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Review

Development Trends in Soil Erosion Fields Based on the Quantitative Evaluation of Innovation Subjects and Innovation Content from 1991 to 2020

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Abstract: This paper mainly quantitatively analyzes papers in the field of soil erosion from an objective evaluation perspective. The purpose is to provide researchers in the field of soil and water conservation with a comprehensive understanding of the field. The bibliometric method was used to evaluate the technological innovation and evolution characteristics of soil erosion research. In terms of research scale, China and the United States have an absolute lead in this field. China started late, but the growth rate is faster. The evolution process of soil erosion research is classified into three stages (1991–2000, 2001–2010, and 2011–2020). In terms of innovation subjects (countries and institutions) in soil erosion fields, dominant countries exhibit more concentrated results, with an increase from 57% to 80% with respect to the ratio of the number of output papers in these countries to the total number of output papers in the research field of soil erosion. In contrast, research institutions are increasingly divergent, with a decrease from 36% to 26% with respect to the ratio of the number of output papers in the dominant institutions to the total number of output papers in the research field. The comparison results of the comprehensive innovation strength of major countries indicate that soil erosion research has experienced processes such as domination by the United States, and other countries have caught up via concerted efforts, with China and the USA finally leading comprehensively. The overall leading ability of China and the United States in soil erosion research continues to converge and improve. Belgium and other European countries have small research scale characteristics but greater influence capacities. The study of erosion mechanisms and erosion modelling has always been the main research direction in this field, while the quantitative study of soil erosion on large scales and its effects on element cycling comprises the current main research stream and development trend. The results of the present study could provide scientific support for a better understanding of the evolution of innovation characteristics in the field of soil erosion.

Keywords: innovation subject; comprehensive innovation strength; scale; evolution; bibliometric analysis

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1. Introduction

Soil erosion refers to the process in which soil or other ground components are eroded, transported, and deposited under the action of external forces, such as water power, wind power, freeze–thaw, and gravity [1]. Soil erosion is one of the most important environmental issues in the world, and it seriously restricts the sustainable development of society and the economy [2]. In the process of soil erosion, pollutants and global biogenic factors, such as carbon, nitrogen, and phosphorus, are transported, along with runoff and sediment. Therefore, soil erosion will not only lead to a reduction in land productivity but also become one of the influencing factors of global climate change, water environments, and ecological

health [3]. Soil erosion research is of great significance to regional environment protection, ecological health, and the sustainable development of the economy and society.

Soil erosion, as a major global environmental issue, is receiving increasing attention from governments and scientific and technological workers around the world. The occurrence mechanism and evolution dynamics, spatiotemporal distribution patterns, and future change prediction and restoration strategies of soil erosion induced by human factors have become important components of global change research and will continue to be a hot topic of common concern in the fields of soil science, agricultural science, and environmental science.

Up until now, a large number of reviews have been published in the field of soil erosion, and they mainly focus on soil erosion effects on agricultural production [4]; environment quality and ecosystem health [5,6]; and the comprehensive discussion on soil erosion at different research scales and regions [7–10]. Most of these traditional literature reviews mainly rely on manual research to systematically comb out specific research content and make comments on the development status of specific research in the field of soil erosion. With the rapid development of science and technology, the number of output articles also presents a rapidly increasing trend.

It is necessary to utilize the metrological analysis method in order to meet research requirements in the context of the explosive growth in the scientific and technological literature. Bibliometric analysis is a systematic method for understanding and determining research trends. With the rapid development of data mining and graphics visualization technologies, it is now possible to use software programs to analyze large amounts of data and visualize results. Recently, the bibliometric analysis method has been widely used in scientific and technological information analyses, which can analyze the structure and quantity of a discipline or knowledge field, reflecting the development state and evolution process of the field and providing a systematic and quantitative evaluation for the innovation and development of the field [11,12]. Moreover, the bibliometric analysis method helps provide a comprehensive understanding of the research status in a field and provides beneficial enlightenment for the theoretical research and development of the field [13].

At present, the bibliometric analysis method has been applied in the field of soil erosion [14–16]. For example, Shi et al. [15] conducted a quantitative analysis of the development status of soil erosion and soil and water conservation in China and abroad during the 2010–2019 period. However, these research studies mainly focused on the analysis of the progress and prospect of research content in the field of soil erosion; the evolution progress of innovation subjects and their comprehensive innovation strength were normally overlooked.

In the present study, the bibliometric analysis method and innovation-influencing indicators are used to analyze the innovation evolution process in the field of soil erosion from the two dimensions of general development and specific evolution characteristics with respect to three aspects: innovation subject, comprehensive innovation strength, and innovation content. Bibliometrics can obtain statistics based on a large amount of paper data, explore the development trends and characteristics of the field, and enable researchers to have a comprehensive macro-understanding of their research field. However, displaying some microfeatures via big data and more accurately grasping the field may not be easy. It is necessary to conduct in-depth investigations. Representative papers from each trending research direction with high influence are selected and interpreted in a professional and detailed manner, which can not only capture the development trend of the entire field but also analyze representative research results in detail. The corresponding author of the paper has long-term research experience in this field. In the analysis of research hotspots, representative papers were thoroughly interpreted, providing a more accurate and comprehensive interpretation of the development of the field from the perspective of research content.

