



Research trends and areas of focus on water rights: a bibliometric analysis 1971–2020

Hongfei Meng¹ · Guangzu Bai¹ · Liwei Wang¹

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Abstract

This study investigated the research trends, key areas, and directions of water rights (WRs) using bibliometric data based on the Science Citation Index Expanded (SCI-E) and Social Sciences Citation Index (SSCI). This paper presents a comprehensive review of annual output, research fields, cooperative networks, published journals, and hot spot evolution from 1971 to 2020. The results show that the number of published papers on WRs has an exponential upward trend. This research mainly focuses on water resources, environmental sciences, environmental studies, law, agronomy, and political science. Rutgerd Boelens and Barbara Van Koppen are authors of the most widely published and influential factors in the field. Leo Heller, Priscila Neves-Silva, and Jeroen Vos have been the most recently active authors. University of New Mexico and the United States Department of Agriculture are the organizations with the most publications and total citations, respectively. The USA, China, Australia, the UK, The Netherlands, and Spain are among the most productive countries for WR research. Keyword analysis showed that the study of WRs has gone through three stages: the exploration of laws and regulations, comprehensive management, and technology development and application. Literature citation cluster analysis shows that a highly central article provides a strong link between internal research on WRs. Western USA, trading WRs, and constitutional reform were hot spots before 2010, while economic anthropology, combined effect, public attitude, and integrated assessment modeling have become popular recently. The study results can help experts understand the research progress in WRs.

Keywords WRs · Bibliometric analysis · VOSviewer · Thomson data analyzer (TDA) · CiteSpace

Introduction

With the rapid development of the social economy, the depletion of water resources has become a major challenge, and the requirements of human beings for water resources are increasing annually. Therefore, it is of great importance to introduce the concept of property rights into the field of water resources, and the water right (WRs) system has arisen at a historic moment. WRs refers to the ownership of water resources, the rights that are used, and profit derived from ownership. The significance of WRs is increasingly recognized internationally, and the lack of an effective WR system will bring about the management of problems with

increasingly scarce water supply (Speelman et al. 2009). Scholars and experts from various countries have conducted numerous WR studies. Influenced by other factors such as historical factors, water resource endowment, social structure, economic development, and WRs, systems in various countries have both similarities and differences. Establishing a complete WR market is of great significance for improving water use efficiency and solving water shortage problems (Delorit et al. 2019; Payne and Smith 2013; Rosegrant and Binswanger 1994). Using the model framework to study the economic benefits of WR issues, WR management and water volume monitoring are also the focus of research (Bailey et al. 2016; Pessacq et al. 2015; Rosegrant et al. 2000; Senay et al. 2017). Research on WRs is often accompanied by governance of environmental issues, political conflicts, and sustainable development; therefore, comprehensive water resource governance research is particularly important (Berry and Jackson 2018; Boelens et al. 2016; Curran 2019; Hurlbert and Diaz 2013; Punjabi and Johnson 2019). More than 10 years have passed since the concept of the

Responsible Editor: Philippe Garrigues.

✉ Hongfei Meng
menghf@llas.ac.cn

¹ Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China

human right to water was proposed in 2010, and the research and discussion of this concept has been a hot topic (Fantini 2020). The constitutionalizing of human rights to water and the formulation of water human rights-related systems have received much attention (Barnard 2020; Markwell 2015; Schiff 2019). These studies show that WRs are an area of intense scientific interest, and numerous studies have focused on them. Most previous studies are based on the theory of WRs, system construction, technology development, application, and so on. The application of bibliometric methods in the evolution and development trends of analytical disciplines are becoming increasingly widely used (Chen et al. 2016; Laengle et al. 2017; Saravanan et al. 2022). This requires analyzing the research on WRs from the perspective of literature measurement. The research in this paper is only partly about water rights in an economic sense of property rights; it shows how this concept has grown in importance in the context of water governance challenges and choices. Based on the Web of Science (WOS) database, this research presents a detailed analysis of the development track, cooperation network, and hot trends in worldwide WR research through the rational use of bibliometric software, which will provide a new perspective on WRs research.

Methods and data collection

Methodology

Literature visualization methods are widely used in science to discover scientific frontiers and trends (Aria and Cuccurullo 2017). The data and graphics processing in this study are mainly based on Microsoft Excel, Origin 2021, and Adobe Illustrator. The deduplication function of CiteSpace.5.8.R3c and the data cleaning function of the Thomson Data Analyzer (TDA) were used for further data organization to yield more accurate results. Persuasive visual analysis primarily uses VOSviewer, CiteSpace, and Pajek. CiteSpace is a knowledge identifiable analysis software developed by Professor Chen Chaomei of Drexel University based on the Java platform to interpret and analyze. TDA is a patent analysis tool, developed by Thomson Corporation of the USA, that can conduct in-depth mining and visual analysis of literature or patent data. VOSviewer is free bibliometric analysis software for constructing and viewing bibliometric maps. It is based on the principle of co-citation of documents and can be used to draw scientific maps in various fields of knowledge. Pajek software is a large and complex network analysis and visualization tool for the analysis and visualization of large networks with up to one million nodes. In addition, according to the incompatible characteristics of the software and the compatible serial relationship between them, VOSviewer and Pajek are used

for author, institution, and keyword analysis, and VOSviewer and Scimago Graphica are used for national cooperative geographic visualization, which can visually display the geographical location information of documents in detail.

Data sources

The SCI-E and SSCI databases were used in the WOS database. The SCI-E database is one of the main bibliographic databases produced by the Clarivate Analytics Company; SSCI is a social science literature retrieval tool recognized by the academic community. Second, both databases contain detailed reference data to track the development trends and contexts of WR research comprehensively. The retrieval was $TS = ((\text{"* water right*"}))$ or $(\text{"Right* to water"})$ or $(\text{"Water Concession*"}))$, and the time range was from 1900 to 2020. The downloaded data were searched for on May 11, 2021. The retrieval records were 1722, and the retrieval type was article, review, and proceedings because these three types included more than 85% of the total retrieval results (Li et al. 2020). After the retrieval was completed, there were 1558 records, 1495 records after weight loss with CiteSpace software, 63 repeated records were deleted, and the priority publication (publishing time was 2021) and unrelated articles were excluded; the final number was 1490.

