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Opportunities and challenges of interbasin water transfers: a literature review with bibliometric analysis

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Abstract Interbasin water transfers and diversions are among the most controversial water-resources-planning topics worldwide. They provide supply alternatives to receiving basins and potential challenges to the donor basins within a context of changing global water problems. This study presents a bibliometric analysis of global interbasin water transfer research between 1900 and 2014. The bibliometric analysis analyzes general characteristics of publications, the national, institutional, and personal research outputs, participating regions and their research activity, and global trends and hot issues in the field of water transfers. Our results show that the rate of annual publication of interbasin water transfer research grew steadily after 1972 and is rising quickly at present. The United States produced the largest number of single-country publications (37.4 %) and international collaborative publications (46.6 %). However, China had a high growth rate of publications after 2001, and surpassed the United States and ranked 1st in 2012, with the Chinese Academy of Sciences playing a leading role in the emergence of China's research output. The global geographic distribution of publication activity shows that an increasing number of countries, agencies, and scholars have become part of the research enterprise. There is ample opportunity for cooperation between them to be strengthened in the future. The results of keyword evolution generally indicate that the research on interbasin water transfers expanded from 1991 through 2014. The hydrological and eco-environmental impacts of the South-to-North Water Transfer/Diversion Project in China and the corresponding long-term monitoring and conservation strategy have become one of the top topics of attention.

Keywords Bibliometrics · South-to-North Water Transfer Project (SNWTP) · Climate change · Water quality · China

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Introduction

Interbasin water transfer/diversion, transbasin diversion of water, interbasin transfer of water, inter-river transfer, inter-catchment water transfer, large-scale water transfer and long-distance water transfer are all terms used to describe the man-made conveyance of water from one area to another where the water demand has exceeded, or soon will exceed, supply (Davies et al. 1992; Aron et al. 1977; Moncur 1972; Biswas 1983; Golubev and Biswas 1984; Cummings 1974). Interbasin water transfer has a long history as a global human response to water scarcity, climate change, population growth and environmental constraints. It is used to increase water supply for agricultural, residential, commercial, hydropower, and other demands (Cole Sr and Carver 2011; Yevjevich 2001). Significant interbasin water transfer projects have been implemented worldwide, such as the Central Arizona Project (CAP) and the California State Water Project (SWP) in the United States (Chung and Helweg 1985), the Indira Gandhi Canal and Telugu Ganga project in India (Khan et al. 1999), the three-route (East, Middle and West) South-to-North Water Transfer Project (SNWTP) in China (Liu and Zheng 2002; Zhang 2009), the Eastern National Water Carrier (ENWC) in Namibia (Bethune and Chivell 1985), and the Snowy Mountains Scheme in Australia (Hudson 1962).

Interbasin water transfers play an active role in water-supply schemes in southern Africa, in Australia, and in the United States, and in other arid or semiarid regions of the world (Davies et al. 1992). At the same time, interbasin water transfer is also one of the most controversial water-resources-planning topics (Aron et al. 1977). The receiving region benefits from the supply of additional water through such water transfers while the donor region, by virtue of having water removed from it, sustains a reduction to its water availability (Kundell 1988). The potential impacts of reducing the water source of a donor basin may include changes to the natural flow regime, diminish its ability to assimilate pollutants and to support habitat for native aquatic communities, wetlands, and riparian eco-system health, and reduce its availability to provide water-based recreational activities, and aesthetic qualities (Cole Sr and Carver 2011; Loáiciga 2015). Consequently, water transfers between basins generate controversies and conflicts in the field of water resources development, and local communities, particularly those from donor regions, sometimes generate enough opposition to terminate or avoid transfer schemes (Aron et al. 1977; Yevjevich 2001). Many water transfer projects the world over await approval of their construction. These projects, as well as water-diversion projects, may require long periods of study prior to obtaining permits and financing (Yevjevich 2001). This increases planning, design, and construction costs.