Both comprehensive innovation development at the macrolevel and specific research hotspots at the microlevel are analyzed in the field of soil erosion. Based on these results, the present study could provide scientific support for further innovation, improving soil erosion research.

2. Data and Method

2.1. Data Sources

Web of Science (WoS) from Clarivate has been used to obtain articles in the field of soil erosion. The results were limited to the Science Citation Index Expanded (SCIE), and the final date of searching was 30 March 2022 (unless explicitly indicated). A total of 17,489 articles were retrieved and analyzed in the field of soil erosion, and only those with the "Article" literature type were considered.

The analytical methods used in this paper were a data analysis tool—Derwent Data Analyzer (DDA, Version 7)—and knowledge graph visualization software—VOSviewer (Version 1.6.15). DDA is a technology information analysis software and has unique functions with respect to data import, data cleaning, data analysis, and the reporting of analysis results. Based on structured data sources, it can provide matrix analysis and visual chart analysis functions. VOSviewer is a scientific knowledge graph software that can be used to draw scientific knowledge graphs and display the structure, evolution, cooperation, and other relationships of knowledge fields. The most prominent feature of VOSviewer is its strong graphic display ability, which is suitable for large-scale data.

2.2. Evaluation Indicators

The innovation evolution characteristics in soil erosion research were evaluated with respect to two aspects: innovation subject and innovation content. The evolution characteristics of the innovation subject refer to the comprehensive innovation strength of the country and the evolution process of the main institutions. With the combination of the innovation scale indicators and innovation-influencing capacity indicators, the comprehensive innovation strength of the country was evaluated. Innovation content mainly concerns the research hotspot and research direction.

2.2.1. Innovation Scale Indicators

The innovation scale indicators include the number and proportion of output articles, which are used to reflect the degree of the innovation subject in the absolute and relative sense, respectively. The number of output articles with respect to a certain innovation subject is counted according to the principle of equal distribution, which means that the output article from a country or an institution denotes that at least one author is attributed to that country or that institution among all authors of the article. The proportion of output articles is the ratio of the number of output papers in a certain country or institution to the total number of output papers in the research field. The innovation scale indicator of a country (ISI_c) is the percentage of the total number of article output in a certain country to the total number of article output in the field, which represents the scale of the article output of a certain country.

2.2.2. Innovation-Influencing Capacity Indicators

The innovation-influencing capacity indicators include the relative influence index in the field (RII_f) and the relative innovation influence index of a country (RII_c). RII_f was used to characterize the innovative influence capacity of the output articles in the field of soil erosion, which is the ratio of the actual number of citations of a certain article to the expected number of citations for articles in the same research field within the same publication year of a certain article. RII_f denotes the homogenization of the number of citations of each article in the dataset of the entire field of soil erosion. If $RII_f > 1$, this indicates that the influence capacity of the article is higher than the average level of the field. The relative innovation-influencing index of a country (RII_c) can be calculated as the average of RII_f

in the field of soil erosion in a certain country, which reflects the innovation-influencing capacity of a certain country.

2.2.3. Innovation Content

Innovative content refers to the hotspots and research directions that have attracted more attention in the field of soil erosion. Via the co-occurrence cluster analysis of high-frequency keywords, the mapping knowledge domain of research hotspots in the field of soil erosion can be obtained. In the mapping knowledge domain, each point represents a high-frequency keyword, the size of the point reflects the frequency of the keyword, and keyword sets with different colors represent different clusters of different research directions and hotspots.

2.2.4. Evolution Stages of the Subject Domain

According to the life cycle theory of the subject domain [17], four stages, i.e., germination, development, maturity, and decline, could be classified for the evolutionary process of the subject domain. The germination stage is characterized by a lower number of output articles and a low annual growth rate, but it is also characterized by the continuous output of the relevant literature. The characteristics of the growth stage are exhibited by the rapid growth of both the number and growth rate of output articles. With the first increasing and then decreasing trend of the annual growth rate of output articles, the annual article output changes from rapid development to slow development. In the maturity stage, the article output remains stable. After the maturity stage, it will generally develop in two directions. In one direction, the literature output shows a decreasing trend without new topics and represents a negative growth rate of the output articles, which denotes the declining stage of the subject domain. The other direction is to mutate new research directions and research hotspots and further increase the number of output articles, indicating the transformation from a specific research field to another field.

