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REVIEW ARTICLE

The frontier evolution and emerging trends of hydrological connectivity in river systems: a scientometric review

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Abstract With the intensification of climate change and human activities, the watershed ecosystem is seriously fragmented, which leads to the obstruction of hydrological connectivity, and further causes the degradation of the ecosystem. As the value of wetlands continues to be exploited, hydrological connectivity becomes increasingly significant. In this paper, the characteristics and development of hydrological connectivity research from 1998 to 2018 were analyzed through the scientometric analysis based on Web of Science database. CiteSpace, an analytical software for scientific measurement, is used to visualize the results of the retrieval. The analysis results of co-occurrence, co-operative and co-cited network indicate that the hydrological connectivity is a multidisciplinary field which involves the Environment Science and Ecology, Water Resources, Environmental Sciences, Geology and Geosciences. According to Keyword co-occurrence analysis, ecosystem, floodplain, dynamics, climate change and management are the main research hotspots in each period. In addition, the co-cited analysis of references shows that "amphibians" is the largest cluster of hydrological connectivity, and the "channel network" is the most important research topic. It is worth noting that the "GIWS" (Geographically Isolated Wetlands) is the latest research topic and may be a major research direction in the future.

Keywords hydrological connectivity, citespace, ecosystem, geographically isolated wetlands

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1 Introduction

Rivers, lakes, and wetlands are major components of natural water systems (Tan et al., 2018; Zhang et al., 2019; Liu et al., 2020; Meng et al., 2020). They are playing increasing roles in sustaining water not only for human beings but also for ecosystems. At the same time, a well-connected water system can maintain a relatively stable nutritional state in a changing environment (Oolebwski, 2011; Kaus et al., 2019). Hydrological connectivity can promote energy and nutrient cycling of the water system and provide important habitats for a variety of birds, fish and benthic organisms, which is important for maintaining biodiversity and promoting community assembly and dynamics (Lowe, 2006; Carrara et al., 2012; Altermatt et al., 2013; Phillipsen et al., 2014; Seymour et al., 2015; Shao et al., 2019). Particularly, as having interactive pathways along one temporal dimension (i.e., time scales) and three spatial dimensions (i.e., longitudinal, lateral and vertical ones), the hydrological connectivity patterns of watershed is of significance in formation, development, succession and stability of water ecosystems, as well as promoting the exchange of biological and nutrient substances (Ward, 1989; Pringle, 2001; Pringle, 2003; Chadwick, 2008). Recently, due to the dual effects of climate change and human disturbances, freshwater storage areas and biological habitats have been destroyed, which leads to the weakening or even deterioration of hydrological connectivity. (Matson et al., 1997; Chapin III et al., 2000; Elmore and Kaushal, 2008). Moreover, obstructed hydrological connectivity, on the one hand, could lead to shrinking areas of rivers, lakes and wetlands, in insufficient water resources allocation capacity, frequent drought and poor discharge of floods. It would, on the other hand, interfere with the migration and exchange of substances, energy and organisms in water bodies, causing a series of water environmental and ecological problems (Obolewski, 2011; Read et al., 2015; Thoms et al., 2015). The above-mentioned problems are getting increasing concerns, and attracting international attentions to protect freshwater resources, restore species richness and habitat health as well as improve the ability of flood prevention and resilience.

The concept of hydrological connectivity originated from the "river continuum" proposed by Vannote et al. (1980). It was initially widely used to represent the spatial connectivity for river landscape (Pringle, 2003). Since then, scholars in multiple disciplines have been trying to define the connotation of hydrological connectivity from multiple perspectives (Table S1), such as water cycle (Pringle, 2003), landscape features, spatial patterns, and flow processes (Bracken and Croke, 2007; Tetzlaff et al., 2007; Lane et al., 2004; Hooke 2003; Stieglitz et al., 2003; Croke et al., 2005, Knudby and Carrera, 2005; Creed and Band 1998; Vidon and Hill, 2004; Ocampo et al., 2006). However, due to the involved multiple research areas and environments, the concept of hydrological connectivity has not been defined uniformly. The widely accepted hydrological connectivity refers to water-mediated transfer of matter, energy and/or organisms within or between elements of the hydrologic cycle (Pringle, 2003; Bracken et al., 2013; Ali and Roy, 2009). Since hydrological connectivity has attracted a lot of attention in recent years, it is necessary to make a comprehensive review and summarize useful conclusions, as well as to find the key advances of hydrological connectivity. The objective of this research is to obtain a comprehensively and systematically scientometrics review of research on hydrological connectivity.

Bibliometrics, originated in the early 20th century, has become a visual analysis method based on co-occurrence network (Chen, 2004; Cui et al., 2019). CiteSpace, recently, has been widely used to assess the richness and dynamic hotspots of a special field due to the visually demonstrate knowledge structure, development status and research hotspots derived from publications (Cui et al., 2019, Yang et al., 2018). The most obvious advantage of CiteSpace is that it allo ws scholars to investigate specific research areas and obtain useful conclusions about the hotpots and trends through the detailed analysis of citations, co-citation, and geographical distribution (García-Lillo et al., 2016). Based on the data obtained from Web of Science Core Collection, the analysis in this research will mainly focus on the network of co-citation of authors, journals and references, as well as co-occurrence of keywords and categories, respectively. We attempt to obtain accurate and systematic information on hydrological connectivity research, identify the distribution of subjects and journals, and detect the existing hot topics and emerging trends. Therefore, the knowledge characteristics, intellectual structure, main research frontier issues and future prospects will also be explored.

2 Materials and methods

2.1 Data collection and processing

In this paper, we used CiteSpace (Chen, 2006), a Java application for visualizing and analyzing trends and patterns in scientific literatures, and for scientometric analysis. The data used in this paper was extracted from the Science Citation Index-Expanded (SCI-E) of the Web of Science Core Collection (WoSCC). Specific retrieval strategy is as follows: Topic Search was hydrological connectivity OR hydrological connection OR hydrologic connection OR hydrologic connectivity. In addition, timespan was set as 1998–2018, and 3307 bibliographic records including titles, abstracts, and cited references were obtained for subsequent analysis.