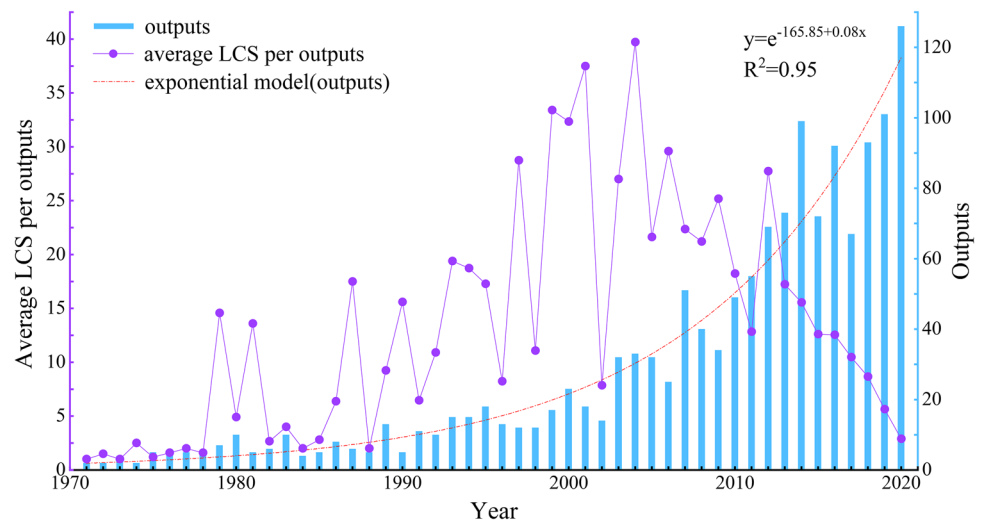
Articles published by the authors in England, Scotland, Wales, and Northern Ireland are considered publications from the UK, which is routine in other bibliometric analyses (Liu et al. 2011). Cooperation between the author, institution, and state is determined by a complete count, which means that the signatories of each article are treated fairly. In addition, inter-institution and international cooperation publications refer to papers co-authored by researchers from multiple institutions and countries. Key analysis is based on the author keywords in the downloaded literature, and document co-citation is based on the references in the downloaded literature data.

Results and discussions

Analysis on the overall scientific research output of WR research

Increasing trend of research papers

In this study, there were only 55 research papers published from 1900 to 1970, accounting for 3.69%. Therefore, we selected data from 1971 to 2020. Figure 1 summarizes the time evolution of the annual volume of documents published and the average number of references per year from 1971 to 2020.

Fig. 1 Temporal evolution of outputs on the WR research

From the fitting curve between the volume of publication and year (red dotted line, $y \leq e^{-165.85+0.08x}$, $R^2 \leq 0.95$), it is evident that there is a significant positive correlation between volume and time in the past 50 years, from 2 in 1971 to 126 in 2020, with an average annual growth rate of 8.82%. The output increasing trend showed a wavy manner from 1971 to 2002 and increased significantly after 2002, of which nearly 80% of the literature was published during the period 2003–2020 (Fig. 1). A total of 59.02% of the papers focused on the last 10 years, which reflects the growing global interest in the subject and indicates that water right-related research is at a stage of rapid growth and has great potential for development. However, the average annual citation frequency of the article shows the trend of “high in the middle and low in both ends” (purple dotted line), which is due to less research at the beginning, and the maturity and communication influence of the paper are limited. With the passage of time and deepening of research, the influence of the paper begins to rise. In 2004, the average article was cited as high as 39.73 times, but this cannot be used as the only index to measure article quality. It depends on the way of the calculation of the local citation score (LCS) and the life cycle period of paper citation. After 2012, the average citation of articles decreased sharply, on the one hand, because the number of articles published gradually increased, and, on the other, there was a time difference between the publication time and the citation of articles. More recently, the number of citations of articles has usually been lower.

The local citation score (LCS) is the number of times an author’s papers in the “WRs database” have been cited by other papers in the database.

Key research areas of WRs

Key research areas can reflect the subject concentration of a research topic, and the direction of the research topic can be understood from a macro point of view. The literature in the WOS database contains the corresponding subject classification. The downloaded literature data were imported into the thermal map template of the VOSviewer research field to analyze the hot field of WRs research (Fig. 2). It can be found that WR research covers a wide range of disciplines. They mainly focus on the following fields: water resources, environmental sciences, environmental sophistication, law, agronomy, and political science.

Most-cited papers on WRs

High-level papers are of great significance for guiding innovation and attaching importance to the influence of scientific research achievements. Table 1 lists the 10 papers cited during the study period. Hayhoe et al. have shown that California’s WR system may be fundamentally destroyed under the A1fi emission scenario at the end of this century (Hayhoe et al. 2004). Anderson MC et al. analyzed how the use of Landsat thermal imaging for WR monitoring, estimating the water consumption of invasive species, and determining the distribution of agricultural and urban water (Anderson et al. 2012). Allen RG et al. found that mapping evapotranspiration with internalized calibration is an effective, accurate, and inexpensive method for water right accounting and groundwater model operation, which has great prospects in estimating the actual evaporation flux of irrigated land during the entire growing season (Allen et al. 2007). Stefanov WL et al. used texture, land use, WRs, urban boundaries,

impact on the protection of river ecosystems (Palmer et al. 2009). Rosegrant MW et al. showed that the establishment of tradable water rights can play an important role in improving the efficiency, equity, and sustainability of water use in developing countries (Rosegrant and Binswanger 1994). Rosegrant MW et al. proposed an integrated economic-hydrological modeling framework for estimating the social and economic benefits of improved water allocation and use efficiency (Rosegrant et al. 2000). Wutich A et al. found that water-related emotional distress is a by-product of social and economic negotiation for access to water distribution systems in the absence of clear procedures or established water rights, rather than due to individual water scarcity (Wutich and Ragsdale 2008). Yang et al. found that clearly defining the water rights and responsibilities of water operators and users of irrigation systems is the basis for promoting water conservation and improving irrigation efficiency (Yang et al. 2003).

Three of them talk about the importance of the development of water rights; Two papers focus on hydrological models; Two articles focus on the application of remote sensing technology in the development of water rights, and one on climate change; One article emphasizes the attention to people in the development of water rights, and the other focuses on environmental flow. It can be found that climate change, environmental flow, and human rights are still the hot topics of current water right research. These research topics are basically consistent with the analysis of the keyword time heat map (Fig. 8). However, the publication time of the literature is earlier than the average time of the keywords; that is to say, the classical literature that pays attention to a certain issue in the field of water rights will often become highly cited literature. These documents provide a research basis and reference value for the follow-up research in the field of water rights.