3. Results

3.1. Overall Development of Soil Erosion Research at the Global Scale

3.1.1. Annual Change Trend of Article Output in the Field of Soil Erosion

As shown in Figure 1, research in the field of soil erosion originated in the early 1930s. In 1934, the "Black storm" event in the western United States became an important historical event in the field of soil erosion, which began to attract the attention of researchers [1]. However, for a long time, there were few relevant studies, and the annual article output was lower than ten before the 1970s. Since the early 1990s, researchers have paid more attention to the field of soil erosion, and the annual article output began to exceed 100. From 1991 to 2000, the average annual growth rate of the article output was 6.13%. After 2000, with more and more attention, the annual growth rate of the article output increased. The average annual growth rate of the article output reached 9% during the periods of 2001–2010 and 2011–2020, with the highest value at 9.76% from 2016 to 2020.

The analysis results of the annual change in article output in soil erosion research show that before 1990, the research soil erosion field focused on the germination stage. Since 1991, the field of soil erosion has focused on the development stage, especially in the rapid development stage after 2011, with article output continuously increasing. Subsequent analyses will be carried out mainly based on the annual growth rate of the article output; specifically, three stages were classified as follows: 1991–2000, 2001–2010, and 2011–2020 (Figure 1).

3.1.2. Country Distribution of Article Output at the Global Scale

There are 162 countries involved in soil erosion research, of which 37 countries have produced more than 100 articles (Figure 2). The top five countries with higher article outputs follow the following order: the United States (4129), China (3858), the United

Kingdom (1225), Spain (1097), and Germany (1050). The total number of articles from the United States and China is far ahead compared to those from other countries.

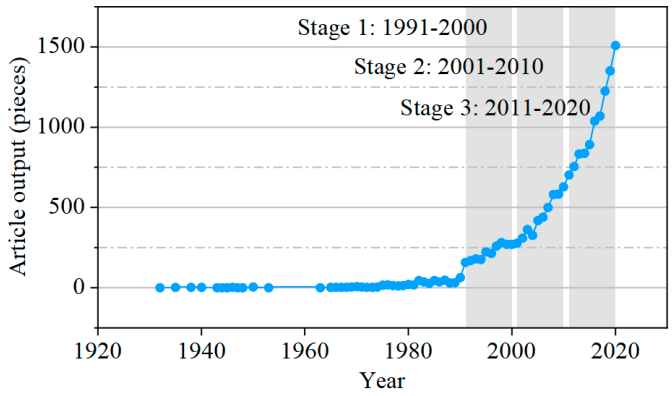


Figure 1. Annual change trend of article output in the field of soil erosion.



Figure 2. Countries with more than 100 articles in the field of soil erosion.

3.2. Evolution Characteristics in Soil Erosion Research

3.2.1. Evolution of the Comprehensive Innovation Strength of a Country

The evolution of innovation scale in the field of soil erosion was analyzed in three stages: 1991–2000, 2001–2010, and 2011–2020 (Table 1). During the years 1991–2000, the highest number of article output is observed in the United States, followed by the United Kingdom, Canada, and Australia. China and India, as developing countries, ranked sixth and eighth, respectively. The number of output articles in the United States (654) was approximately 4.5 times that in the United Kingdom (144). During the years 2001–2010, the article output still showed the highest number in the United States, followed by China, the United Kingdom, and Spain. During this stage, the United States still had a clear leading position, with almost twice the article output in China. However, the gap between the first-place country and second-place country has narrowed significantly compared with the years 1991–2000. During the years 2011–2020, China surpassed the United States to become the country with the highest article output. In terms of volume, the total number of Chinese articles is 1.5 times that of the United States.

As mentioned above, the comprehensive innovation strength of a country was evaluated based on RII_c and ISI_c.

The ISI_c and RII_c of the top 10 countries during the years 1991–2000 are shown in Figure 3. In this stage, the innovation scale in the United States was far ahead of other countries, with ISI_c at 30%. In terms of RII_c, the United States ranked seventh, with RII_c at 1.21. RII_c showed the highest value in Belgium (1.68), followed by Italy, the United Kingdom, and Spain. However, ISI_c values in these countries were less than 7%. Although China and India were listed in the top 10 countries in this stage, both RII_c and ISI_c were lower than the average level during the years 1991–2000.

Table 1. Comparison of article output in the top 10 countries during three stages.

Rank	1991–2000		2001–2010		2011–2020	
	Country	Number of Articles	Country	Number of Articles	Country	Number of Articles
1	USA	654	USA	1261	China	3114
2	UK	144	China	631	USA	2051
3	Canada	132	UK	397	Germany	738
4	Australia	130	Spain	311	Spain	725
5	Germany	62	Australia	286	UK	656
6	China	59	Germany	242	Italy	637
7	Spain	55	Belgium	223	Australia	529
8	India	47	Canada	199	France	486
9	Italy	41	Netherlands	192	Brazil	429
10	Belgium	36	France	175	India	420