2.2 Scientometrics analysis methods

A knowledge map of the publication characteristics, including subject categories, journals, keywords, authors and references was generated based on a certain number of papers published in this field using the functions of Citespace software (co-cited analysis, co-occurrence analysis and co-operative analysis), which shows the hot research issues and emerging trends. A network map contains many nodes and links. Nodes in different kinds of network map represent different meaning such as author, keyword, reference, institution, and the larger the nodes, the more the publications or frequency (Liang et al., 2018). The connecting lines between nodes indicate a relationship of co-operation, co-occurrence or co-citation, and their various colors represent the year that the two nodes are co-cited (Chen, 2006; Xie, 2015; Zhang et al., 2018). Additionally, a node surrounded by a purple ring shows that the node has a relatively strong ($\geqslant 0.1$) centrality, which indicated an extensive connection with other nodes. In this research, most of the analysis was conducted by CiteSpace based on papers published on SCI-E (Science Citation Index Expanded) over the period of 1998 to 2018. Contributing co-cited authors and journals were mapped to identify and visualize major contributing factors for the evolution of hydrological connectivity. Hot issues and frontier research were identified based on the frequency of popular keywords, which can be divided into 3 periods (i.e., 1998 to 2004, 2005 to 2011, and 2012 to 2018). Highly co-cited references will also be conducted as an effective supplement to the related research hotspots. In addition, burst detection of co-cited authors was applied to identify the author whose research achievements is significant in this research field. Therefore, the analysis of co-operative and co-occurrence network as well as co-cited ones with the frequency, centrality and burst will be conducted to identify research characteristics and emerging trends on hydrological connectivity.

3 Results and discussion

3.1 Characteristics of publication outputs

The total publications (3307) of all types in SCI-E related to hydrological connectivity from 1998 to 2018 were shown in Fig. 1. Among all types of the publications, articles occupy the dominant position, comprising 90% of the total publications, followed by proceedings, reviews, and others. Since Vannote proposed the concept "river continuum" in 1980, hydrological connectivity had gradually come into people's sight (Vannote et al., 1980). As time comes to 2005, the number of publications increased significantly and over 100, 250, and 400 papers were published in 2008, 2014, and 2018, respectively. In addition, it can be seen that although the number of the published papers in 2010, 2012 and 2016 is less than the previous year, the overall trend shows a continuous rise. The annual average was 14.88%, especially in 2017 and 2018, obtained the growth rates of 15.06% and 15.10%, respectively.

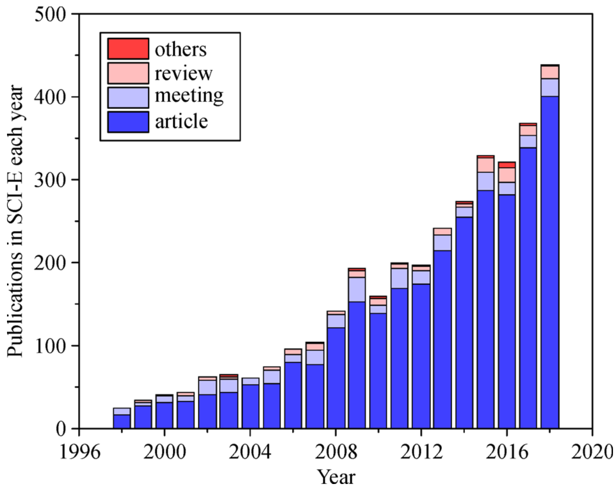

Fig. 1 Publication output performance during 1998–2018.

3.2 Subject category distribution

The co-occurrence analysis of subject categories was conducted. As the co-occurrence network from 1998 to 2018 shown in Fig. 2, Environment Science and Ecology is the most popular research area (frequency, 1413) above all. The others of top 3 are Water Resources (1135) and Environmental Sciences (1029). In addition, Fig. 2 displays some nodes have high centrality as there are purple outer cycles surrounding them, the details are shown in Table 1. Among the top 15 subject categories, Environmental Sciences has the highest centrality in hydrological connectivity. The second is Biodiversity and Conservation, followed by Geosciences, Multidisciplinary, Ecology, physical Geography. Therefore, the study of

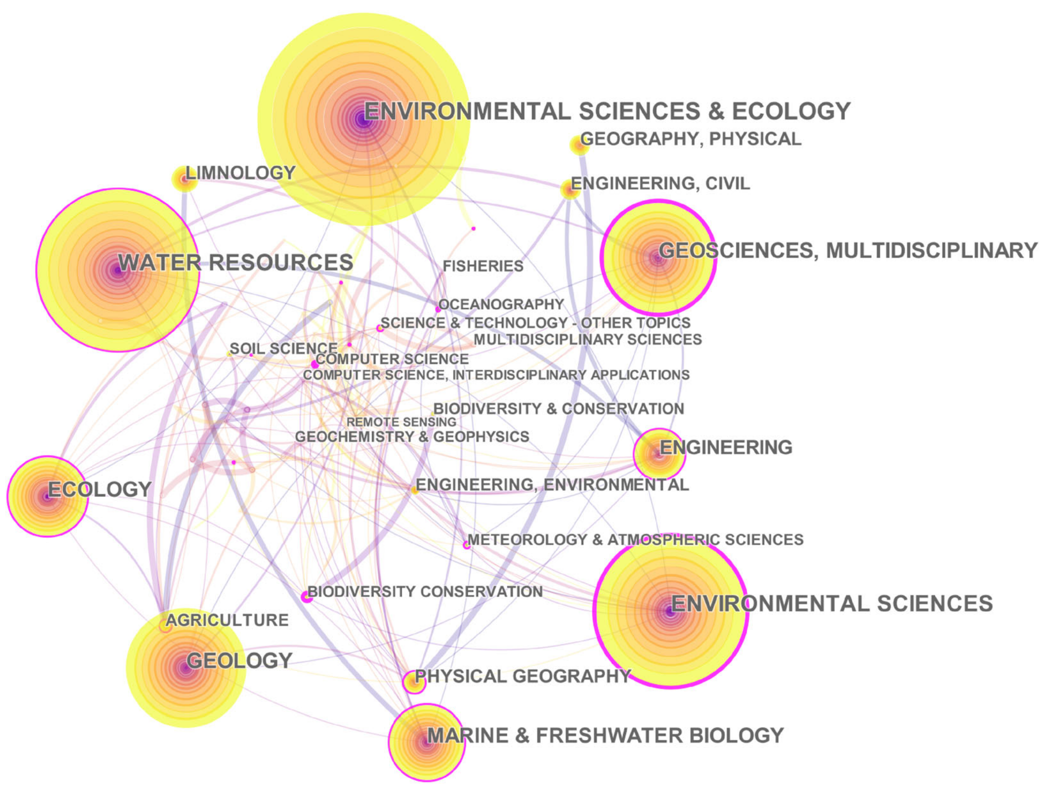

Fig. 2 Subject category network for hydrological connectivity during 1998–2018.