During the past few decades, interbasin water transfer research has increased steadily, covering a variety of topics, such as fish migration responses to water diversions (Lindsey 1957; Ellender and Weyl 2014; Rose et al. 2014), economic assessment of interbasin water transfers (Moncur 1972; Aron et al. 1977; Fisher 1978), hydrological impact of water diversions (Poff and Matthews 2013; Putty et al. 2014), risk of water pollution and degradation of drinking water supplies (Sun et al. 2014; Tang et al. 2014), ecological impact of interbasin water transfers (Kingsford 2000), impact of water transfer on groundwater (Ye et al. 2014), legislation and policy regarding interbasin water transfers (Micklin 1978), diversions of water for irrigated agriculture (Lindenmayer et al. 2011), and regional strategies to cope with accelerating global problems (Aeschbach-Hertig and Gleeson 2012; Loáiciga 2009). This paper focuses on interbasin water transfer research, relying on a quantitative and comprehensive statistical review of the global scientific output of interbasin water transfer research.

The term bibliometrics was introduced in 1969 as an application of mathematical and statistical methods to books and other media of communication (Pritchard 1969). It quickly gained acceptance in the field of information science. It primarily refers to the research methodology employed in library and information sciences for citation analysis and content analysis. Bibliometrics has wide applications to assess the characteristics of publications, such as the number of publications, source countries and agencies, outlet journals, and research fields in various topics, such as world aerosols (Xie et al. 2008), biosorption technology (Ho 2008), biological invasions (Qiu and Chen 2009), wetlands (Zhang et al. 2010), drinking water (Fu et al. 2013), groundwater (Niu et al. 2014), and non-point source (NPS) pollution modeling (Li et al. 2014). New information has been added to bibliometrics recently in research-trend studies, such as CiteSpace for visualizing the evolution of a knowledge domain's co-citation network (Chen 2004), and social network analysis for building co-word and collaborative networks (Zhuang et al. 2013).

This study applies bibliometric methods to quantitatively and qualitatively investigate the global interbasin water transfer research. The specific aims are to: (1) identify general characteristics for publication outputs, (2) assess national, institutional, and personal research outputs, and investigate participating regions and their activity (3) summarize global trends and hot issues in the field of interbasin water transfer research. This work's results attempts to provide a basis for the better understanding of the global changing landscape in the field of water transfer, which may serve as a potential guide for future novel research.

Data sources and methodology

The bibliometric database of this paper was built based on the online version of the Science Citation Index Expanded (SCIE) via the Web of Science. The online version of SCIE was searched under the topic of phrases representing interbasin water transfer ("*basin* water transfer*" or "watershed* transfer* of water*" or "water diversion*" or "diversion* of water*" or "water transfer project*" or "water transfer scheme*", etc.) to compile a bibliography of all papers related to interbasin water transfer research during 1900–2014. Contributions of different agencies, institutions, and countries were estimated by the affiliation of at least one author to the publications. Collaboration type was determined by the addresses of the authors, where the term "single country publication" was assigned if the researchers' affiliations were from the same country. The term "internationally collaborative publication" was designated to those articles that were coauthored by researchers from multiple countries. The term "single institute publication" was assigned if the researchers' affiliations were from the same institute. The term "collaborative publications involving more than one institute" was assigned if authors were from different institutes.

A total number of 1116 publications related to interbasin water transfer research appeared during 1900–2014 were obtained. All the publications were assessed by the following aspects: characteristics of publication outputs, agency, country and author activities, and temporal evolution of keywords. The agencies' locations and their publication activity were extracted from the author's affiliations using CiteSpace (Chen 2004) and visualized in ArcGIS software. The author-cooperation network was drawn using NetDraw.

