

Progress of bibliometric-based research on ecological security in urban agglomerations

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Abstract: How to ensure the ecological security of urban agglomerations in the context of rapid urbanization and industrialization has become a critical issue in the fields of ecology and urban science. This study employs CiteSpace software to visualize and analyze the current state and development trends of research on the ecological security of urban agglomerations, based on a dataset of 791 articles retrieved from the CNKI and WOS databases spanning 2000 to 2024. The results indicate that (1) The research on the ecological security of urban agglomerations can be categorized into four distinct stages: the exploratory stage (2000-2010), the budding stage (2011-2015), the developmental stage (2016-2018), and the explosive stage (2019-2024). (2) The analysis of co-occurring keywords reveals that “Urban agglomeration”, “Ecological security”, “Land use”, and “Urbanization” are central to the field. The keyword mutation indicates that the “Driving factors”, “Spatial and temporal evolution”, “Coupling and coordination”, and “Ecological resilience” have become the research frontiers on the development of ecological security in urban agglomerations after 2022. (3) The clustering keywords reveal a significant overlap between domestic and international research, which can be grouped into four major themes: “Ecological security and sustainable management”, “Urban agglomerations and urbanization development”, “Regional ecological and environmental research”, and “Modeling and methodology”.

1 Introduction

In the 21st century, urban agglomerations have become the core areas of population concentration and economic growth [1]. High-intensity resource consumption, land expansion, and population growth have resulted in ecological security issues within urban agglomerations, which have significant implications for human well-being and sustainable socio-economic development. The focus of related research has evolved from defining the concept of urban agglomerations [2] and exploring the mechanisms driving their development [3] to examining the ecological security of these urban agglomerations [4]. Furthermore, the scope of research has expanded from individual cities to regional urban agglomerations. A systematic review of the research on urban agglomeration ecological security, along with an analysis of domestic and international research hotspots and trends, can help to understand the theoretical knowledge system and research framework of urban agglomeration ecological security and provide reference and reflection for grasping the research direction and development trend of this field.

2 Concept Definition

2.1 Urban Agglomeration

An urban agglomeration is a product of the development of the urbanization process at a certain stage and refers to a specific regional area composed of cities of varying sizes, which are interconnected through transportation networks, creating a mutually dependent and integrated urban system [5]. In the 1950s, the French geographer Gottman [6] introduced the term Megalopolis to describe urban areas with strong economic and social ties. Building on this concept, scholars have developed terms such as Mega-Urban Regions [7], Extended Metropolitan Regions [8], and Megaregion, to refer to various forms of urban agglomerations. In China, research on urban agglomerations began following the reform and opening-up period. In the 1980s, Yu [9] and Zhou [10] introduced the concept of Megalopolis and proposed the ideas of Megalopolis and Metropolitan Contiguous Area, respectively. In 1992, Yao [11] defined an urban agglomeration as a cluster of cities with a considerable number of diverse natures, types, and scales, relying on a certain natural environmental condition. This cluster typically includes several cities, with one or two megacities or large cities at the core, driving regional economic development. As observed, Megalopolis, Mega-Urban Regions, Extended Metropolitan Regions,

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Megaregion, Huge urban belts and urban conurbations are the core concepts of defining urban agglomerations over time. In addition, metropolitan area, dense urban area and dense urban area are also used to define the concept of urban agglomeration and, therefore, serve as key terms in literature selection.

2.2 Ecological Security

The concept of ecological security originated from ecological risk analysis [12]. The establishment of the World Conservation Union for Conservation of Nature (IUCN) in 1948 laid the foundation for global cooperation in ecological protection. In 1972 the concept of harmonious coexistence between human activities and the environment was first put forward in the Declaration on the Human Environment, and in 1987, the concept of sustainable development was put forward in the report "Our Common Future", which provided theoretical support for the coordinated development of ecological security and economic and social development. However, during this period, the focus was on the direct threats to ecosystem stability posed by environmental issues, a systematic framework for global ecological security has yet to be formed.

