, the economy, society, ecological environment, and technology and is relatively independent. It

is therefore necessary to strengthen the cooperation among scientists in different fields and countries and to absorb the innovative methods and ideas of other disciplines, which is of great significance for sharing research resources and promoting the development of the fields.

2) Improving the methods and systems of ecological risk assessment. In recent years, the assessment of the ecological risks of land use change has attracted considerable attention, with an increasing number of case studies. However, the current theory and method system need to be improved. Ecological risk management has not yet formed a mature framework system, and the research from theoretical methods to specific cases is not rich enough. In addition, based on the literature analysis, we found that there was no unified index system for the evaluation of the ecological risks of land use change. Because of the different research areas and objects selected in each case, the selection of the evaluation indicators was also different. With the improvement of the GIS technology and the development of the internet technology, big data, deep learning, and GIS can be used in future studies to establish a unified ecological risk assessment framework and method based on the data management platform, strengthening the research on the ecological risks of land use change. In addition, cultivating research reserve talents in this field is also an important part of the future development.

There are many studies assessing the ecological risks of land use change in areas with strong human activity. In the process of urbanization, how to rationally use land resources and protect the ecological environment should be given sufficient attention. Most studies on the ecological risks of land use change focused on a certain river basin, region, or city, and most studies put forward corresponding management directions and suggestions based on the results. Although this assists policy makers in the formulation of ecological risk control policies in different regions, some studies have failed to better combine the ecological risk assessment results with ecological restoration. To effectively solve the ecological problems arising in the context of global ecological governance, it is necessary to conduct more in-depth and broader research. When the results of ecological risk assessment are well combined with land use planning and management, adequate measures can be taken to promote the coordinated development of the ecological environment and the economy.

## 5 Conclusion

For this review, we searched the studies in the field of ecological risks of land use change from 1991 to 2021, based on the Web of Science database, and conducted data mining in combination with the advantages of the Bibliometrix bibliometrics software. The aim was to quantitatively analyze the research status in this field. From 1991 to 2021, the number of published studies showed an increasing trend. The development can be divided into three stages: initial stage (1991–2008), growth stage (2009–2015), and high-production stage (2016–2021). In terms of citation sources, *Science of the total environment, Science, Nature, Proceedings of the national academy of sciences of the united states of America, and Conservation biology* and other journals influenced this research field. According to the author analysis, a total of 15,910 authors were involved in respective publications. From the perspective of the distribution of research countries, the papers published from 1991 to 2021 came from 104 countries or regions, mainly from Asia, America, and Europe.

With the deepening of research on global change and ecological risks, the ecological risks of land use change have received more attention, with many studies in areas with strong human activities. Strengthening theoretical research and improving the method system of the assessment of the ecological risks of land use change are at the focus of future research. To be more efficient, respective research should be combined with other fields of global change. Through an in-depth discussion on the evolution of regional ecological risk patterns under the influence of land use change, a series of ecological problems arising from global change can be addressed for effectively. In addition, how to use land resources rationally and protect the ecological environment should also become a research focus.

## Author contributions

CC and WS: methodology, software, validation, writing. CC: software, investigation, validation, data curation, writing-original draft. WS: methodology, validation, project administration, writing-review and editing. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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