Table 1 Subject categories for hydrological connectivity over 1998 to 2018

Rank	Subject category	Frequency	Centrality
1	Environmental Sciences & Ecology	1413	0.08
2	Water Resources	1135	0.13
3	Environmental Sciences	1029	0.28
4	Geology	847	0.03
5	Geosciences, Multidisciplinary	807	0.21
6	Marine & Freshwater Biology	606	0.12
7	Ecology	600	0.19
8	Engineering	409	0.13
9	Limnology	280	0.03
10	Physical Geography	252	0.19
11	Geography, Physical	252	0
12	Engineering, Civil	216	0
13	Agriculture	153	0.12
14	Engineering, Environmental	144	0.09
15	Biodiversity & Conservation	111	0.24

hydrological connectivity is carried out within the scope of a multidisciplinary diversity, from Environmental Sciences to Biodiversity, Water Resources, Ecology. Particularly, the Environment Science and Ecology and Water Resources played predominant roles.

3.3 Journal co-citation analysis

A total of 3307 publications on hydrological connectivity were published in 783 journals from 1998 to 2018. Table 2 shows the top 10 journals and co-cited journals in hydrological connectivity. *Hydrological Processes* is the most productive journal, and has published 193 papers (accounting 5.8%), followed by *Journal of Hydrology* (149 publications, 4.5%) and *Water Resources Research* (139 publications, 4.2%). Among the top 10 productive journals, *Science of the Total Environment* has the highest impact factor (IF) of 5.589. Moreover, the journal with the most citation count was *Hydrological Processes*, 1585 totally, followed by *Journal of Hydrology* (1561 records) and *Water Resources Research* (1517 records). The network given in Fig. 3 is to obtain information about the co-cited relations between journals. As it can be seen (Fig. 3), the co-cited relationship between each journal is very close, especially the journal represented by the node with the purple ring. Moreover, seven of the top ten co-cited journals had high centrality. Particularly, some journals, however, with a small number of publications still have a high centrality, which indicates that the articles published in these journals have a strong research value.

3.4 Keyword co-occurrence analysis

Research topics and hot spots in a period can be obtained through co-occurrence analysis of keywords, and research frontier of three periods can be analysis accordingly (Yu et al., 2017; Ouyang et al., 2018). As shown in Figs. 4, 5 and 6, with time going on, the nodes of keyword number are increasing and diversified, and the density of the keyword co-occurrence is also getting stronger. In addition, the first 15 keywords related to hydrological connectivity in the three stages are also listed in Table 3. The analysis of keywords is discussed based on frequency and centrality according to Fig. 4 to 7 and Table 3.

Figure 4 shows the co-occurrence network of keywords during 1998–2004. It can be seen that the keyword “ecosystem” is the main research content in this period and has high co-occurrence with connectivity, wetland, floodplain and biodiversity. During this period, land use change and river reconstruction in European countries lead to a serious decline in the hydrological connectivity of floodplain wetland which further affects the ecosystem and ecological functions (Gumiero et al., 2013). As a sequence, with the decrease of hydrological connectivity of floodplain, the richness of species and diversity of ecosystem

Table 2 The top 10 journals and co-cited journals for hydrological connectivity over 1998 to 2018

Rank	Journals	*N* (%)	IF	Co-cited journals	*N*	IF
1	Hydrological Processes	193 (5.8)	3.189	Hydrological Processes	1585	3.189
2	Journal of Hydrology	149 (4.5)	4.405	Journal of Hydrology	1561	4.405
3	Water Resources Research	139 (4.2)	4.142	Water Resources Research	1517	4.142
4	Freshwater Biology	79 (2.4)	3.404	Freshwater Biology	1137	3.404
5	River Research and Applications	75 (2.3)	1.954	Science	1109	41.037
6	Hydrobiologia	72 (2.2)	2.325	Hydrobiologia	954	2.325
7	Hydrology and Earth System Scien	66 (2.0)	4.936	Ecology	913	4.285
8	Geomorphology	63 (1.9)	3.681	Nature	906	43.07
9	Wetlands	56 (1.7)	1.854	Bioscience	836	6.591
10	Science of the Total Environment	53 (1.6)	5.589	Hydrology and Earth System Scien	753	4.936