Since the 21st century, the issue of ecological security has become a prominent international research focus, and the connotation of ecological security has been gradually expanded to include ecosystem services, resource carrying capacity, ecological environment quality, biodiversity protection, and more. In 2001, the United Nations launched the Millennium Ecosystem Assessment, in which more than 1,300 experts from around the world scientifically assessed the functioning of the global ecosystem services, and pointed out that the degradation of ecosystem services will seriously impact human living conditions and threaten regional and global ecological security. Following this, global initiatives for ecological security cooperation were established, accompanied by various declarations and agreements, such as the Global Cities Report issued in 2001, the Johannesburg Declaration on Sustainable Development issued in 2002, and the International Ecological Security Cooperation Organization (IESCO) led by China in 2006. These efforts have significantly influenced research on the ecological security of urban agglomerations. The terms ecological security, ecological risk, and ecosystem are central to studying the security and carrying capacity of ecosystems. To ensure the comprehensiveness of the literature selection, keywords such as ecological environment and ecology are also employed.

3 Materials and Methods

3.1 Materials

Literature searches were conducted in the Web of Science and CNKI databases, with the scope limited to CSCD, CSSCI, and PKU. The search, covering the period from 2000 to 2024, the Search method is "Topic=Metropolis OR Urban Agglomeration OR Mega-Urban Regions OR

Extended Metropolitan Regions OR Megaregion AND Topic= Ecological security OR Ecology OR Ecological Environment OR Ecosystem OR Ecological Risk". The CNKI database returned 3,118 documents, of which 466 were relevant. The Web of Science yielded 2,181 documents, with 325 articles retained after filtering out irrelevant ones.

3.2 Methods

CiteSpace is a knowledge graph visualization software developed based on the Java platform, widely used in bibliometric analysis to reveal development trends, knowledge structures, and research hotspots within a given field through co-occurrence, co-citation, and clustering [13]. In this study, CiteSpace was employed to visualize and analyze the literature on ecological security in urban agglomerations, focusing on the distribution of publication timelines, collaboration networks, keyword bursts, and keyword clustering.

4 Results and discussion

4.1 Publication volume statistics

The number of papers published in a professional field is an important indicator for evaluating the development status [14]. Based on the quantitative analysis of domestic and foreign literature from 2000 to 2024 (Fig. 1), the number of Chinese papers (466) was significantly higher than that of foreign papers (325), reflecting China's emphasis on the ecological security of urban agglomerations. The development trend of ecological security in urban agglomerations can be divided into the following categories according to the number of publications: the exploratory stage (2000-2010), the budding stage (2011-2015), the developmental stage (2016-2018), and the explosive stage (2019-2024).

Exploration Stage (2000-2010): The number of publications during this stage was very small, with an annual publication volume of 3.4 papers. The content of the research mainly focused on the basic theoretical framework of ecological security and the construction of an evaluation index system. This stage was limited by the lack of special policies at the national level, and a systematic urban agglomeration analysis framework had not yet been formed. It is worth noting that the establishment of the International Ecological Security Cooperation Organization in 2006 provided an initial platform for Chinese scholars to participate in transnational research through documents such as the Beijing Convention (2010).

Budding Stage (2011-2015): The number of publications has increased since 2011, with an annual publication volume of 9.8 papers. In 2008, the country's first regional strategic document formulated for "urban agglomerations" proposed the "Outline of the Reform and Development Plan for the Pearl River Delta Region (2008-2020)", followed by the "Regional Plan for the Yangtze River Delta Region" (2010), "National Main Functional Area Plan" (2011), and other policies. In

particular, the "National Main Functional Area Plan" pointed out that the three major urban agglomerations such as Beijing-Tianjin-Hebei in the "optimized development area" will be listed as the core of the national strategy, requiring the coordination of ecological security and economic development.