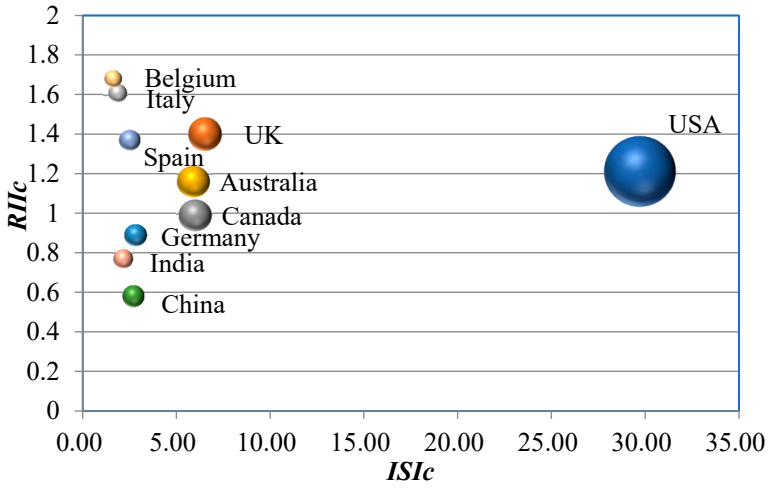


Figure 3. Comparison of comprehensive innovation strength in top 10 countries during years 1991–2000.

Figure 4 shows the ISI_c and RII_c of the top 10 countries during the years 2001–2010. As shown in Figure 4, the innovation scale indicator (ISI_c) also showed the highest value in the United States (28%), with relatively high innovation-influencing capacities (RII_c = 1.12) during the years 2001–2010. This suggested that the United States kept the leading position, with a higher comprehensive innovation strength in the field of soil erosion. However, both ISI_c and RII_c decreased in the United States in this stage compared with the previous stage, with RII_c ranked 7th. In terms of the innovation-influencing capacity, RII_c also showed the highest value in Belgium (2.0), followed by the Netherlands, Spain, France, Australia, and the United Kingdom. Both the RII_c and ISI_c of Belgium increased in this stage compared with that in the previous stage. The gap between the innovation scale in these countries and the United States was also narrowed in this stage. In this stage, the ISI_c of China ranked at the second position (14%), which was almost half of that of the United States, with a narrower gap than that in the previous stage. The RII_c of China also increased and was higher than the average level at this stage; it ranked eighth.

In the third stage, China surpassed the United States to become the country with the highest article output in the field of soil erosion during the years 2011–2020, with an ISI_c of 30% (Figure 5). Meanwhile, China's research innovation-influencing capacity had also improved, with a RII_c close to the United States, reaching 1.1. The United States had experienced a relative decline in innovation scale, with an ISI_c at 20% with respect to soil erosion in this stage. Among the top 10 countries, the highest RII_c was observed for Italy (1.69), with an ISI_c at 6%. Britain, Spain, Germany, France, and Australia have a higher RII_c than that in China and the United States. Although there were increasing trends of ISI_c in

these countries, ISI_c still showed a significant gap in these countries compared with China and the United States.

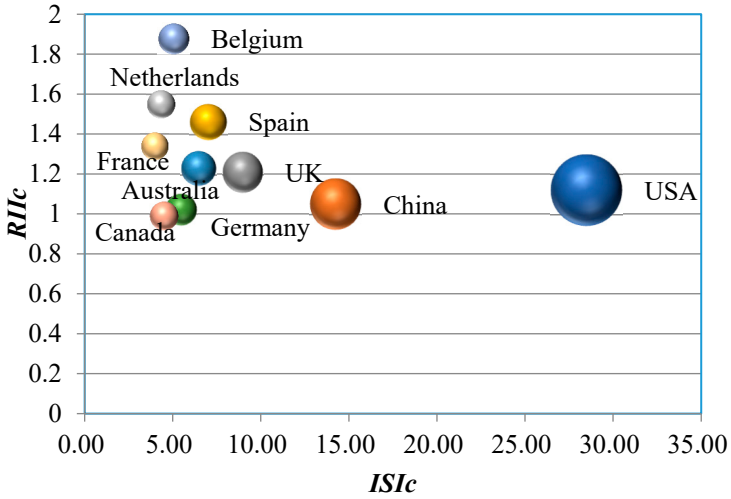


Figure 4. Comparison of comprehensive innovation strength in top 10 countries during years 2001–2010.

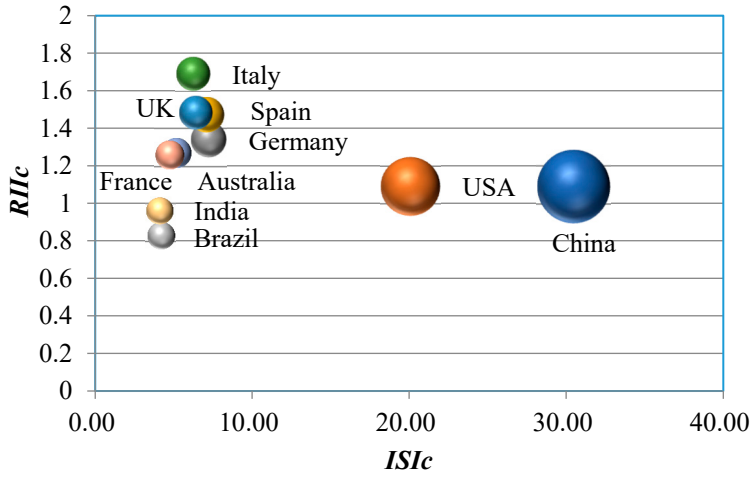


Figure 5. Comparison of comprehensive innovation strength in top 10 countries during years 2011–2020.