Analysis of WR research cooperation network

Research on author cooperation networks

The authors' cooperation network analysis can identify the main researchers in the field and their relationships. This study sorted out the information of 14 authors who published six or more papers (Table 2). Wurbs Ralph A, Boelens Rutgerd, Heller Leo, and van Koppen Barbara are among the top four in the number of articles published; the top four authors of the average number of citations per paper are Boelens Rutgerd, Libecap Gary D, Vos Jeroen, and van Koppen Barbara. Some authors with few citations may also be related to their recent publication years. The top two h-indexes are Boelens Rutgerd and Van Koppen Barbara. From the average publication year, Heller Leo,

Table 2 Top 14 with the most publications on WR research

Name	N	TC/N	H-index	Ave-PY
Wurbs Ralph A	21	9.19	6	2006.57
Boelens Rutgerd	17	38.35	12	2013.47
Heller Leo	14	7.43	6	2018.14
Van Koppen Barbara	12	22.58	9	2011.92
Kim Tae Jin	8	2.50	3	2013
Speelman Stijn	7	11.71	5	2011
Wang Zhongjing	7	15.29	6	2012.43
Xu Wenchao	7	7.14	4	2016
Zheng Hang	7	11.57	6	2013.29
Libecap Gary D	6	30.50	6	2011.17
Neves-Silva Priscila	6	9.33	4	2018
Perez-Foguet Agusti	6	12.67	6	2015
Van Huylenbroeck Guido	6	10.33	5	2011.17
Vos Jeroen	6	27.83	4	2016.17

Neves-Silva Priscila, Vos Jeroen, and Xu Wenchao have been the most active authors in recent years. Overall, Boelens and Van Koppen are the authors with the largest number of publications and highest impact factor in the field. In recent years, Heller Leo and Vos Jeroen have made remarkable achievements in terms of the number of publications or influence.

According to the distribution of Price literature authors (Price Law), half of the literature on the same research topic comes from a group of core authors (Roy 2019), and the core author's calculation formula is $M_p = 0.749 \sqrt{N_{pmax}}$; N_{pmax} is the number of publications of the most prolific authors in the field during the statistical time period, and M_p is the minimum number of documents that the core author in this field should publish in the same period. In this study, the source authors with the largest number of documents in the database issued 21 articles, $N_{pmax}=21$, and the M_p value was approximately 3.4. According to the rounding principle, authors who published three or more articles can be regarded as the core authors in this field. As a result, there are 135 core authors in the field of international WR research, and 543 articles have been published by the core authors, accounting for only 34.15% of the total relevant literature, which is far from the target of 50% of the total literature published according to the Price Law. Although the WR research field has formed a more obvious author cooperation cluster, a core author group has not yet been formed.

N , number of publications; TC/N , average number of citations per paper; $Ave-PY$, average publication year.

There were 587 articles by one author, accounting for 39.93% of the total literature, and 167 articles by five or more authors, accounting for 11.21% of the total. In addition, Fig. 3 shows that the cooperative relationship between the authors of WR research is weak, which shows a trend

Fig. 3 Co-authorship network on WR research



Table 3 The top 10 most productive and high-citation institutions

Institution	Outputs	Institution	TLCS
UNM	34	USDA	1495
CSU	32	UI	936
UA	32	WUR	886
TAMU	28	UCB	761
WUR	28	IWMI	726
CU	23	CSU	711
IWMI	22	ASU	676
USU	20	Stanford University	639
HHU	19	UA	607
ASU	18	NCAR	580

UNM University of New Mexico, *CSU* Colorado State University, *UA* University of Arizona, *TAMU* Texas A & M University, *WUR* Wageningen University & Research, *CU* University of Colorado, *IWMI* Int Water Management Institute, *USU* Utah State University, *HHU* Hohai University, *ASU* Arizona State University, *USDA* United States Department of Agriculture, *UI* University of Idaho, *UCB* University of California, Berkeley, *Stanford University* Leland Stanford Junior University, *NCAR* National Center for Atmospheric Research

of individual combat or small team combat, suggesting that exchanges and cooperation between countries should be further strengthened.

Research on institutional cooperation networks

The co-occurrence map of institutions can intuitively reflect the distribution of research strength and the cooperative relationships among research groups in a certain field. As shown in Table 3, the number of documents issued by the top ten institutions is not large overall, and the gap between them is small, which indicates that the research on WRs started relatively late, and the research institutions lack certain discipline accumulation and precipitation. In addition, there is no dominant situation for each institution, and WR research strength is relatively scattered, which is conducive to healthy competition and academic exchange among research institutions. The total citation frequency of the USDA ranks first, but its publication quantity is not in the top 10, which indicates that the scientific research output of this institution is of good quality and great influence. There are five institutions in the top 10 for publication and total citation frequency (CSU, UA, WUR, IWMI, and ASU), which shows that these five institutions can guarantee the quality of scientific research output under the premise of maintaining a high quantity of scientific research output.

Figure 4 shows that the institutions with the same color in the mechanism co-occurrence atlas were divided into six clusters of WRs research institutions. Cluster 1 has the