Results and discussion

Characteristics of publication outputs

The total amounts of SCIE publications (1116) related to interbasin water transfer research during 1900–2014 were counted and are displayed in Fig. 1. The first article emerged in 1957 during this period. Lindsey (1957) assessed the possible effects of water diversions on fish distribution in British-Columbia in 1957. Subsequently, two papers on the topics of interbasin transfers of water were published in 1972 (Moncur 1972; Stevens 1972). According to Fig. 1, widespread interest in interbasin water transfer research did not emerge until about 1990, with only few publications related to interbasin water transfer appearing before that year. The growing scientific productivity was also ascribed to the development of the SCIE. Interbasin water transfer research grew steadily after 1991, and accelerated in the past two decades. It appears that the number of scientific publications dealing with interbasin water transfer research is posed for fast growth in the foreseeable future.

The trend in interbasin water transfer related publications growth before 2000 is in agreement with the growth trend of their *h*-index (Fig. 1). The *h*-index is defined as the number *h* of papers published by a source that have at least *h* citations each. Before 2000, the relationship between the number of publication and the *h*-index is significant ($R = 0.977$, $p < 0.001$). The citation times of the publications related to interbasin water transfer research is relatively high if compared to the number of publication outputs. It is seen in Fig. 1 that the annual *h*-index is almost equal to the annual total number of publications before 2000, but different growth trends between publications number and the *h*-index is observed after 2000. This result also indicates a stable growth and collaborative communication within the interbasin water transfer research community.

Interbasin water transfer papers were published on more than 100 journals. Among them, the Journal of Hydrology published the most papers (3.8 % of all published papers), while Water Resources Research ranked second (3.4 %); Water Resources Management

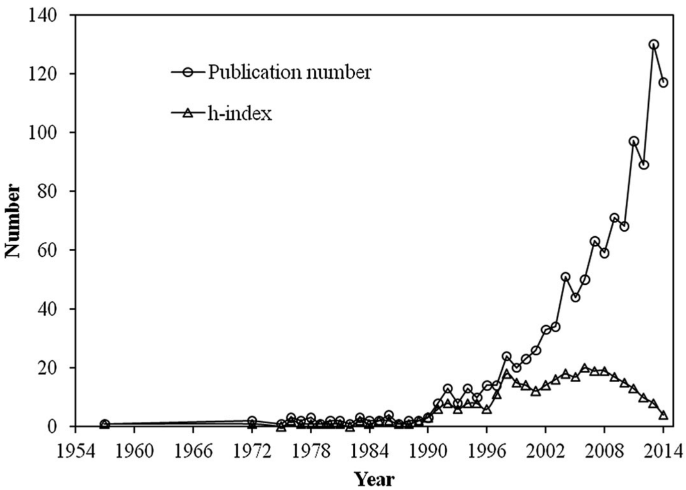


Fig. 1 Growth trends in interbasin water transfer related publications and their *h*-index

(3.2 %), Hydrological Processes (2.2 %), Environmental Management (1.7 %) and Water International (1.7 %) ranked 3rd, 4th, and 5th, respectively, in the studied period.

Distribution of country/area publications

The contribution of different countries/areas was estimated by the location of the affiliation of at least one author of the published papers. The top 15 countries/areas were ranked by the number of total publications during 1991–2014, including the number and percentage of single country articles and internationally collaborated articles (Table 1). The most prolific country was the United States (USA) (419 publications, representing 39.4 % of the total number of publications), which also produced the large number of single-country publications (37.4 %) and international collaborative publications (46.6 %), followed by China and Australia. The result shown in Table 1 demonstrates that developed countries played a leading role in interbasin water transfer research. Moreover, a few developing countries are listed as active in publishing in Table 1.

The annual variation trend between 1991 and 2014 among the top six most prolific countries is depicted in Fig. 2. An obvious rise can also been observed in the number of publications related to interbasin water transfer research of all six countries. The rapid development of this type of research may have been aroused by a series of high-visibility interbasin water transfers during the past decade. The United States dominated interbasin water transfer research since 1991. However, China had a high growth pace after 2001, eventually surpassing the United States and ranked first in 2012. In 2002, the three-route (East, Middle and West) South-to-North Water Transfer/Diversion Project was implemented to mitigate the increasing water resource deficits in north China. This event greatly promoted interbasin water transfer related studies in China (Liu and Zheng 2002; Zhang 2009).