3.2.2. Evolution Process of the Main Institutions

Table 2 shows the top 10 institutions with the highest article output in the field of soil erosion during the three stages from 1991 to 2020. In the first stage (1991–2000), there were four institutions from government departments or national research institutes and six other institutions from universities among the top 10 institutions. Six of the top ten institutions are from the United States, two are from Australia, and there is one each from China and Canada, respectively. The United States Department of Agriculture (USDA) produced the highest number of articles (195), followed by Agriculture and Agri-Food Canada (AAFC), with 57 output articles. The Chinese Academy of Sciences (CAS) ranked seventh in position, with 25 output articles.

In the second stage (2001–2010), there were five institutions from government departments or national research institutes and five other universities among the top 10 institutions. The country distribution of the top 10 institutions was more scattered compared with the previous stage, with two institutions each from the United States and China and one institution each from Belgium, Spain, Australia, the United Kingdom, the Netherlands, and Canada. Still, USDA remained in first place with 357 output articles, followed by CAS with 353 output articles.

Table 2. Comparison output articles in the top 10 countries during three stages.

Rank	1991–2000		2001–2010		2011–2020	
	Institution	**Number of Articles**	**Institution**	**Number of Articles**	**Institution**	**Number of Articles**
1	United States Department of Agriculture (USDA)	195	United States Department of Agriculture (USDA)	357	Chinese Academy of Sciences (CAS)	1345
2	Agriculture and Agri-Food Canada (AAFC)	57	Chinese Academy of Sciences (CAS)	353	Northwest A&F University	451
3	Purdue University	41	Katholieke Universiteit Leuven	171	University of Chinese Academy of Sciences	365
4	The Ohio State University	39	Beijing Normal University	79	Beijing Normal University	345
5	Griffith University	27	Consejo Superior de Investigaciones Cientificas (CSIC)	76	United States Department of Agriculture (USDA)	420
6	The University of Nebraska	27	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	68	Ministry of Water Resources of the People's Republic of China	328
7	Chinese Academy of Sciences (CAS)	25	University of Exeter	64	Consejo Superior de Investigaciones Cientificas (CSIC)	142
8	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	25	Purdue University	60	Katholieke Universiteit Leuven	137
9	The University of Georgia	22	Wageningen University & Research	59	Wageningen University & Research	127
10	Colorado State University	21	Agriculture and Agri-Food Canada (AAFC)	56	Beijing Forestry University	126

In the third stage (2011–2020), there were four institutions from government departments or national research institutes and six other universities among the top 10 institutions. The country distribution of the top 10 institutions was more concentrated compared with the previous stage, with six institutions from China; two institutions each from the United States and Australia; and one each from Spain, Belgium, and the Netherlands, respectively. However, CAS produced the highest output articles (1345), followed by the Northwest Agriculture and Forest University of China (NAFUC) with 451 output articles.

3.2.3. Evolution of Research Hotspots

1. The first stage during the years of 1991–2000

The mapping knowledge domain of research hotspots in the field of soil erosion during the years 1991–2000 is shown in Figure 6. In this stage, the research hotspots included three aspects: a soil erosion model, soil erosion mechanism, and soil erosion impacts on agriculture.

The first research hotspot mainly focused on the quantitative method or measurement to simulate the amount of soil erosion [18]. Among different research studies, the RUSLE (Revised Universal Soil Loss Equation) published by USDA has received the most attention and has been cited more than 800 times to date [19]. This revised model is an improvement based on the Universal Soil Loss Equation (USLE) released by USDA in 1978 [20], which has been the most widely used empirical model in the field of soil erosion. The European Soil Erosion Model (EUROSEM), which could simulate the soil erosion process [21], also has substantial influence and has been cited nearly 800 times. The model was developed in

collaboration with several European countries, including the UK, Belgium, Italy, Germany, and Denmark. Since the 1990s, GIS technology has been combined with soil erosion models to evaluate soil erosion on a regional scale. Among them, a GIS-related algorithm program developed in Belgium has attracted more attention [22].