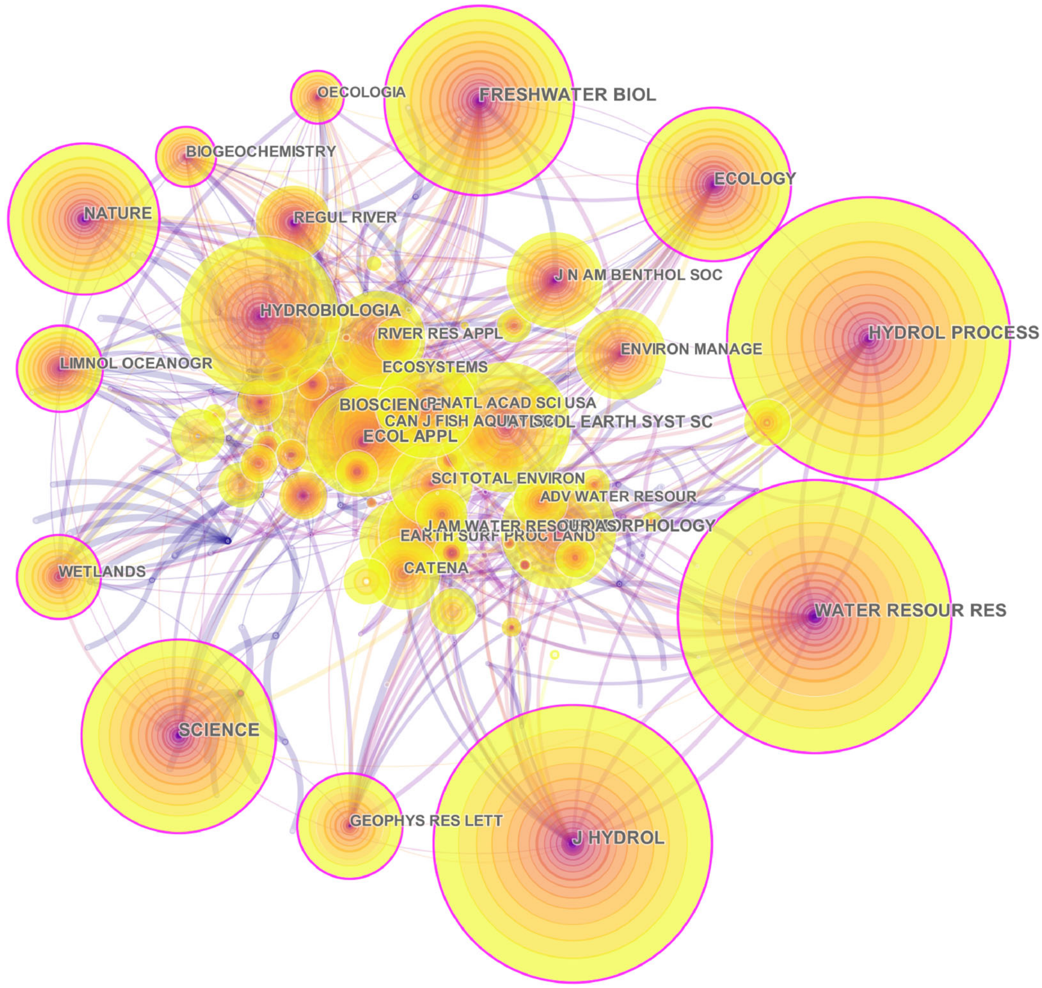

Fig. 3 Co-cited journals network for hydrological connectivity during 1998–2018.

gradually decrease. According to the Flood Pulse Concept (FPC), the exchanges of nutrients and sediments between river and its floodplain is a more significant ecosystem function than those of longitudinal processes (Aarts et al., 2004). Hence, scholars in this period have done a lot of research on the effects of floodplain on ecosystem and biodiversity. Chovanec and Waringer (2001) believe that horizontal connectivity is an important feature of ecological integrity in floodplains, which is coincided with the main idea of FPC. By analyzing the breeding behavior of dragonflies, he provided a new method for the ecological integrity evaluation of the river-floodplain system. In addition, hydrological connectivity, the theme of this paper, however, did not appear in the top 15 of the keyword co-occurrence networks at this period. This indicates that hydrological connectivity had not been the major research focus at this period.

With the passage of time, the number of nodes in the keyword co-occurrence network is increasing, and the connection density between each node is significantly enhanced, which means that hydrological connectivity attracts increasing attention in this period (Fig. 5). As shown in Table 3, during the period from 2005 to 2011, the ecosystem maintained a high co-occurrence frequency and centrality, which was inseparable from the hydrological connectivity and the close connection between the ecosystem and biodiversity. The word "hydrological connectivity" appeared and rank second in the top 15, indicating that the research topic of hydrological connectivity developed rapidly at this period. Furthermore, the "water" and "hydrology" rose up to the top five, while "wetland" "floodplain" and "biodiversity" have heated down or even drop out of the top 15, this might because that the researchers in the previous period were mainly from the field of ecology, and more researchers doing hydrology and water resources were involved in 2005–2011. In addition, the frequency of node "dynamics" has increased significantly, and its centrality suggests it has attracted more attention in this period. The hydrological connectivity of water system has a decisive influence on

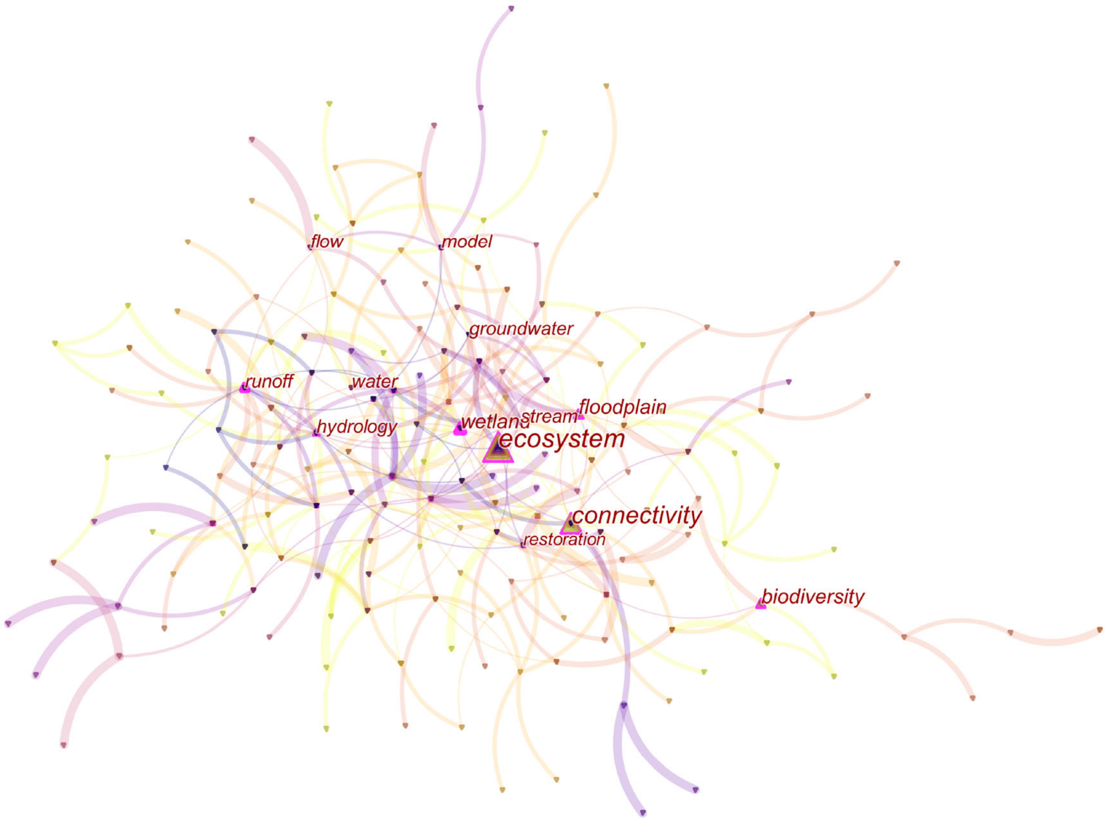

Fig. 4 Keywords network for hydrological connectivity during 1998–2004.