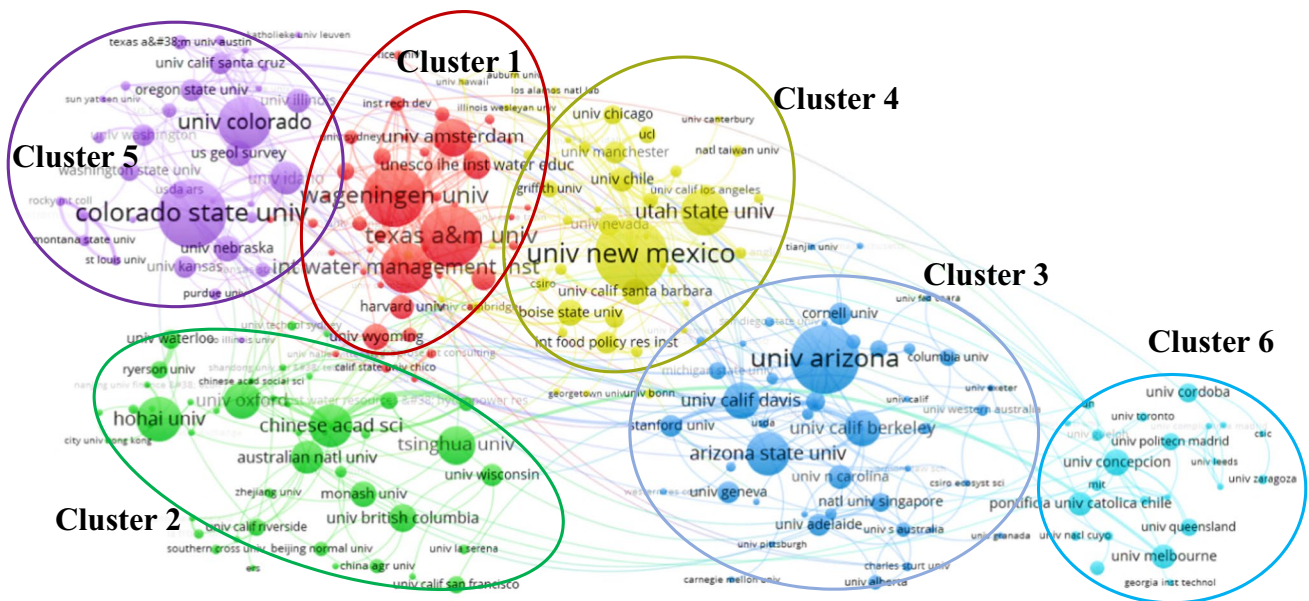


Fig. 4 The top 6 clusters on WR research

largest node scale, containing 48 institutions and 254 articles, indicating that these institutions not only have a large number of publications, but also have a good cooperative relationship with other institutions. Among them, Texas A&M Univ, Wageningen Univ (28 articles), is the most published, and works closely with Int Water Management Inst, Univ Amsterdam, UNESCO-IHE Institute for Water Education, and other universities and scientific research institutions. Cluster 2 contains 47 institutions, 227 articles. The top three are Chinese institutions, Hohai Univ, Chinese Acad Sci, and Tsinghua Univ, respectively, who cooperate closely with Univ Oxford, Australian Natl Univ, Univ British Columbia, Monash Univ, Univ Wisconsin, and so on, indicating that cluster 2 reflects the main WR research institutions in China and their cooperative relations. Cluster 3 contains 46 institutions and 243 articles; the most published is Univ Arizona (32 articles), which works closely with universities such as Arizona State Univ, Univ Calif Berkeley, and Univ Calif Davis. These research institutions are located in Arizona and California in the western United States. The two states share the same geographical units, and there are great similarities in the natural environment and water supply, which also leads to more cooperative research between them. Cluster 4 contains 46 institutions and 233 articles; the largest number of articles is from Univ New Mexico (34 articles). In addition, it works closely with Utah State Univ, Boise State Univ, Univ Calif Santa Barbara, Univ Chile, and so on. Cluster 5 contains 34 institutions and 212 articles. The largest number of articles is from Colorado State Univ (32 articles), which works closely with universities and institutions such as Univ Colorado, Univ Idaho, Univ Nebraska,

US Geol Survey, and Univ Illinois. Cluster 6 is the smallest, with only 24 institutions and 96 articles; the largest number of articles is from Univ Concepcion (10 articles). In addition, it works closely with Pontificia Univ Catolica Chile, Univ Melbourne, etc.

From a comprehensive point of view (Fig. 5), cluster 1 has a large number of publications and recent publication times, attributes belonging to the group of key research institutions in current WR research. Cluster 6 is not dominant in terms of institutions and number of publications, and its overall publication time is the earliest; therefore, it has no advantage in the field of WR research. At the institutional level, the University of New Mexico, Texas A/M University, Wageningen University, Int Water Management Institute, University Arizona, Colorado State University, Arizona State University, Chinese Acad Sci, and Hohai University are hot research institutions for WRs.

Research on national cooperation networks

Geographical view analysis of a national cooperation network can provide an intuitive understanding of WR research and cooperation among countries (Fig. 6). Seven countries published more than 50 articles (circle size), including the USA (594), China (112), Australia (90), the UK (89), the Netherlands (69), Spain (54), and Canada (54). For the total number of citations (figures in parentheses) exceeding 1000, these included the USA (10,554), Australia (1960), the Netherlands (1923), the UK (1888), China (1180), and Spain (1147), with the USA having a total number of citations far more than other countries. According to the