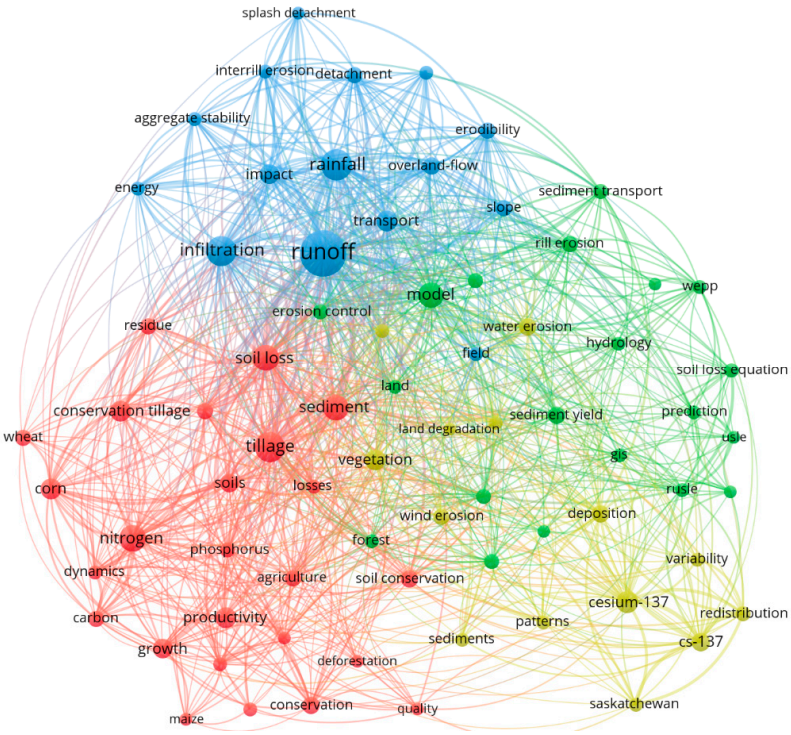


Figure 6. Research hotspots in the field of soil erosion from 1991 to 2000.

The second research hotspot for the years 1991–2000 mainly focused on soil erosion mechanisms. Via rainfall and runoff simulation experiments, erosion mechanisms based on soil properties were examined, including soil water seepage, soil water retention, and soil structural stability [23–25]. Highly influential articles were also published relative to this trending research topic, such as a study on the changes in soil structure under different tillage conditions by AAFC [26] and a comparative study on soil permeability parameters under the condition of rainfall simulations by the University of California [27].

The third research hotspot during the years 1991–2000 mainly focused on soil erosion impacts on agriculture, such as the relationship between soil erosion and land productivity [28] and soil erosion impacts on agricultural non-point source pollutants [29]. The land vulnerability assessment conducted by the United States Department of Agriculture based on the non-point source pollutants of phosphorus and soil erosion characteristics has a high influencing capacity up until now [30].

2. The second stage during the years of 2001–2010

As shown in Figure 7, research hotspots in the field of soil erosion mainly included four aspects during the years 2001–2010. Among them, the soil erosion mechanism and soil erosion model were continued as trending research topics from the previous stage. The influencing factors of soil erosion and soil erosion impacts on the environment were two new directions. In terms of influencing factors, vegetation and land use types were recognized as the key factors affecting soil erosion and climate change [31]. For example, the effects of climate and land use change on gully erosion were investigated through monitoring and modeling analysis, and this was carried out by the University of Leuven in Belgium [32], which has been cited nearly 1000 times, exhibiting a highly influential capacity. The correlation between farming methods and soil erosion was investigated by the University of Washington [33], which has also attracted widespread attention, and

has been cited nearly 1000 times. Another research hotspot is soil erosion's impact on the environment, including a study on the correlation between water pollution and soil erosion [34]. Meanwhile, the influence of soil erosion on the global element cycle is also a hot topic. The roles of soil erosion in the global sediment flow were investigated by the Australian Institute of Scientific and Industrial Research (CSIRO) and the University of Colorado [35], which became the most influential research study of the period with more than 1600 citations. The impacts of soil erosion control practices and relative management methods with respect to ecosystem restoration were also attractive research topics during this period [36].