Development Stage (2016-2018): The number of publications increased rapidly during this phase, with an annual publication volume of 22 papers. In 2013, the National New Urbanization Plan included "ecological security" in the development goals of urban agglomerations for the first time, directly promoting the growth of related research. The Outline of the Development Plan for the Yangtze River Economic Belt (2016) proposed the principle of "ecological priority", which gave rise to the study of ecological risk assessment at the basin scale; the Chengdu-Chongqing Urban Agglomeration Development Plan (2016) promoted technical breakthroughs such as geological disaster sensitivity analysis in mountainous urban agglomerations. More importantly, the Measures for the Evaluation and Assessment of Ecological Civilization Construction Goals (2016) included urban agglomerations such as Beijing-Tianjin-Hebei and the Yangtze River Delta in the assessment scope, prompting the research paradigm to transform to the "pattern-process-effect" coupling analysis.

Explosive Stage (2019-2024): The annual number of publications has exploded, with an annual publication volume of 45.3 papers. This transition was driven by multiple factors: At the policy level, the reorganization of the Ministry of Ecology and Environment (2018) and the

Outline of the Yellow River Basin Ecological Protection and High-quality Development Plan (2020) strengthened institutional constraints; at the practical level, the construction of Xiongan New Area gave rise to new demands for dynamic simulation of ecological security; at the technical level, the popularization of big data and machine learning methods promoted in-depth innovation in research, and research at this stage showed significant interdisciplinary characteristics.

Further analysis shows that there is a significant "policy trigger-academic response" time lag in the study of ecological security in China's urban agglomerations (about a 3-year cycle), and it presents a spiral upward path of "basic theory to method innovation to system application". This dual attribute of policy sensitivity and technology dependence essentially reflects the transformation logic of China's ecological civilization construction from concept advocacy to institutional practice.

The growth of WOS publications is relatively stable, from 2000-2015, the number of publications was low, averaging just one article per year; from 2016-2018, the number of publications increased to 7.3 articles per year; after 2018, similar to the CNKI trend, it showed explosive growth, with an average of 41.1 articles per year. Overall, the number of CNKI publications is generally higher than the number of WOS publications, reflecting China's dominant position in the field of urban agglomeration ecological security research. Foreign studies also began to grow rapidly after 2015, reflecting the increasing global recognition of urban agglomeration ecological security as a key issue.

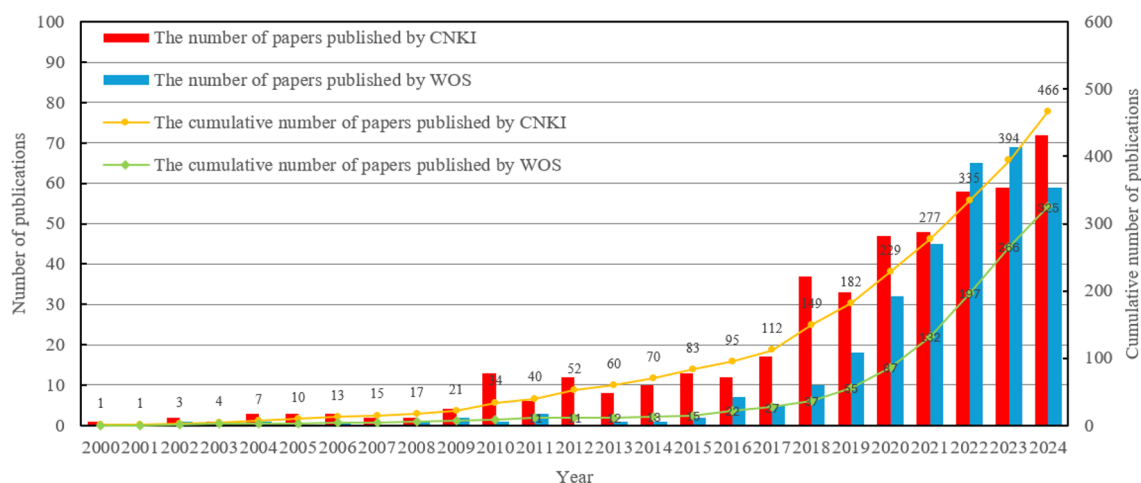


Figure 1. The number of publications on ecological security in urban agglomerations in CNKI and WOS databases.