Table 1 The fifteen most prolific countries/areas during 1991–2014

Country/area	TP	*R* (TP%)	*R* (SP%)	*R* (CP%)	*R* (FP%)	*R* (RP%)
USA	419	1 (39.4)	1 (37.4)	1 (46.6)	1 (33.3)	1 (46.6)
China	287	2 (27.0)	2 (24.8)	2 (34.9)	2 (24.3)	2 (34.9)
Australia	72	3 (6.8)	3 (6.3)	6 (8.6)	3 (5.9)	6 (8.6)
France	53	4 (5.0)	4 (3.6)	5 (9.9)	4 (3.8)	5 (9.9)
UK	46	5 (4.3)	5 (2.6)	3 (10.3)	6 (2.8)	3 (10.3)
Canada	45	6 (4.2)	6 (2.5)	3 (10.3)	5 (3.4)	3 (10.3)
Spain	31	7 (2.9)	7 (2.4)	9 (4.7)	7 (2.4)	9 (4.7)
Netherlands	30	8 (2.8)	11 (1.2)	6 (8.6)	11 (1.6)	6 (8.6)
Germany	29	9 (2.7)	12 (1.1)	6 (8.6)	10 (1.7)	6 (8.6)
South Africa	28	10 (2.6)	8 (2.3)	13 (3.9)	8 (2.3)	13 (3.9)
Iran	26	11 (2.4)	9 (2.2)	15 (3.4)	9 (2.0)	15 (3.4)
India	21	12 (2.0)	10 (1.7)	16 (3.0)	13 (1.3)	16 (3.0)
Brazil	17	13 (1.6)	15 (0.8)	11 (4.3)	12 (1.4)	11 (4.3)
Italy	17	13 (1.6)	14 (1.0)	13 (3.9)	14 (1.0)	13 (3.9)
Mexico	15	15 (1.4)	17 (0.6)	11 (4.3)	16 (0.8)	11 (4.3)

TP total publications, *SP* single country publications, *CP* international collaborative publications, *FP* publications as first author, *RP* publications as corresponding author, % percentage share of publications, *R* rank

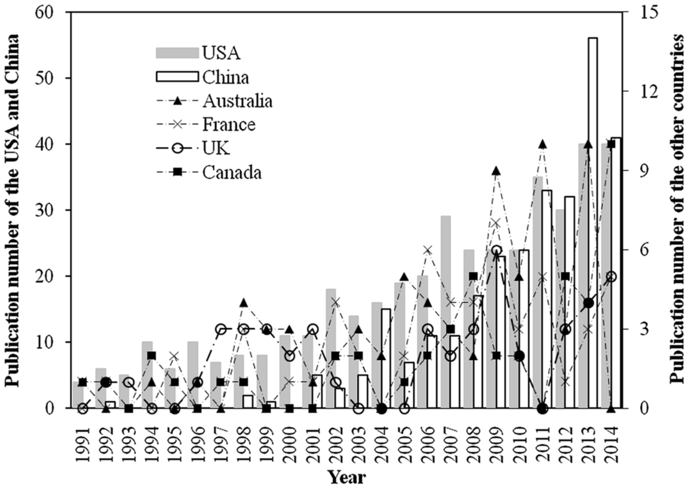


Fig. 2 Comparison of the publication trends of the top six most prolific countries during 1991–2014

Geographic distribution dynamics of institutional publication activity by agencies

The most prolific agencies in interbasin water transfer research field from 1991 to 2014 are displayed in Table 2. Of those there are ten, nine, and one in the USA, China, and Iran, respectively, that rank among the top 20 research institutions. The Chinese Academy of Sciences, the University of California, Davis, and the US Geological Survey are the top three research agencies, with 100, 53, and 36 publications, respectively.