Table 3 Keywords for hydrological connectivity over periods of 1998 to 2004, 2005 to 2011, and 2012 to 2018.

1998–2004			2005–2011			2012–2018		
Keyword	Frequency	Centrality	Keyword	Frequency	Centrality	Keyword	Frequency	Centrality
ecosystem	57	0.13	connectivity	133	0.11	hydrological connectivity	370	0.27
Connectivity	53	0.10	ecosystem	114	0.04	Connectivity	362	0.11
wetland	23	0.27	hydrological connectivity	108	0.19	Ecosystem	218	0.11
floodplain	23	0.12	Water	73	0.11	climate change	213	0.05
biodiversity	22	0.12	hydrology	69	0.02	river	198	0.10
stream	20	0.16	wetland	64	0.08	pattern	183	0.12
model	20	0.14	river	63	0.10	water	182	0.06
groundwater	19	0.08	model	63	0.14	model	163	0.11
hydrology	18	0.12	Stream	58	0.04	dynamics	161	0.05
Runoff	17	0.24	Flow	56	0.06	management	140	0.11
Water	16	0.09	Dynamics	54	0.16	flow	137	0.09
Flow	16	0.04	Pattern	54	0.09	Runoff	136	0.04
Restoration	15	0.15	Groundwater	54	0.07	Stream	136	0.17
Dynamics	14	0.16	Floodplain	52	0.08	Biodiversity	130	0.07
Ecology	14	0.05	Catchment	49	0.11	Impact	129	0.09

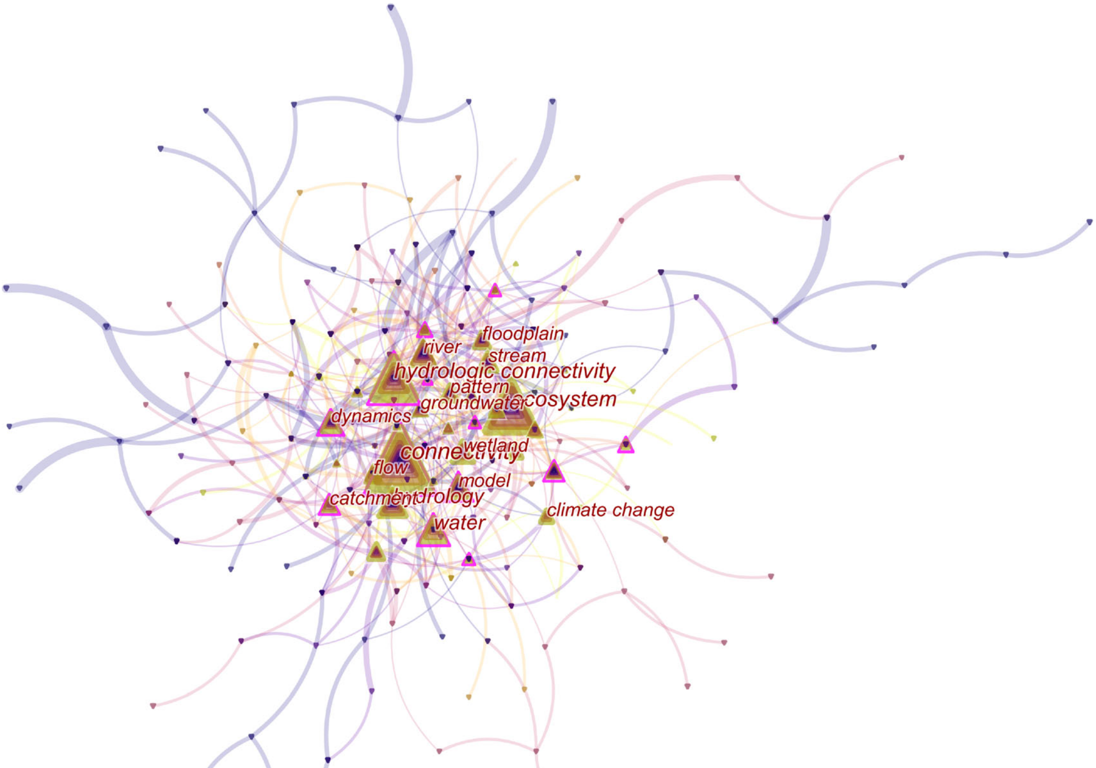

Fig. 5 Keywords network for hydrological connectivity during 2005–2011.

the hydrological dynamic characteristics. With the intensification of human activities at this period and the improvement of urbanization, the utilization measures of rivers, such as the construction of dykes and dams, changed the hydrological dynamic conditions of rivers, thus blocking the hydrological connectivity of rivers.

The keyword co-occurrence network from 2012 to 2018 is shown in Fig. 6. It can be seen that, in recent years, the study of hydrological connectivity has made great progress. “Ecosystem” still occupies a major position as a key point of hydrological connectivity. In addition, “climate change” first appeared in top 5, which means the impact of climate change on hydrological connectivity has gradually entered the research focus of many scholars. In the past half century, as the climate warms, the total amount of global river runoff tends to decrease, the frequency and intensity of extreme hydrological events increase, and the hydrological pattern of wetlands has undergone profound evolution and developed in the direction of severe decrease of hydrological connectivity. Future climate projections for the Amazon indicated a rise of temperature (Ipcc et al., 2013), total rainfall is likely to decrease (Malhi et al., 2008). Such dry-warm conditions would likely reduce the capacity of ecosystems to store water and buffer emissions and increase the frequency of low-water events in large rivers (Costa et al., 2002), lead to the interruption of hydrological connectivity, which adversely affects the local ecosystem, hydrological dynamic processes and water quality accordingly.

Though “management” does not have a high frequency as “climate change,” the number of nodes co-occurrence with “management” are more than “climate change,” and the centrality is higher, too. Facing the problems of water resources, environment and ecology brought by climate change and human activities, it is a good management method to build hydrological connectivity projects of rivers, lakes and marshes to face the needs of water supply, flood control and drought prevention, as well as water quality and ecological security. Hence, in recent years, scholars have conducted a large number of studies on the characteristics, classification systems and influencing factors of river and lake system connectivity, aiming to provide technical support for the construction planning and operation management of hydrological connectivity projects. Therefore, the topic related to hydrological connectivity at this period mainly focus on the comprehensive impacts of climate change and human activities, including but not limited to water quality, hydrological hydrodynamics and water ecosystem.