4.2 Cooperation networks

4.2.1 Country Cooperation Networks

The results show that 38 countries and 43 partnerships have engaged in collaborative research on the ecological security of urban agglomerations. The top ten countries with the highest frequency of publications are listed in Table 1. China has the highest frequency and the strongest

centrality, followed by the United States and Australia. The significant increase in China's publications can be attributed to the government's promotion of urban agglomeration development in 2015, which drew greater academic attention to the ecological security of these areas. Additionally, a review of foreign scholars' publications reveals that foreign scholars mostly focus on ecosystem security, such as water resources security[15], and food security[16].

Table 1. Frequency table of countries in WOS database

Code	Freq.	Centrality	Country
1	291	0.66	PEOPLES R CHINA
2	24	0.20	USA
3	8	0.07	ENGLAND
4	8	0.14	AUSTRALIA
5	7	0.09	GERMANY
6	5	0.00	CANADA
7	4	0.01	SOUTH AFRICA
8	4	0.00	ITALY
9	4	0.00	INDIA
10	3	0.00	JAPAN

4.2.2 Institutional cooperation networks

The statistics reveal that 211 institutions and 364 partnerships are involved in collaborative research. The top ten institutions with the highest frequency of cooperation are all found to be Chinese institutions (Table 2), with the top nine intermediary centrality all greater than 0.1, demonstrating that domestic institutions hold more academic influence, among which the Institute of Geographic Sciences and Natural Resources of the Chinese Academy of Sciences has the highest intermediary centrality.

Table 2. Frequency table of institutions in WOS database

Code	Freq.	Centrality	Institution
1	62	0.28	Chinese Academy of Sciences
2	40	0.37	Institute of Geographic Sciences & Natural Resources Research
3	30	0.28	University of Chinese Academy of Sciences
4	22	0.18	Beijing Normal University
5	20	0.19	China University of Geosciences
6	13	0.13	Wuhan University
7	10	0.12	Nanjing University
8	9	0.15	Huazhong Agricultural University
9	8	0.16	Sun Yat-Sen University
10	7	0.06	Tianjin University

4.2.3 Author Collaboration Network

Author collaboration networks were analyzed separately based on the WOS and CNKI databases, and the ten authors with the highest publication frequency in each database were identified. The analysis revealed that all ten authors with the highest frequency in the WOS database were Chinese (Table 3), among which Huang [17]

evaluated the ecological network based on Shandong Peninsula urban agglomeration in terms of the overall structure and network function, which made up for the lack of the ecological network in the spatial scope; Qi [18] using the ecological footprint method to evaluate the ecological security bureau of the Min Delta urban agglomeration, pointing out that it is necessary to optimize the industrial structure, scientifically plan the construction land, and strengthen the early warning with the ecological security in the future.

Table 3. Frequency table of authors

WOS Database				CNKI Database		
Code	Freq.	Year	Author	Freq.	Year	Author
1	3	2022	Huang, Longyang	6	2018	Qi Xinhua
2	2	2023	Zhao, Yongyu	5	2015	Kuang Wenhui
3	2	2023	Li, Zhigang	3	2005	Zhou Guohua
4	2	2020	Li, Zhao-Tian	3	2009	Li Shuangcheng
5	2	2024	Liu, Huayan	3	2011	Fu Lihua
6	2	2022	Yang, Jun	3	2011	Zhang Ye
7	2	2023	Fang, Chuanglin	3	2016	Zhou Weiqi
8	2	2024	Xiao, Wenfa	3	2018	Liu Jinya
9	2	2022	Wang, Jing	3	2018	WangDongchuan
10	2	2024	Wang, Dongyan	3	2018	Chen Wenhui

4.3 Keyword Analysis

4.3.1 Keyword Co-Occurrence

The frequency of keyword occurrence reflects both the research hotspots in the field over time and the centrality of the keywords[1]. The 466 documents in the CNKI database were used for keyword mapping (Fig. 2).