The geographical distribution of agency publication activity in interbasin water transfer was analyzed using CiteSpace on the basis of author's institutional affiliations. The activity refers to the frequency of a site appearing in author's institutional affiliations (Li et al. 2014). Figure 3 portrays a significant expansion of research activity in interbasin water transfer research worldwide during 1991–2014. From 1991 to 1996 (Fig. 3a), worldwide agency publication activity in interbasin water transfer was relatively low and mainly limited to North America and Western Europe. Related research in this field expanded in North America and Western Europe during 1997–2002. An increased number of agencies in Asia, Oceania, Africa, and South America participated in interbasin water transfer research, and a hotspot, Sydney (Australia), appeared in Oceania (Fig. 3b). A substantial geographical expansion of research in interbasin water transfer was observed during the third period (2003–2008), with numerous hotspots appearing in the USA, China, and Western Europe during this period (Fig. 3c). During 2009–2014 several agencies became noticeably visible. Beijing, Nanjing, and Wuhan, all three in China, became the most active hotspots related to interbasin water transfer research (Fig. 3d).

Author activity and cooperation

The thirteen most prolific authors in interbasin water transfer research field are listed in Table 3. Besides the number of total articles (TA) and articles as first author or corresponding author (FCA), the academic impacts of the authors were also assessed with total

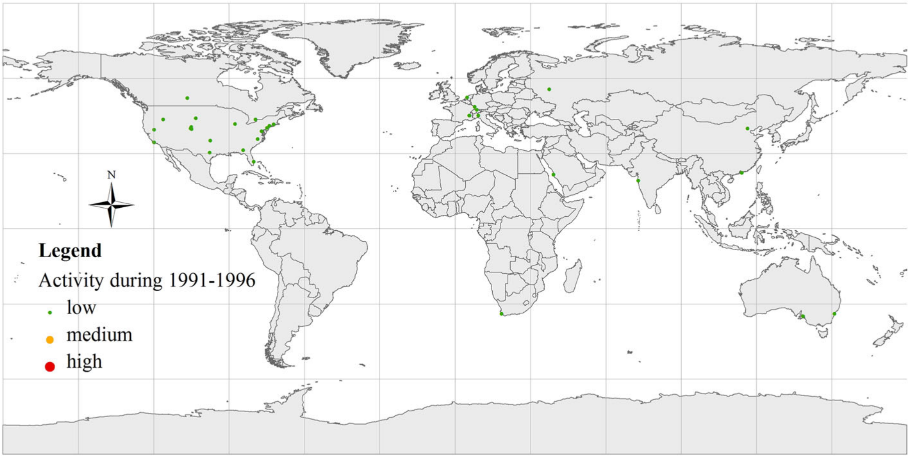
Table 2 The twenty most prolific agencies during 1991–2014