3.5 Author co-cited analysis

The network of co-cited authors is shown in Fig. 7. Compared with the total number of articles published by the author, co-citation analysis is more representative of the value of published articles. It can be seen in Fig. 7 that

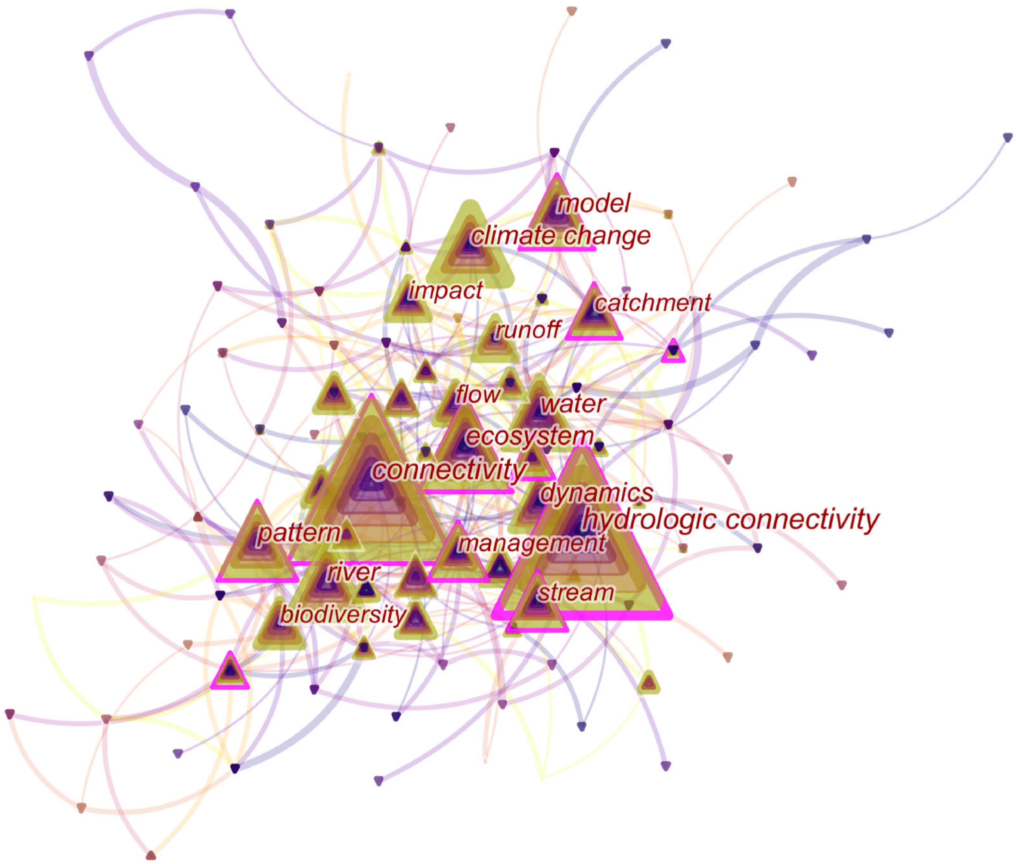

Fig. 6 Keywords network for hydrological connectivity during 2012–2018.

Ward has the most co-cited frequency, accounting for 461, followed by Junk (409) and Tockner (396), and the top three co-cited authors also have strong centrality, which means their publications were accepted by more scholars. A citation burst means that a reference has a sharp increase in citations in one year or multiple years, which can reflect whether a publication is hot or not for the research area (Yu, 2015). Table 4 lists the top 15 co-cited authors with the Strongest Citation Bursts. The top ranked is Bracken L J with bursts strength of 30.3936, second one is Tetzlaff D, 21.2137, followed by Schiemer F (17.6171). In addition, we found that the burst detection red line of some co-cited authors expired several years ago (Schiemer F), which means that he had a strong burst period and was the hot topic at that time, but now the heat has decreased. While some authors' (e.g., Bracken and Tetzlaff) burst detection red lines extend to 2018, indicating that the author's articles still have high hot spots in recent years which may continue in the future.

3.6 References co-cited analysis in hydrological connectivity research area

The co-cited analysis of references can obtain the scientific development and intellectual structure of related topics. Clustering analysis can aggregate literatures in related fields and identify the clusters (Ouyang et al., 2018). As shown in Fig. 8, the larger cluster means containing more terms, and the silhouette values of the top ten clusters we obtained are all over 0.5, which indicates that the cluster we generated is reasonable (Kaufman and Rousseeuw, 1990). The TF-IDF (term frequency-inverse document frequency), a commonly used weighting technique for information retrieval and data mining, is used to label the clusters. It can be seen in Fig. 8 that "amphibians" is the largest (#0) cluster, which also indicates that amphibians and biodiversity as well as ecosystem are the most productive area about hydrological connectivity. The second (#1) is the "channel network," which means that soil erosion, sediment dynamics and river-floodplain interaction influenced by climate change and human activities also attract many researchers' attention. Moreover, the study of channel network also provides better suggestions for the management of hydrological connectivity. Followed is "transport" (#2), the research of which is mainly focuses on the transport and utilization of water resources, agriculture and Nitrogen source. The No. 4–No.9 clusters are "temporary rivers," "hillslope scale,"