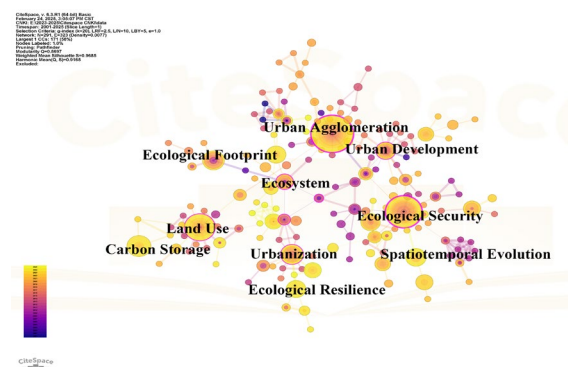


Figure 2. keyword Co-Occurrence map in CNKI database

The important keywords sorted by the year of occurrence are presented in Table 4.

Table 4. Keyword Co-Line Table of CNKI database

Code	Freq.	Year	Keywords	Code	Freq.	Year	Keywords
1	4	2001	Metropolitan area	11	15	2014	Urbanization
2	13	2003	Urbanize	12	8	2016	Ecological restoration
3	52	2004	Urban agglomeration	13	6	2016	Urban expansion
4	36	2005	Ecological security	14	9	2018	Beijing, Tianjin and Hebei
5	10	2005	Ecosystems	15	8	2018	Factor
6	14	2005	Ecological footprint	16	2	2018	Anticipate
7	4	2006	Municipalities	17	9	2021	The Yellow River basin
8	5	2006	System of indicators	18	7	2021	Ecological corridor
9	3	2010	Land ecology	19	11	2022	Time-space evolution
10	27	2011	Land use	20	10	2023	Ecological resilience

Before 2010, the research focused on the environmental problems brought about by urbanization and the coping strategies, and the main research object was the ChangZhuTan Urban Agglomeration, with key topics including the evaluation of land ecological security, the assessment of ecological service function values, and the environmental challenges faced during ChangZhuTan's urbanization, along with proposed countermeasures. From 2011 to 2015, the amount of literature increased, with research expanding to include the ChangZhuTan, Pearl River Delta, Beibu Gulf, Central Plains, and Yangtze River Delta Urban Agglomerations. The research contents are related to land use, ecological barriers, sustainable development, and spatial evolution characteristics. In 2014, the Central Committee of the Communist Party of China (CPC) issued the National New Urbanization Plan, which aims to optimize and enhance urban agglomerations in the eastern region, promote the development of urban agglomerations in central and western regions, and establish a coordinating mechanism for their development. From 2015 onwards, the state approved the Yangtze River Delta, Pearl River Delta, Jing-Jin-Ji, and Chengdu-Chongqing Urban Agglomerations, marking a shift towards an increased focus on research related to urban agglomerations. Between 2015 and 2018, research topics included land use changes in urban agglomerations, ecological restoration, optimization of spatial structure, and the impact of urban expansion on the ecological environment. Additionally, the field began to incorporate ecological security prediction. After 2018, research primarily focused on ecological corridors, ecological restoration, ecological security patterns, spatial and temporal evolution, driver analysis, multi-scenario simulations, and comparative studies of city clusters. This shift indicates that research on urban agglomerations has become more diverse and in-depth, with a broadened scope and an evolving focus from individual cities to more complex urban networks.

The keywords in WOS are largely similar to those in CNKI, although relevant WOS studies tend to be published later than those in CNKI (Fig. 3). From 2000 to 2010, there were only a few studies on the ecological spaces of urban agglomerations. From 2010 to 2018, research primarily focused on evaluation models and ecosystem optimization. After 2018, research on the ecological security of urban began to increase, with more in-depth studies, primarily concentrating on the construction of ecological security patterns, spatiotemporal analysis of land use, and multi-scenario simulations. Overall, research on urban agglomerations in foreign countries emerged later, with fewer studies and a slight lag compared to China.