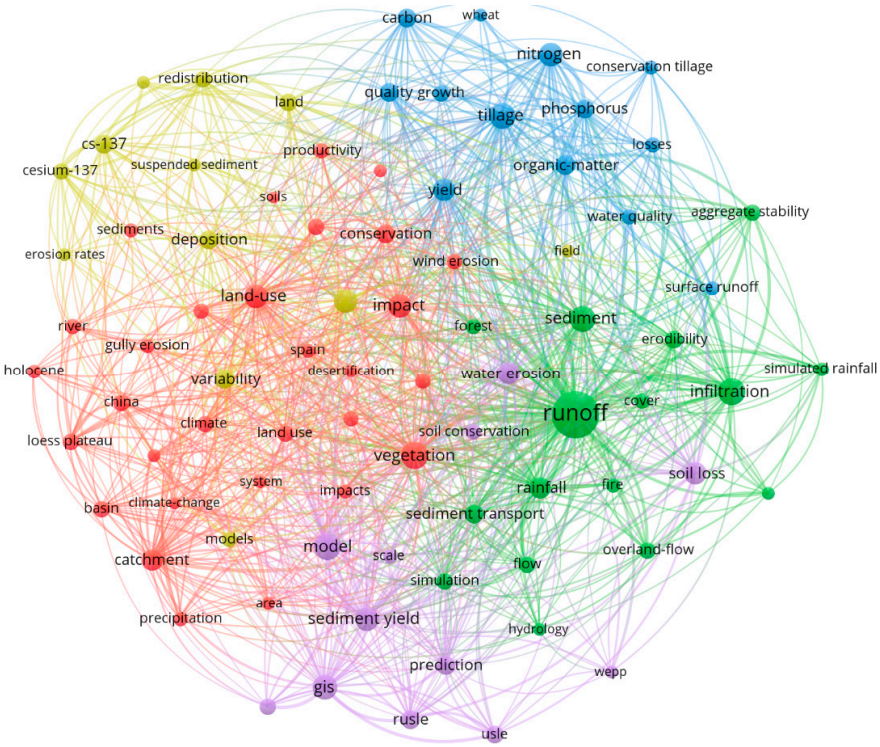


Figure 7. Research hotspots in the field of soil erosion from 2001 to 2010.

3. The third stage during the years of 2011–2020

As shown in Figure 8, research in the field of soil erosion also mainly included four aspects during the period of 2011–2020. Among them, the three research directions of soil erosion mechanisms, influencing factors, and soil erosion impacts on the environment were continued from the research studies of the previous stage, with more in-depth investigations and the application of multiple new monitoring technologies. For example, in terms of mechanism research, it focused on the quantitative investigation of the evolution processes of slope erosion, such as rills and shallow gully erosion [37,38]. In terms of influencing factors, the interrelationship between global biogenic factors, especially the carbon cycle, soil erosion, and climate change by several European countries [39], attracted more attention, with more than 800 citations. In particular, the global circulation of major elements has also been a significant research direction in this field in recent years, and the study of elements, such as carbon and phosphorus, has also comprised a highly cited paper in this field in recent years [40,41].

In the third stage, multiple techniques and methods have been applied to the soil erosion model. For example, the application of the soil and water assessment tool (SWAT) and spatial distribution model has increased [42–44]. The application of comprehensive quantitative analyses of geographic information data based on a digital elevation model (DEM) in the assessment of soil erosion also received more attention [45]. Models from other fields, such as the backpropagation (BP) neural network, have also been introduced

into soil erosion models [46,47]. In addition, research on soil erosion assessments based on deep learning has also received considerable attention in recent years [48].

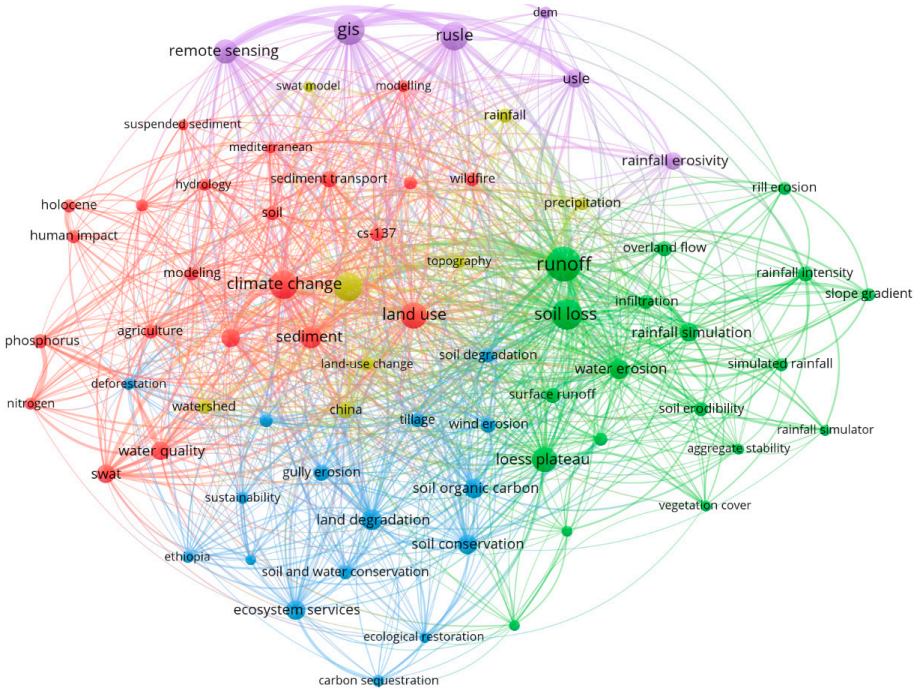


Figure 8. Research hotspots in the field of soil erosion from 2011 to 2020.

In this stage, the new research direction was soil erosion prevention, and controlled research aimed at improving ecosystem service functions [49]. In recent years, the trend of interdisciplinary crossover and integration has been strengthened, and research in the field of soil erosion has started to pay attention to the relationship between soil biodiversity change caused by land use and the ecosystem [50,51]. The impacts of human activity on the ecosystems of Earth were investigated with respect to a combination of soil erosion and biogeochemical cycle processes among the land, atmosphere, and ocean cycles [52], and these topics have gained a high number of citations and substantial influencing capacity. In recent years, research on the interaction between soil erosion and the ecological environment has also been a hot topic in this field [53,54].