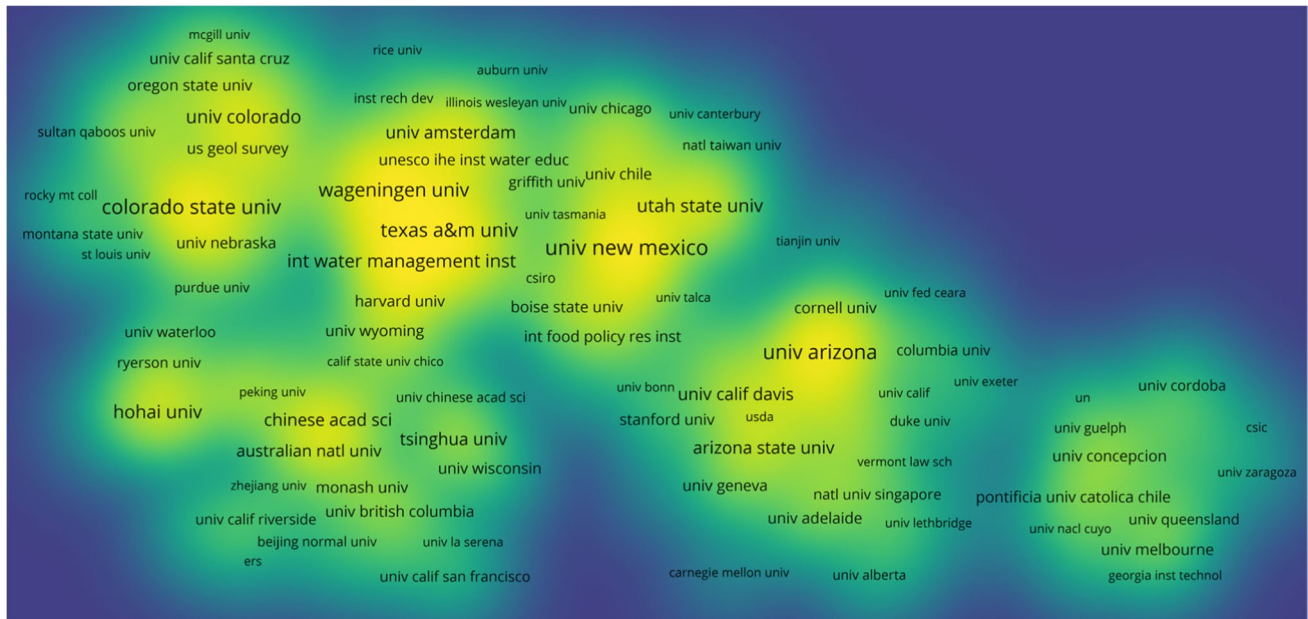


Fig.5 Thermal map of WR research institute

average time of issuance, China has been active in recent years, which is closely related to recent water conservancy policy. After 2000, with the promotion of the Ministry of Water Resources, China began an upsurge in research on the WR market. WRs are a major issue in China's current social environment. However, the USA, Australia, and other countries began earlier. These two countries are experienced in the construction of the WR system, which coincided with the development of the WR market. WR markets emerged in Australia, the USA, and Chile in the early 1980s. From the perspective of national cooperative relations (the thickness of the connection between countries), cooperative research between the USA and the UK; the USA and China; the USA and Chile; the USA and Australia; and the UK and Australia are most frequent, and WR research in the USA, Australia, and the UK is more internationalized. In terms of regional distribution, overall WR research in Africa is weak, and WR research is only found in South Africa, Tanzania, and Ethiopia. As an economically underdeveloped area with severe water shortages, the WR environment is very fragile.

Journal analysis

The literature examined in this study was published in 434 journals. There were 660 (44.30%) journal publishing among the top 20 journals (4.61%); 259 (59.68%) journals published only one article; 67 (15.44%) journals published two articles; 32 (7.37%) journals published three articles; and 388 (89.40%) journals published no more than five articles. These results indicate that the output of WR research

in journals is highly dispersed. According to Table 4, *Natural Resources Journal*, *Water International*, *Water Policy*, *Water Resources Research*, *International Journal of Water Resources Development*, *Agricultural Water Management*, and *Water Resources Management* are the eight high-yield journals on WR research.

The output-time trends for the eight journals are shown in Fig. 7. The *Natural Resources Journal* and *Water Resources Research* have the longest time span and a relatively stable number of publications; they have been concerned with WR research for a long time. The other six journals began publication after 1990, among which *Water International*, *Water Policy*, and *Water* have large volumes and obvious growth trends in recent years.

The total local citation score is typically used to evaluate the relative impact of academic journals. Among the top 20 output journals, with the exception of the *Journal of the Water Alternatives-an Interdisciplinary Journal on Water Politics and Development*, *Journal American Water Works Association*, *Journal of Water Resources Planning and Management-Asce*, *Irrigation and Drainage*, *Physics and Chemistry of the Earth*, *American Journal of Agricultural Economics*, *California Law Review*, and *Water Resources Bulletin*, the other 12 journals are also in the top 20 in TLCS. These results show that the number of published articles has a significant impact on the TLCS value of journals. *Remote Sensing of Environment*, *Proceedings of the National Academy of Sciences of the United States of America*, *Journal of Irrigation and Drainage Engineering*, *World Development*, *Ground Water*,

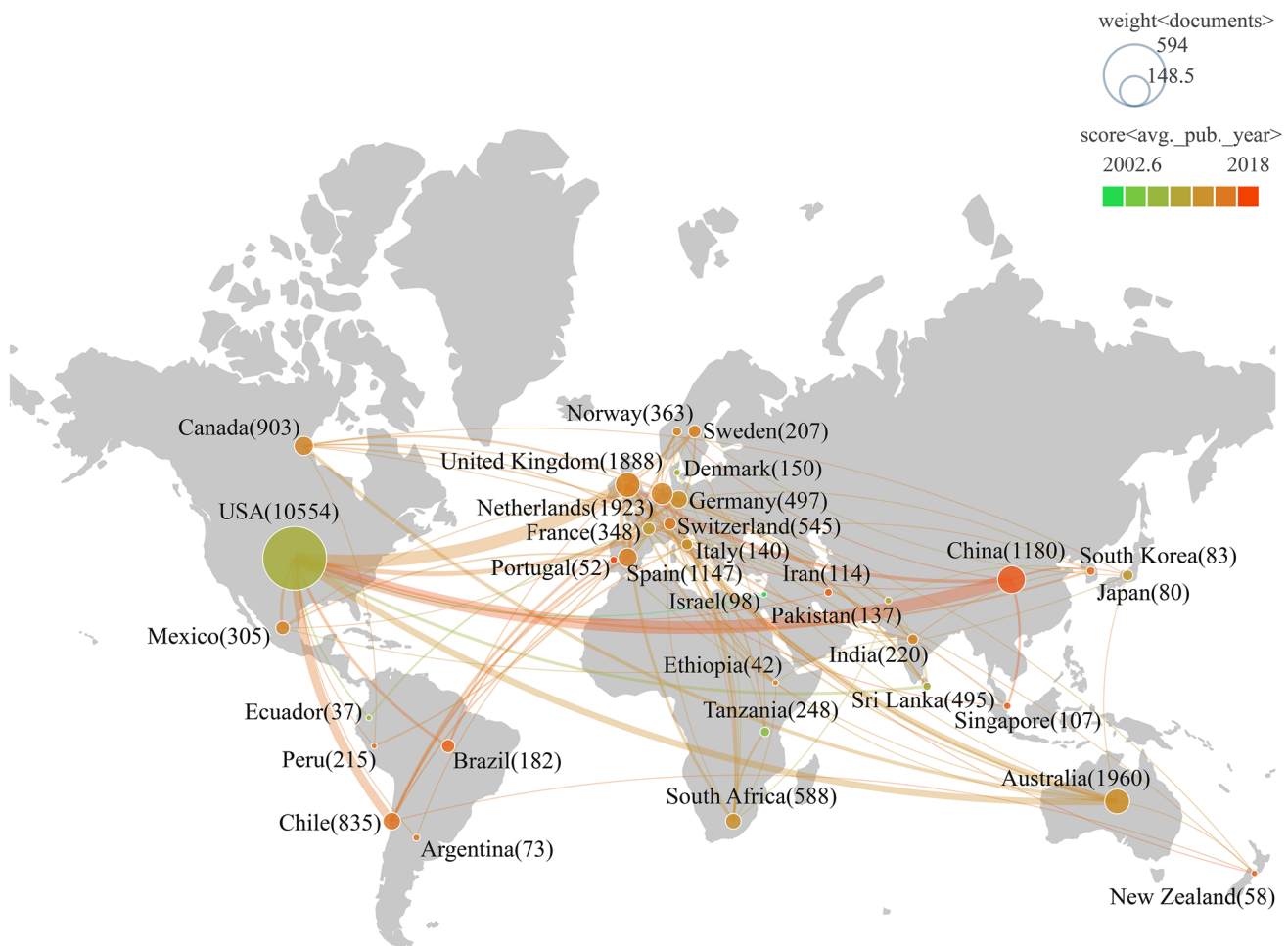


Fig. 6 Geographical view of national cooperation in WR research

Journal of Environmental Management, Ecology and Society, and Environmental Management were not included in the top 20 output journals, but ranked in the top 20 TLCS journals. All 28 journals in the top 20 in output and TLCS could be considered marked journals for WRs research.