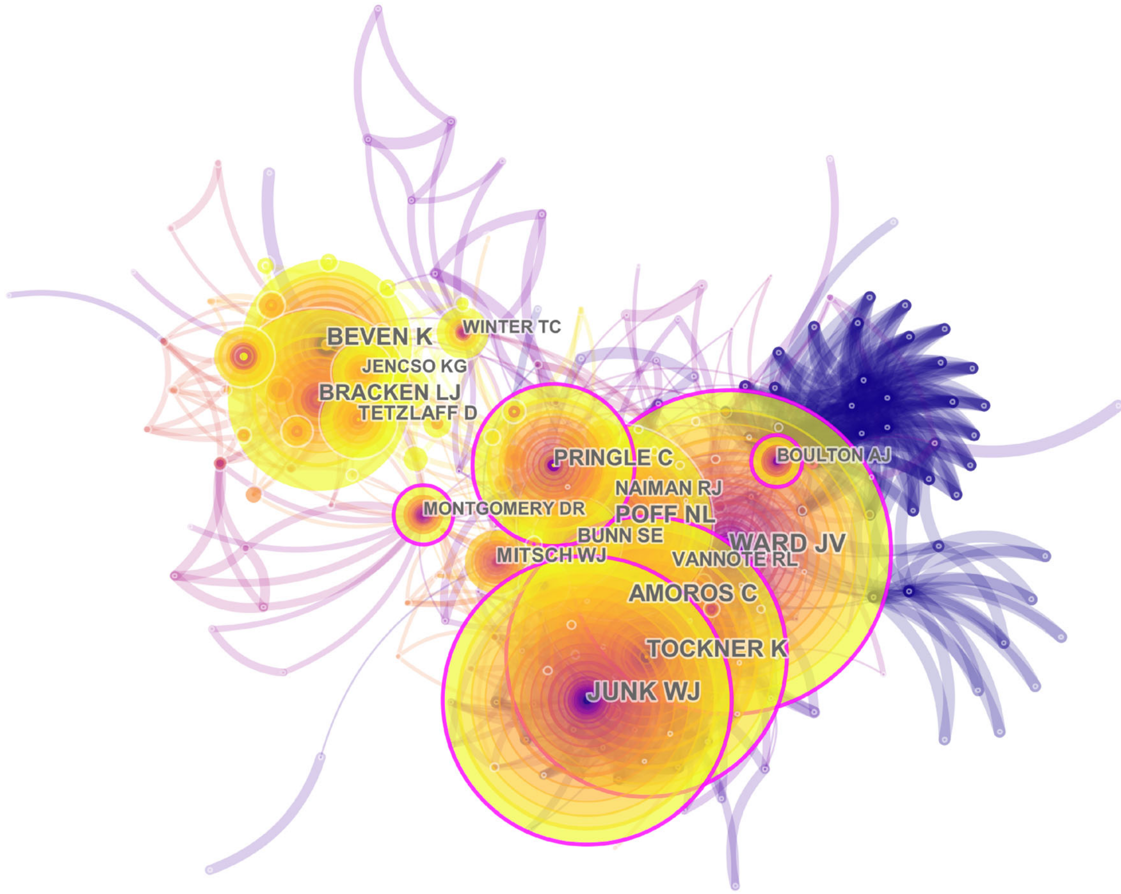

Fig. 7 Author co-cited network for hydrological connectivity during 1998–2018.

Table 4 Top 15 cited authors with the strongest citation bursts for hydrological connectivity over 1998 to 2018

Cited authors	Year	Strength	Begin	End	1998–2018
Bracken L J	1998	26.67	2015	2018	
Tetzlaff D	1998	21.2137	2013	2018	
Schiemer F	1998	17.6171	1999	2009	
Jencso K G	1998	17.2929	2014	2018	
Mcdonnell J J	1998	16.4053	2015	2018	
Hein T	1998	16.0482	2003	2009	
Allan J D	1998	15.2731	2016	2018	
Bunn S E	1998	14.6637	2012	2015	
Mcglynn B L	1998	14.3745	2014	2015	
Palmer M A	1998	13.8234	2014	2015	
Petts G E	1998	13.5599	1998	2004	
Winter T C	1998	13.4082	2016	2018	
Kirchner J W	1998	13.362	2015	2016	
Thorp J H	1998	13.2829	2003	2009	
Tromp-van M H J	1998	13.1571	2010	2011	

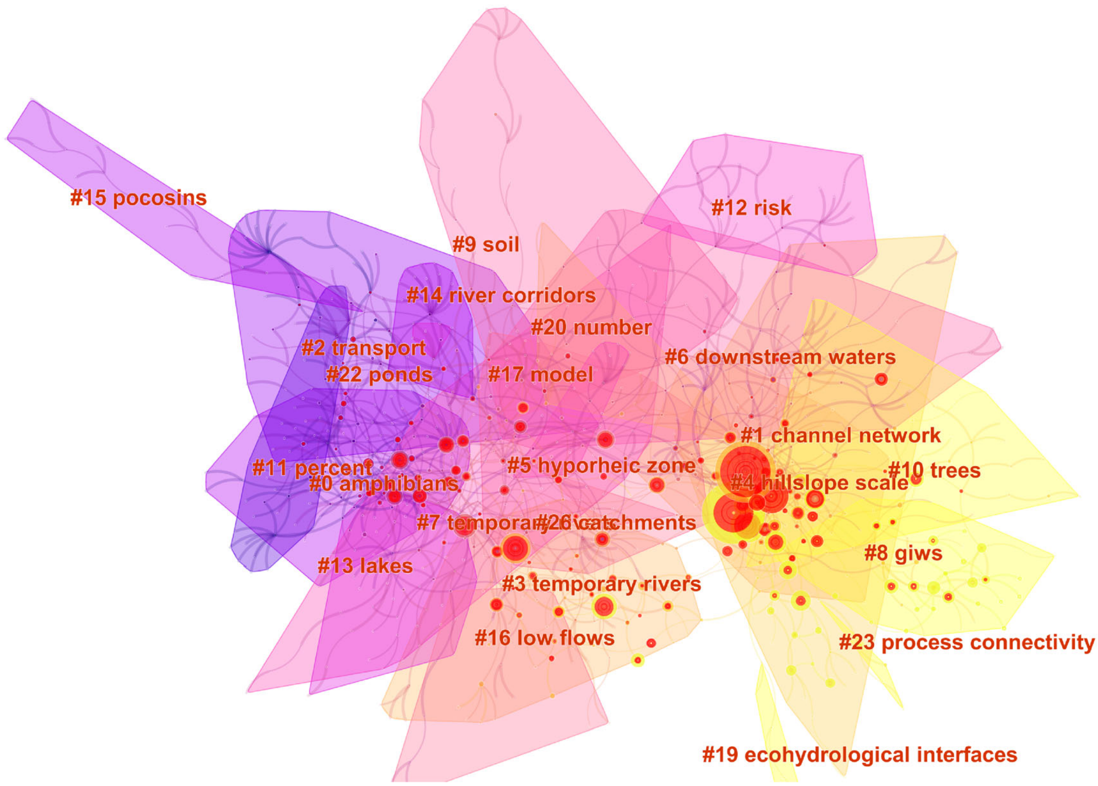

Fig. 8 References co-cited network and main references cluster for hydrological connectivity during 1998–2018.

"hyporheic zone," "downstream waters," "giws (geographically isolated wetlands)" and "soil," respectively.

Through the analysis of co-cited references, high-citation articles about hydrological connectivity research were obtained, and the definitions of hydrological connectivity concept from different perspectives were obtained and shown in Table S1.