Also, investigations by China in the field of soil erosion gained more attention in this new stage [55–58]. For example, the investigations on soil erosion, conservation, and eco-environment changes in the Loess Plateau of China gained substantial attention, with more than 500 citations [59]. Research on ecological restoration and the sustainable development of the Loess Plateau has become a hot topic in recent years [60,61].

4. Discussion

Based on the analysis of the evolution of the comprehensive innovation strength of a country, we can find that the United States has exhibited the most outstanding performance, while China started relatively late but developed rapidly. The comparison results of the comprehensive innovation strength of major countries indicate that soil erosion research has experienced processes such as domination by the United States, and other countries have caught up via concerted efforts, with China and the USA finally leading comprehensively.

During the years 2001–2010, the comprehensive leading advantage of the United States was still relatively obvious, but other countries have formed a common development trend to catch up and narrow the gap with the United States. China became the second largest research country during the years 2011–2020, and China's comprehensive innovation strength had significantly improved, ranking at the forefront of the field along with the United States and also leading the United States in terms of innovation scale. Moreover,

the leading role of the top 10 countries in the field of soil erosion had been strengthened in this stage, with the total ISI_c of the top 10 countries increasing from 57% in the first stage (1991–2000) to 80% in the third stage (2011–2020).

Via the comparative analysis of the top 10 institutions in different stages, it can be observed that government departments, national research institutions, and universities have always been innovation subjects in the field of soil erosion, among which universities have always been the main participants in research activities. Among the top ten institutions with the highest output articles, the number of universities always accounted for 50% to 60%, but government departments and national research institutions play the most important roles. USDA had been the most productive research institution in the field of soil erosion until 2010. CAS has produced the most articles in the field of soil erosion since 2011. The proportion of the output articles of the top 10 institutions to the total output articles in the field of soil erosion decreased from 36% in the years 1991–2000 to 26% in the years 2011–2020, which indicated that more and more institutions are participating in soil erosion research.

5. Conclusions

This paper mainly quantitatively analyzes articles in the field of soil erosion from an objective evaluation perspective. The purpose is to provide researchers with a comprehensive understanding of this field, including the development history, with respect to which countries and institutions have performed outstandingly at different stages and research directions have received more attention. These contents will have a good inspiring effect on researchers in this field and are not available in traditional review research. With the rapid increase in the number of papers, it will be difficult for researchers to have a comprehensive understanding of the research status in the field solely through manual review. A bibliometric-based review can help researchers attain a comprehensive understanding of the research development trend in the entire field.

Research in the field of soil erosion originated in the early 1930s, but it did not attract much attention for a long time until the 1990s. An innovative assessment of output articles in the field of soil erosion during the period of 1991–2020 was conducted from two aspects: overall development and evolutionary characteristics. Soil erosion research was divided into three stages based on the life cycle theory of the subject domain: 1991–2000, 2001–2010, and 2011–2020. In terms of the overall development, the increased rate of output articles in these three stages accelerated continuously in the field of soil erosion, resulting in the current rapid development stage. In terms of innovation evolutionary characteristics, the comprehensive innovation strength of the top 10 countries and the evolution process of the top 10 institutions at different stages were assessed in soil erosion research, and research hotspots were also analyzed in the three stages. The results show that the United States had dominant power in the field of soil erosion in the first stage, followed by the joint efforts of many countries to catch up in the second stage, and this was led by China and USA in the third stage, both of which exhibited the highest comprehensive innovation strength. The distribution of research institutions showed more and more divergent trends, with Chinese institutions playing an increasingly important role in research activities. The USDA in the United States was the most productive research institution in soil erosion research until 2010, while the CAS of China has become the most productive institution since 2011. From the perspective of research hotspots, soil erosion mechanisms and modelling have always received substantial attraction, with new research directions at different stages, leading to broadening systematic characteristics with respect to research hotspot development. Soil erosion models based on erosion mechanisms, processes with multiple technical methods for large-scale erosion simulations, and soil erosion effects on elemental cycling have been the current mainstream research and development trend.

Research in the field of soil erosion is currently in a rapid development stage, and China's overall innovative research performance in this field is outstanding. However, with respect to specific research directions, such as the study of soil erosion mechanisms,

especially erosion models, questions regarding how innovative China's performance is and which countries and institutions in the international community are already at the international leading level are our next research goals. In addition, it is necessary to consider the practicality of this innovative research topic: that is, whether high-level innovative activities can ultimately solve real problems caused by soil erosion. In the future, based on the analysis of engineering papers or patents, application research and technological innovation in this field will be analyzed, and a comprehensive analysis and evaluation of innovative activities in the field of soil erosion can be conducted from the perspective of the innovation chain.

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