Institute	TP	*R* (TP%)	*R* (SP%)	*R* (CP%)	*R* (FP%)	*R* (RP%)
Chinese Academy of Sciences, China	100	1 (9.4)	1 (8.1)	1 (10.4)	1 (7.4)	1 (7.4)
University of California, Davis, USA	53	2 (5.0)	3 (3.7)	2 (5.9)	2 (2.8)	2 (2.7)
US Geological Survey, USA	36	3 (3.4)	2 (3.9)	3 (3.0)	3 (2.2)	3 (2.4)
Colorado State University, USA	25	4 (2.3)	4 (2.2)	4 (2.5)	4 (1.7)	6 (1.6)
Hohai University, China	21	5 (2.0)	5 (2.0)	9 (2.0)	4 (1.7)	4 (1.7)
East China Normal University, China	21	5 (2.0)	8 (1.3)	4 (2.5)	6 (1.6)	4 (1.7)
China Institute of Water Resources and Hydropower Research, China	21	5 (2.0)	6 (1.5)	6 (2.3)	8 (1.1)	7 (1.2)
Beijing Normal University, China	19	8 (1.8)	9 (1.1)	6 (2.3)	8 (1.1)	8 (1.1)
Oregon State University, USA	17	9 (1.6)	12 (0.7)	6 (2.3)	11 (0.8)	14 (0.7)
University of Arizona, USA	16	10 (1.5)	10 (0.9)	9 (2.0)	7 (1.2)	9 (1.0)
Shandong University, China	13	11 (1.2)	12 (0.7)	13 (1.6)	10 (0.8)	10 (1.0)
Peking University, China	13	11 (1.2)	15 (0.4)	11 (1.8)	15 (0.6)	16 (0.6)
Texas A&M University, USA	13	11 (1.2)	15 (0.4)	11 (1.8)	17 (0.5)	17 (0.5)
Wuhan University, China	11	14 (1.0)	19 (0.2)	13 (1.6)	11 (0.8)	11 (0.8)
Tsinghua University, China	11	14 (1.0)	15 (0.4)	16 (1.5)	14 (0.7)	11 (0.8)
Univ of Tehran, Iran	10	16 (0.9)	6 (1.5)	22 (0.5)	11 (0.8)	11 (0.8)
University of Wyoming, USA	10	16 (0.9)	12 (0.7)	20 (1.2)	15 (0.6)	14 (0.7)
University of California, Berkeley, USA	10	16 (0.9)	19 (0.2)	16 (1.5)	17 (0.5)	17 (0.5)
University of California, Santa Barbara, USA	10	16 (0.9)	10 (0.9)	21 (1.0)	17 (0.5)	17 (0.5)
Utah State University, USA	10	16 (0.9)	19 (0.2)	16 (1.5)	17 (0.5)	20 (0.4)

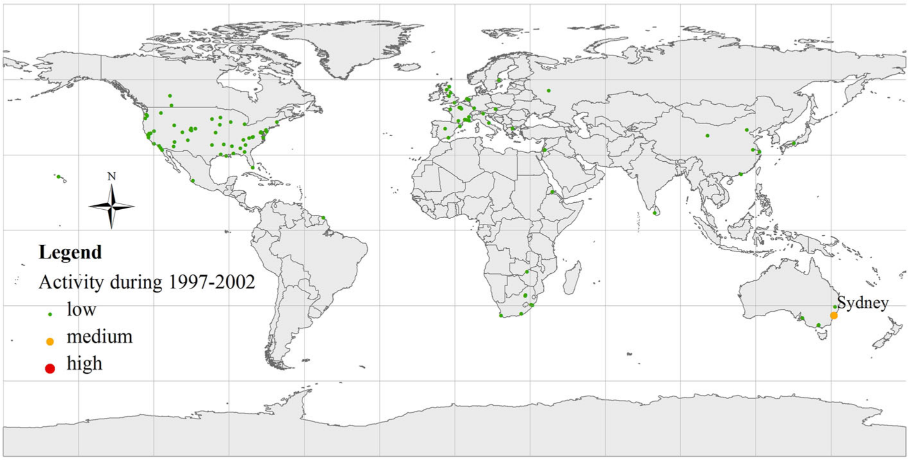
TP total publications, *SP* single agency publications, *CP* collaborative publications involving more than one agency, *FP* publications as first author, *RP* publications as corresponding author, % percentage share of publications, *R* rank

citations (TC), citation per publication (CPP), and the *h*-index. Seven authors from Asian agencies, four from American institutes, and two from European agencies were ranked among the top thirteen most prolific authors of publications in interbasin water transfer research. Among them, Zhang, Q.F., from the Wuhan Botanical Garden, CAS, is the most prolific author in interbasin water transfer research according to both the TP (15) and the FCA (11), and ranks first in *h*-index. Kingsford, R.T., from the University of New South Wales, has the highest TC (595) and CPP (60). Our results demonstrate that scientific researchers from Asian, the United States, and European agencies played important roles in the field of interbasin water transfer research.