The timeline visualization displays the research time span of each cluster, as well as recent research hotspots. It can be seen from Fig. 9 that "transport" (#2) is the earliest research topic relate to hydrological connectivity and almost lasted from 1990 to nearly 2007, followed by "amphibians" (#0) from 1992 to 2005. In addition, "channel network" (#1) might have highly cited or citation bursts or both due to much of them has large size nodes, and the primrose yellow color means they attracted the most attention on the hydrological connectivity research recently. Moreover, giws (#8 "geographically isolated wetlands") has the same primrose yellow as channel network, which means it is also a new hot topic. Studies have often focused on direct connectivity of water systems, ignoring the connectivity brought by geographically isolated wetlands might be affected by climate responses, such as rainfall and evapotranspiration. As an emerging research direction, the "geographically isolated wetlands" has attracted a lot of attention, and since it started later than the channel network (as shown in Fig. 8), it might indicate that geographically isolated wetlands will be the next research hotspot in the research of hydrological connectivity.

4 Conclusions

This research summarized a comprehensive scientometric review on hydrological connectivity from multiple perspectives based on web of science retrieval and combined with CiteSpace. The relevant information of hydrological connectivity research is conducted, including the contribution analysis of subject categories, keywords, and co-cited analysis of authors, journals, and references. Valuable insights can be obtained from the results accordingly. Over the past decades, there were 3307 publications on hydrological connectivity, and the published number has steadily increased each year, which has significantly improved the depth and breadth of hydrological connectivity research. Studies on hydrological connectivity are mainly carried out from a multi-disciplinary perspective, among which the most important fields are Environmental Science and Ecology, Water Resources, GeoScience, Environmental Science and Ecology. Additionally, Hydrological Processes, Journal of Hydrology, Water Resources Research, Freshwater Biology and Science are the top 5 most frequently cited journals as well as several repre-

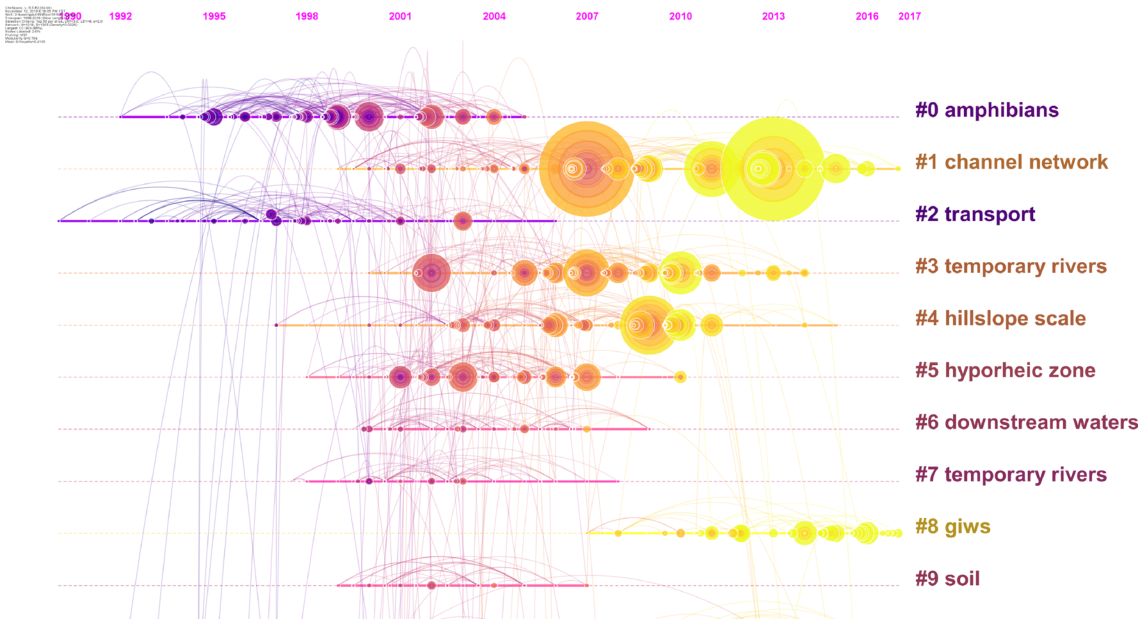

Fig. 9 Timeline visualization of main references cluster for hydrological connectivity during 1998–2018

sentative journals in the direction of hydrological connectivity. Moreover, Ward JV, Junk WJ, Tockner K are the researchers who have made outstanding contributions in this field due to their publications have a better citation rate, and Bracken LJ has the Strongest Citation Bursts, indicated the publications of whose are of great value.

Several hot spots and the high co-occurrence frequency points in the research field are found based on the co-occurrence analysis of keywords in 3 periods, and it may have certain reference significance for the study of the development and frontier evolution of hydrological connectivity. Early studies mainly focused on the hydrological connectivity in small scale floodplains as well as the impact on ecosystems and biodiversity. With time going on, the topic of the study has shifted to the dynamics of hydrological connectivity and the use of hydrological models for simulation. Recently, more attention has been paid to integrity and comprehensiveness of hydrological connectivity, the climate change as well as the evolution of spatial patterns have attracted more attention, and the management of hydrological connectivity has also received a lot of attention. According to co-cited analysis and clustering results of references, amphibians is the largest clustering cluster, and channel network is the most cited clustering cluster, which is currently the main research direction. It is worth noting that GIWS (geographically isolated wetlands) is the latest cluster of clustering, and due to its potential impact on regional hydrological connectivity, GIWS has received a lot of attention, which may be a research hotspot in the future.

As time progresses and with the development of the environment, economy, and society, the research subjects in different stages vary, but on the whole, the research on hydrological connectivity presents a stage of steady development and continuous innovation. The scale of hydrological connectivity is from small patch to large watershed and landscape, also the development of dimension is from single dimension to multi-dimensional spatio-temporal coupling.

In addition, we applied CiteSpace software to conduct co-occurrence and co-cited analysis of literatures. The results of this study are based on objective data analysis which are less affected by subjective experience, with stability and objectivity. However, compared with the traditional review methods, there are some limitations that need to be compensate for improving application category and depth analysis. For example, we can only combine some similar keywords artificially, while some keywords with low frequency may be ignored. It is necessary to include synonyms in Web of Science Core Collection (WoSCC) input so that the results can be more accurate. While it is trustworthy that with the continuous develop of CiteSpace software group, these drawbacks will be overcome and the accuracy will also be enhanced in the future.

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