Evolution of WR research hotspots

Research on co-occurrence networks of keywords

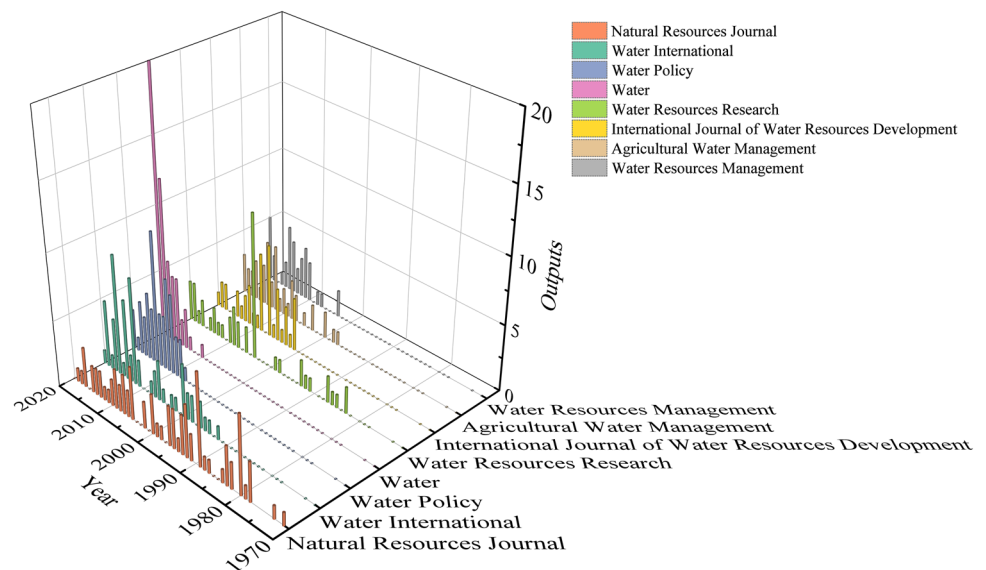
Keywords provide important information about research trends and frontiers, revealing areas of research interest (Chiu and Ho 2007; Ji et al. 2014; Zhang and Chen 2020). The keywords for WR research were divided into five clusters (Fig. 8). In the figure, the ball represents keywords, the line represents the relationship between keywords, and the color of the ball represents the average time of keywords. Cluster 1 includes conceptual studies, including the legal basis of WR research, human rights factors, and the corresponding institutional framework. The main keywords are

human rights, human rights to water, water law, and so on. Cluster 2 concerns the basic management and allocation of water resources. The main keywords include irrigation, water allocation, water management, groundwater, and climate change. Cluster 3 mainly discusses the basic theory of WRs and water market and water control, and the main keywords are WR trading, water governance, environmental flows, and water security. Cluster 4 focuses on mathematical models based on game theory to study efficient transactions of WRs in the water market. The main keywords are water markets, property rights, transaction costs, and game theory. Cluster 5 relates to the practical promotion of WRs, technical applications, and so on, including main keywords remote sensing and evapotranspiration.

In terms of the time dimension, earlier keywords included water allocation, water law, water management, irrigation, water policy, water markets, and groundwater. Human rights, climate change, environmental flow, water governance, human rights to water, and game theory became popular keywords in recent years. The study of WRs has gone

Table 4 Top 20 outputs and the total local citation score (TLCS) by journals

Journal	Outputs	Journal	TLCS
Natural Resources Journal	83	Agricultural Water Management	1494
Water International	61	Water Resources Research	989
Water Policy	58	Remote Sensing of Environment	738
Water	55	Water International	628
Water Resources Research	46	International Journal of Water Resources Development	622
International Journal of Water Resources Development	43	Journal of Hydrology	600
Agricultural Water Management	42	Proceedings of the National Academy of Sciences of the United States of America	574
Water Resources Management	35	Water Resources Management	562
Journal of the American Water Resources Association	31	Journal of Irrigation and Drainage Engineering	560
Journal of Water Resources Planning and Management	26	World Development	519
Journal of Hydrology	24	Water Policy	514
Water Alternatives-an Interdisciplinary Journal on Water Politics and Development	23	Natural Resources Journal	445
Journal American Water Works Association	20	Water	389
Journal of Water Resources Planning and Management-Asce	20	Geoforum	362
Geoforum	19	Ground Water	335
Irrigation and Drainage	16	Journal of Environmental Management	327
Physics and Chemistry of the Earth	16	Journal of Water Resources Planning and Management	310
American Journal of Agricultural Economics	14	Ecology and Society	299
California Law Review	14	Journal of the American Water Resources Association	295
Water Resources Bulletin	14	Environmental Management	286

Fig. 7 A graph of the changes in publications of the top 8 journals between 1971 and 2020

through several stages, such as systems and regulations, theoretical exploration, comprehensive management, technological development, and application level. The United Nations General Assembly declared that “safe and clean drinking water and sanitation are an essential human right for the full enjoyment of the right to life and other rights.” In July 2010, human rights to water began to become a hotspot in the study of WRs.