Cooperation clusters of the top thirty authors are depicted in Fig. 4. The larger black nodes are associated with the high *h*-index of the authors, and the thicker ties between nodes are associated with the large numbers of co-authored articles. It can be seen in Fig. 4 that authors' cooperation was mainly limited to within their agencies, such as (1) the University of California, Davis, USA, and (2) the CAS (Chinese Academy of Sciences), (3) Beijing Normal University, and (4) Shandong University, the last three in China. Our analysis indicates that the latter agencies are leading sources of interbasin water transfer research, but that there is tenuous cooperation among them.



(a)



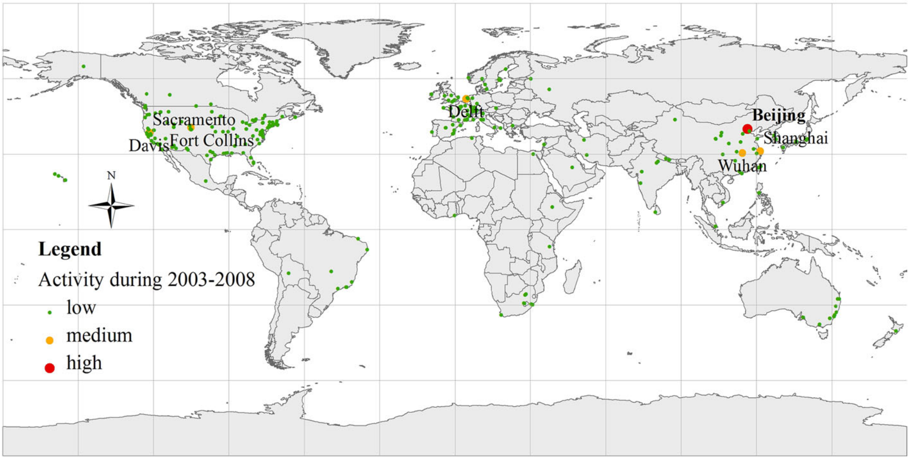
(b)

Fig. 3 Global geographic distribution of agency publication activity during **a** 1991–1996, **b** 1997–2002, **c** 2003–2008, **d** 2009–2014. The agency publication's activity is designated as low if the site appeared less than 3 times in the institutional affiliation of the publications in the specific period, as medium if the appearing frequency was between 4 and 6 times, and as high if the site appeared more than 7 times

General research trends and hot issues

Overall trends

The total number of SCIE publications (1116) regarding interbasin water transfer research is relatively small in comparison to those of other topics, such as groundwater (a total of 64,376 papers during 1993–2012) (Niu et al. 2014), drinking water (a total of 37,078 papers during 1992–2011) (Fu et al. 2013), and wetlands (a total of 16,871 papers during 1991–2008) (Zhang et al. 2010). However, the number of annual publications regarding interbasin water transfer research grew stably after 1991 and seems posed for fast growth



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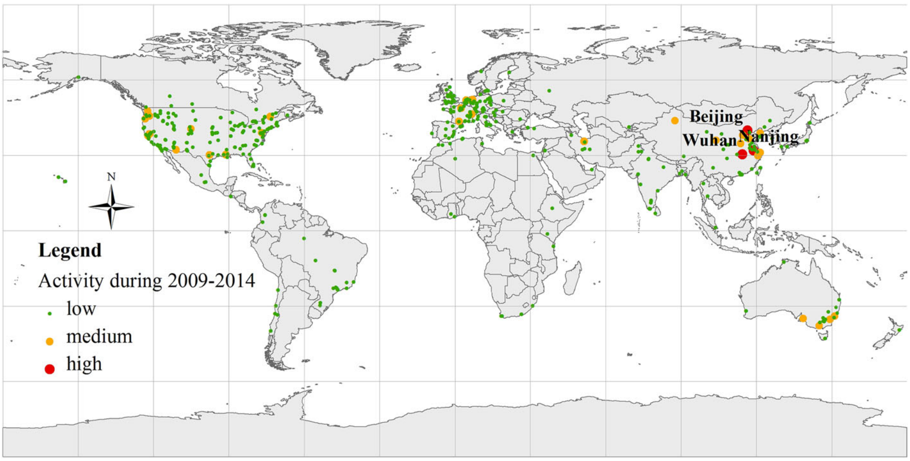

(d)

Fig. 3 continued

in the future (Fig. 1). Moreover, the annual *h*-index of interbasin transfer publications is relatively high, indicating a genuine concern about this issue. The national, institutional, and personal publication activity in interbasin water transfer research exhibited growth exercised by countries, agencies, and scholars. Yet, our analysis indicates that there is ample opportunity for cooperation among this community of researchers to be strengthened in the future.