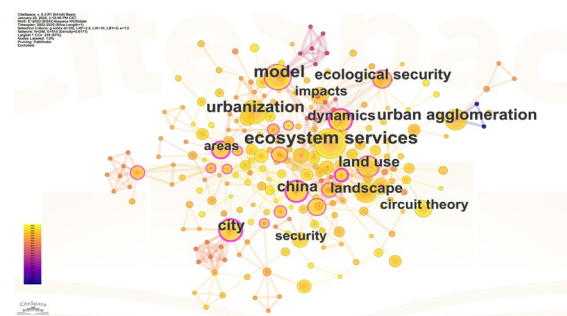


Figure 3. Keyword Co-Occurrence map in WOS database

4.3.2 Keyword bursts

Mutant words are keywords that experience explosive growth within a specific period in a research field, and changes in these words directly reflect the dynamic shifts occurring in the field. Based on the CNKI database and WOS database, conducted a keyword emergence visualization analysis and obtained Fig. 4 and Fig. 5.

Top 10 Keywords with the Strongest Citation Bursts

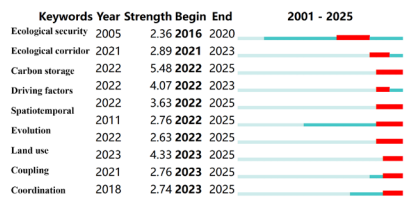


Figure 4. Keyword bursts map in CNKI database

Top 10 Keywords with the Strongest Citation Bursts



Figure 5. Keyword bursts map in WOS database

Summarizing the research focus and trends, the emergence time of "ecological security" in the two databases appeared earlier and lasted longer, but the emergence time in the WOS database was from 2016 to 2021, while related research appeared in China in 2005. This time difference reflects China's first-mover advantage in the field of ecological security of urban agglomerations. The Yellow River Basin keyword appeared in the CNKI database research, indicating that China has adopted different research strategies for different urban agglomerations. In addition, both domestic and foreign countries emphasize land use, environmental change, etc., and in recent years, research hotspots have focused on carbon storage, ecological resilience, land use, and sensitivity analysis. Research has gradually developed in the direction of refined, multi-scale, and comprehensive analysis. From the perspective of the research frontier, land use has become a hot topic of common concern at home and abroad since 2022. This shift is closely related to the promotion of global sustainable development goals.

4.3.3 Keyword Cluster

The keyword clustering spectrogram (Fig. 6) was generated based on CNKI literature statistics. CiteSpace provides two indicators to assess the clarity of network structure and clustering: the Q-value, which measures network structure clarity, and the S-value, which evaluates clustering confidence. A Q-value greater than 0.3 indicates a significant clustering structure, while an S-value less than 0.7 indicates high clustering confidence[19]. In this study, the Q-value is 0.870 and the S-value is 0.967 for Chinese literature, indicating that the clustering structure is highly significant and the clustering results are reliable.

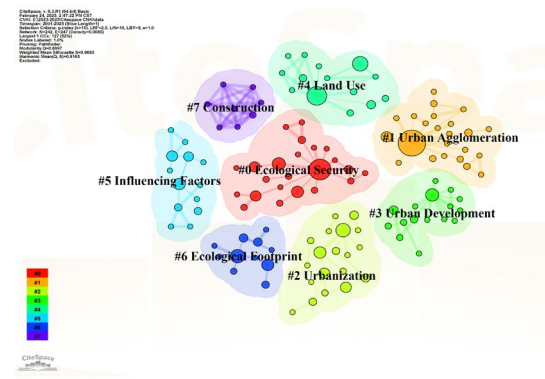


Figure 6. Keyword clustering map in CNKI database

The clustering results of the Chinese literature are organized by size, name, intensity, year of occurrence, and keywords, as shown in Table 5.

Table 5. keyword clustering table in CNKI database

Code	Size	Cluster name	Mean Year	Keywords
0	23	Ecological security	2017	Ecological security; Spatial and temporal evolution; Beijing-Tianjin-Hebei; Drivers
1	23	Urban agglomeration	2017	Urban agglomerations; Coupled coordination; Land ecology
2	19	Urbanization	2018	Urbanization; ecological resilience; Landscape patterns; Ecological corridors
3	16	Urbanize	2010	Urbanization; Changzhutan; Systematic evaluation
4	14	Land use	2017	Land use; Carbon stocks; Ecological space
5	13	Factor	2021	Yellow River Basin; Influencing factors; Spatial and temporal evolution
6	11	Ecological footprint	2011	Ecological footprint; Ecosystem; Energy value analysis
7	8	Construct	2011	Construction; Ecological base; Protection

The English literature in this study has Q = 0.786 and S = 0.907, indicating a significant clustering structure and high confidence in the clustering results (Fig. 7).