Analysis of co-citation of literature

The literature co-citation function of CiteSpace can better reflect the research foundation and frontier. As shown in Fig. 9, on the left is the co-citation, and on the right is the clustering diagram of co-citation of literature map. It is formed by clustering on the basis of the former, which reflects the key topics concerned by the literature in the left

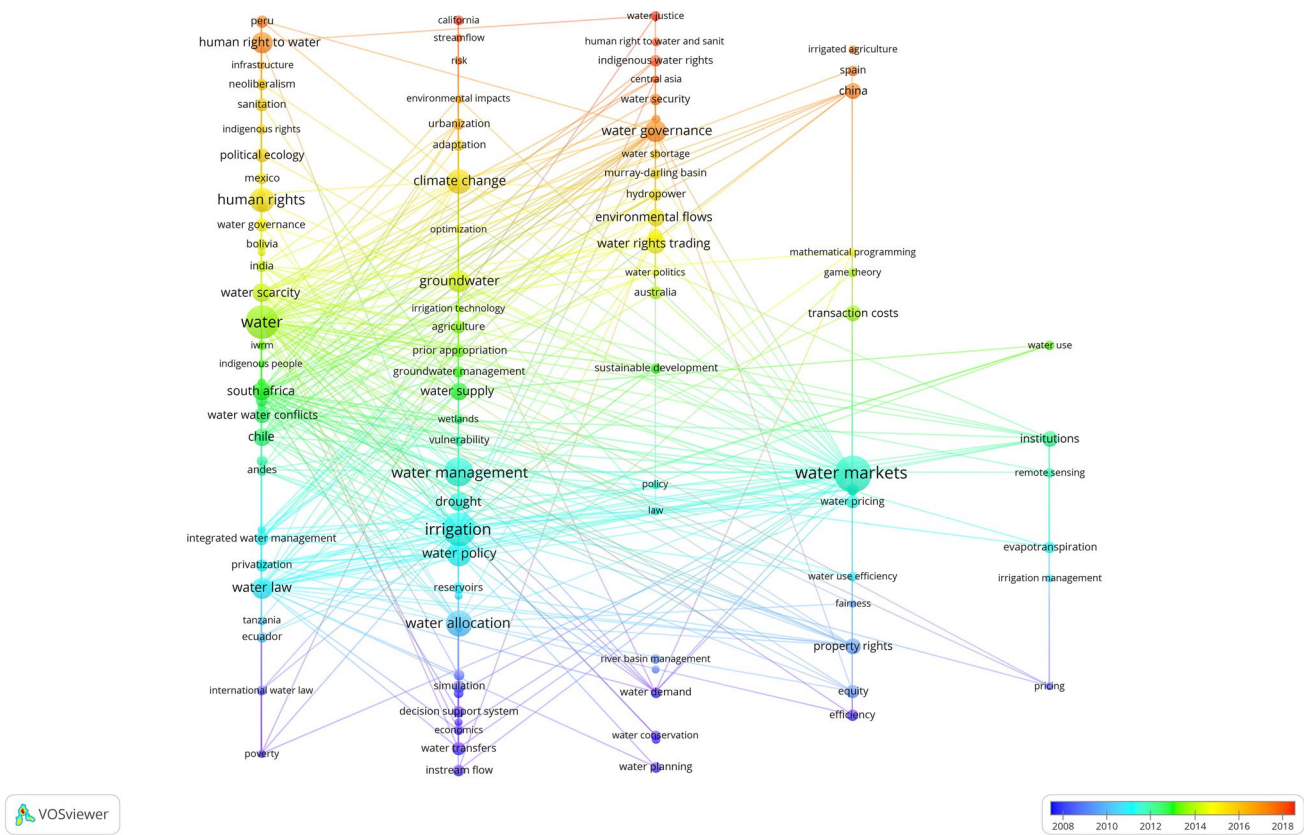


Fig. 8 Time thermal map of each keyword in five clusters

figure. The two figures are put together to facilitate comparative analysis. In the left figure, the warmer the color, the closer the publication date of the publications; in contrast, the colder the color, the earlier the publication time. The size of the circle indicates the number of times the literature was cited, and the red circle represents an explosive increase in the number of references in a corresponding period. The purple outer circle (centrality more than 0.1) indicates that the literature acts as a bridge between different clusters, which may be the key literature causing paradigm transfer. Two highly central citations were analyzed. Although the citation frequency of the article entitled “Revisiting the Human Right to Water from an environmental justice lens” is not high (5), the centrality goes up to as 0.11, which connects with clustering Nos. 1 and 3. This study investigates and analyzes discussion about human rights to water (Harris et al. 2015), bridging the development and spread of human rights between these two clusters. The study with the second-highest centrality established a comprehensive hydrologic economic watershed management model and analyzed the potential economic benefits of tradable WRs. The new model provides a novel idea for distinguishing WR transactions between different watersheds (Bekchanov et al. 2015).

The details of the top 10 clusterings are shown in Table 5, where size represents the number of references in clustering, and the silhouette coefficient is used to evaluate the effect of clustering. The value is $-1 \sim 1$. The larger the value, the better the clustering effect. The average year represents the average publication year of references in the cluster. Clusters 5, 10, 3, and 2 are relatively new. It can be seen from the label words that economic anthropology, combined effect, public attitude, and integrated assessment modeling have become hot research areas in recent years. Western USA, Trading Water Right, and Constitutional reform were hot spots before 2010; well-known water markets have been established in the Western USA, and a long-term, stable, and market-oriented WR trading system has been realized. The cited paper (Freq top2) represents the two most frequently cited pieces of literature in each cluster, is the representative literature for each cluster, and represents the disciplinary basis in the field of WRs. Citing paper (top1) refers to the citing papers with the highest coverage in each cluster, which represent the frontier literature of a certain period of time in the field of WRs. It can be found that there is more or less of a time difference between the basic literature and the frontier literature, which means that the cited literature

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 WoS: C:\Users\imh\Desktop\water right\shuj\data
 Timespan: 1921-2020 (Slice Length=1)
 Selection Criteria: Top 50 per slice, LRF=3.0, L/N=5, LBY=5, e=2.0
 Network: N=761, E=2018 (Density=0.007)
 Largest CC: 453 (59%)
 Nodes Labeled: 1.0%
 Pruning: Pathfinder