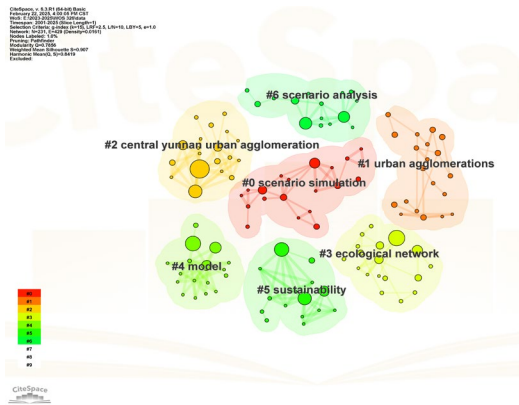


Figure 7. Keyword clustering map in WOS database

Organize the English literature clusters by size, name, intensity, average year of occurrence, and keywords as presented in Table 6.

Tale 6. keyword clustering table in WOS database

Code	Cluster name	Size	Mean Year	Keywords
0	Scenario simulation	20	2014	Patterns; Management; Services; Cellular automata
1	Urban agglomerations	20	2021	Urban agglomerations; Environment; Identification
2	Central yunnan urban agglomeration	18	2020	Ecosystem services; Framework; Land use change
3	Ecological network	17	2015	Model; Conservation; Biodiversity
4	Model	15	2020	Urbanization; Areas; Landscape
5	Sustainability	15	2018	Land use; City; Security
6	Scenario analysis	15	2018	Analysis; Ecological security; Cover change
7	FLUS model	14	2020	Area; Evolution; Spatiotemporal evolution

A comparative analysis of the clustering results from the Chinese and English literature revealed overlap in keyword clustering, leading to the identification of the following four comprehensive keyword groupings:

4.3.4.1 Ecological security and sustainable management:

The cluster includes clustering keywords such as #0 ecological security, #4 land use in the CNKI database,

and #3 ecological network, #5 sustainability in the WOS database, the clustering focuses on environmental protection, ecological restoration, and how to achieve sustainable development. Scholars have in-depth discussions on how to achieve ecological protection, improve the resilience of ecosystems, and ensure ecological security and sustainable management on a global scale under the background of global climate change.

4.3.4.2 Urban agglomerations and urbanization development:

The cluster includes clustering keywords such as #1 urban agglomerations, #2 urbanization, and #3 urbanization in the CNKI database, and urban agglomerations in the WOS database. The core content of the research is how to balance economic, social, and ecological needs, and explore how to achieve coordinated development of city clusters, rational use of resources, ecological resilience construction, and landscape pattern optimization in the process of rapid urbanization. In particular, how to promote green development and ecological environmental protection in the context of urban expansion and environmental pressure.

4.3.4.3 Regional ecological and environmental research:

The cluster includes keywords such as #5 influencing factors, #7 construction in the CNKI database, and #2 Central Yunnan Urban Agglomeration in the WOS database. The research mainly explores the resource management, ecological security, and environmental protection issues of specific regions, focusing on the relationship between regional ecological environment changes and regional development and protection. China's research in this field focuses more on solving specific regional problems and proposing practical solutions.

4.3.4.4 Modeling and Methodology:

The cluster includes keywords such as #6 ecological footprint in the CNKI database, #0 scenario simulation, #4 model #6 scenario analysis, and #7 FLUS model in the WOS database. The research mainly focuses on exploring how to predict and evaluate changes in ecosystems and urbanization processes through simulation and model analysis. Commonly used tools and methods include FLUS models, cellular automata, and scenario simulation, which are applied to fields such as land use change, ecological security, and resource management.