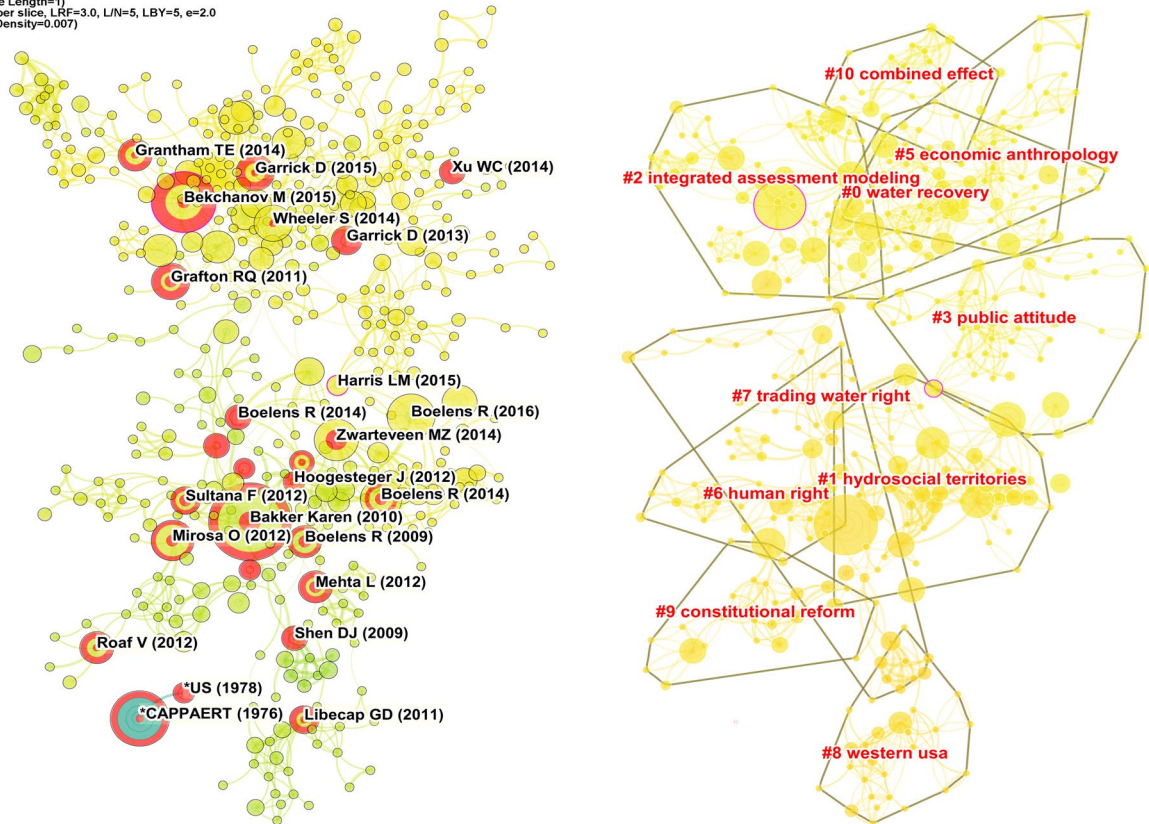


Fig. 9 Literature co-citation analysis chart of WR research

Table 5 Summary of the largest 9 clusters

Cluster ID	Size	Silhouette	Average year	Label (LLR)	Cited paper (Freq top2)
0	58	0.999	2014	Water recovery	(Wheeler et al. 2014) (Bauer 2015)
1	54	0.999	2012	Hydrosocial territories	(Boelens et al. 2016) (Zwarteveen and Boelens 2014)
2	54	1	2015	Integrated assessment modeling	(Bekchanov et al. 2015) (Grafton et al. 2011)
3	48	0.999	2016	Public attitude	(Sultana and Loftus 2015) (Harris et al. 2015)
5	37	1	2017	Economic anthropology	(Moore 2015) (Grafton and Wheeler 2018)
6	35	1	2012	Human right	(Bakker 2010) (Sultana 2012)
7	31	0.999	2009	Trading water right	(Shen and Speed 2009) (Wang 2012)
8	26	1	2008	Western USA	(Libecap 2011) (Rigby et al. 2010)
9	25	0.999	2009	Constitutional reform	(Mirosa and Harris 2012) (Roaf 2012)
10	23	0.999	2017	Combined effect	(Boisier et al. 2016) (Babidge 2016)

goes through a time accumulation process from publication to becoming a highly cited.

Taking cluster No. 0 as an example, the first basic document (cited paper) investigates the adoption of water trading in the Darling Basin, Australia, and emphasizes that policies, systems, and governance measures should be highly adjustable and adaptive. The second paper discusses the continuous reform of Chilean water law; however, there remains a lack of institutional guarantee for efficient water governance and comprehensive water resource management, which led to water conflict becoming a national political problem. The label (water recovery) comes from a series of cited documents themselves citing basic documents, among which the document with the highest coverage is entitled “Economics of Water Recovery in the Murray Darling Basin, Australia.” This study investigated the economic benefits of water recovery after water reform in the Darling Basin. The results show that buyback is much more cost-effective than subsidiaries, and many of the gains from water recovery accrue as private benefits to irrigators (Grafton and Wheeler 2018). It can be seen that the two cited papers emphasize that the system should better protect and adapt to the development of WRs, while the cited papers go further on the basis of basic documents, which is a specific practice and reform of WRs system.

Conclusion

In this paper, 1435 articles in SCI-E and SSCI were taken as the research object, and the WR research trend was analyzed from the point of view of worldwide literature measurement. From 1971 to 2020, there was an exponential growth trend in the number of papers published on WRs. The number of citations per paper is influenced by the attention of the research field, the paper’s quality, and the date of publication, showing the trend of “high in the middle and low at both ends.” In the field of WRs, the discipline is highly specialized and concentrated on water resources, environmental sciences, environmental duties, law, agronomy, and other fields. Highly cited papers are often iconic documents with great representative and reference value in the development and application of concepts, theories, models, and technologies.

Wurbs Ralph A was the author with the most articles in the field of WRs. Boelens Rutgerd and van Koppen Barbara are cited with the most frequently and have great influence. Heller Leo has been an active author in recent years. The number of documents issued by the mechanism as a whole is small, and the difference is not significant; UNM and USDA are institutions with the highest number of documents and total cited frequency, respectively; CSU, UA, ageningen, ur, IWMI, and ASU have great comprehensive influence. Owing to the geographical attributes of the research subject, the

main research institutions of the same cluster have similar regional or national attributes. The USA, China, Australia, the UK, and the Netherlands are the major countries for WR research. Under the comprehensive influence of water resource endowment, historical reasons, and the development of WR systems in various countries, the WR system in the USA is mature, and the date of publications is relatively early. The WR issue is the focus of the current social environment in China, which is now a country with more active research. Journal articles have the characteristics of “overall growth and high dispersion.” Most journals began to focus on publishing articles on WRs after 1990, which is in line with the trend of the late start and rapid development of WR research.

The research hotspot of WRs has gone through several stages, such as institutional regulations and theoretical exploration, water market and water management research, model development, technology development, and application. Overall, affected by factors such as the development of the concept of human rights to water, technological progress, and climate change, WR research pays more attention to public attitudes and comprehensive governance.

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Declarations

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