Judging from the keywords and research trends in the above four fields, "urban agglomeration" and "ecological security" have received widespread attention in the global academic community. Especially in the context of regional issues and ecosystem protection, researchers continue to explore in depth how to achieve ecological security and sustainable development in rapidly

developing urban agglomerations. Chinese research focuses more on ecological problems and system assessments in specific regions, while international research tends to use scenario simulations and ecological models to address global environmental issues. Over time, the research field has gradually deepened, especially in terms of ecological security, ecological restoration, and ecosystem services, reflecting a multi-dimensional and comprehensive discussion of environmental issues.

5 Conclusions

We systematically review and analyze the research literature on the ecological security of urban agglomerations both domestically and internationally, providing a comprehensive study of the development trends and characteristics of related research. The number of domestic publications surpasses that of foreign ones, with research progressing through four distinct phases: the exploratory stage (2000-2010), the budding stage (2011-2015), the development stage (2016-2018), and the outbreak stage since 2018. Foreign research, though slightly delayed, has experienced explosive growth after 2018, with an accelerated growth rate compared to previous years. The clustering analysis of urban agglomeration ecological security research shows overlap between domestic and international studies, which can be summarized into four subgroups: (1) Ecological security and sustainable management: focusing on strategies to achieve ecological protection and address ecological risks and climate change at both global and regional scales; (2) Urban agglomerations and urbanization development: exploring how to balance economic, social, and ecological needs during rapid development; (3) Regional ecological and environmental research: offering solutions to ecological and environmental issues through analysis of specific regions; (4) Modeling and methodology: emphasizing the application of simulation methods in ecosystems and urbanization processes. Although domestic institutions and authors dominate the field of urban agglomeration ecological security research, there is a lack of strong collaboration, with limited exchanges across institutions, regions, and disciplines.

The research in this field exhibits three main characteristics. First, there has been a shift from conceptualization to refinement in research content. Early studies focused on conceptualizing and developing driving mechanisms, but over time, the research has gradually moved toward more specific areas, including ecological security assessment, ecological risk management, and ecological restoration. In recent years, research hotspots have evolved to include topics such as optimization of ecological security patterns, spatial and temporal evolution analysis, driving factor analysis, and multi-scenario simulation. Emerging themes like carbon neutrality, ecological resilience, and coupled coordination have increasingly become central to research. Secondly, the focus of research has shifted from individual cities to regional urban agglomerations. Initially concentrated on typical cities such as Qingdao

and Changsha, the research scope has expanded to include multiple urban agglomerations, both within China such as ChangZhuTan, Yangtze River Delta, Pearl River Delta Urban Agglomeration, and globally. Finally, the research methodology has evolved from qualitative to quantitative approaches. With advancements in technology, methods have shifted from traditional qualitative analysis to more quantitative and spatially explicit techniques. Tools such as the ecological footprint method, the minimum cumulative resistance (MCR) model, and the FLUS model are now widely applied. In conclusion, research in the field of ecological security of urban agglomerations has deepened, with content becoming more refined, research objects expanding, and methodologies becoming more quantitative.

Based on the review and analysis of relevant literature both domestically and internationally, three future directions for research on the ecological security of urban agglomerations in China are proposed. Firstly, future research can move beyond traditional single-dimensional analysis frameworks by developing a composite model that couples climate change scenarios, carbon sink potential assessments, and ecological security early warnings. This would enable the exploration of multi-scale and multi-dimensional evaluation methods, ultimately facilitating a comprehensive assessment. Secondly, expanding from single-city cluster studies, research can focus on comparative studies of multiple-city clusters. This could include cross-national comparisons of city clusters along the "Belt and Road" and within the RCEP region. Emphasizing the spatial heterogeneity of the ecological hinterland of mega-city agglomerations, future studies should establish evaluation systems that incorporate factors such as terrain barriers and watershed system integrity, while also revealing the ecological security thresholds for city agglomerations at various stages of development. Finally, establishing a coordinated governance mechanism for ecological security in urban agglomerations is essential. This would promote cross-regional and cross-sectoral cooperation to collectively address ecological security challenges.

Acknowledgment

This research work was supported by the National Natural Science Foundation of China (42477515).

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