Keywords analysis and hot topics

Keywords appearing in publications related to interbasin water transfer research from 1991 through 2014 were calculated and ranked by total number of publications in 4 6-year periods. Keywords analysis is an effective method to assess the development of an area of

Table 3 The thirteen most prolific authors and their academic impacts

Author	Institute	TP	FCA (*R*)	TC (*R*)	CPP (*R*)	*h*-index (*R*)
Zhang, QF	Wuhan Botanical Garden, CAS	15	11 (1)	328 (2)	22 (9)	12 (1)
Cech, JJ	University of California, Davis	12	0 (27)	105 (11)	9 (21)	5 (6)
Li, SY	Wuhan Botanical Garden, CAS	11	9 (3)	264 (4)	24 (7)	10 (2)
Xu, JX	Institute of Geographic Sciences and Natural Resources Research, CAS	11	11 (1)	164 (8)	15 (10)	8 (3)
Kingsford, RT	University of New South Wales	10	9 (3)	595 (1)	60 (1)	8 (3)
Wang, H	China Institute of Water Resources and Hydropower Research	9	1 (21)	99 (13)	11 (17)	4 (12)
Liu, CM	Institute of Geographic Sciences and Natural Resources Research, CAS; Beijing Normal University	8	2 (16)	184 (6)	23 (8)	4 (12)
Van der Zaag, P	Delft University of Technology; UNESCO Institute of Water Education	7	2 (16)	104 (12)	15 (10)	4 (12)
Moyle, PB	University of California, Davis	7	1 (21)	268 (3)	38 (3)	6 (5)
Xu, ZF	Institute of Geology and Geophysics, CAS	6	1 (21)	152 (9)	25 (6)	5 (6)
Ward, FA	New Mexico State University	6	5 (5)	168 (7)	28 (4)	5 (6)
Young, PS	University of California, Davis	6	2 (16)	68 (15)	11 (17)	5 (6)
Kerachian, R	University of Tehran, Iran	6	5 (5)	50 (21)	8 (21)	4 (12)

TP total publications, *FCA* publications as first author or corresponding author, *TC* total citations, *CPP* citations per publication, *R* rank in the list, *CAS* Chinese Academy of Sciences

research, to identify hot issues of a research field, and to provide statistical information about research trends by researchers (Zhang et al. 2010). Table 4 shows the top thirty most frequently used keywords in interbasin transfer research. The keywords analysis reveals the contents of interbasin water transfer related publications during 1991–2014 in detail. The distribution of the keywords with rank and percentage in different periods is shown in Table 4.

The result of keyword evolution generally indicates that the research interests of interbasin water transfer expanded between 1991 and 2014. Interbasin transfer of water creates opportunities for regional agriculture, commerce, and economic development in receiving basins in response to changing global conditions. It also brings about potential challenges regarding hydrological and eco-environmental impacts, especially to the donor basin (Cole Sr and Carver 2011).

According to the keywords analysis (Table 4), the most popular interbasin water transfer research related issues are as follows. The most frequently used keywords are “climate change”, followed by “irrigation”, “South-to-North Water Transfer/Diversion Project”, “China”, and “drought/s”. The relation between climate change and interbasin water transfer (a human adaptation to climate change and water scarcity) is the most popular topic in this field. Semiarid and arid regions occupy one-third of the world’s land surface area (Thomas 1989; Comín and Williams 1994; Walker et al. 1995; Kingsford et al. 1998). Reviewed research suggests that water resource scarcity and habitat degradation in

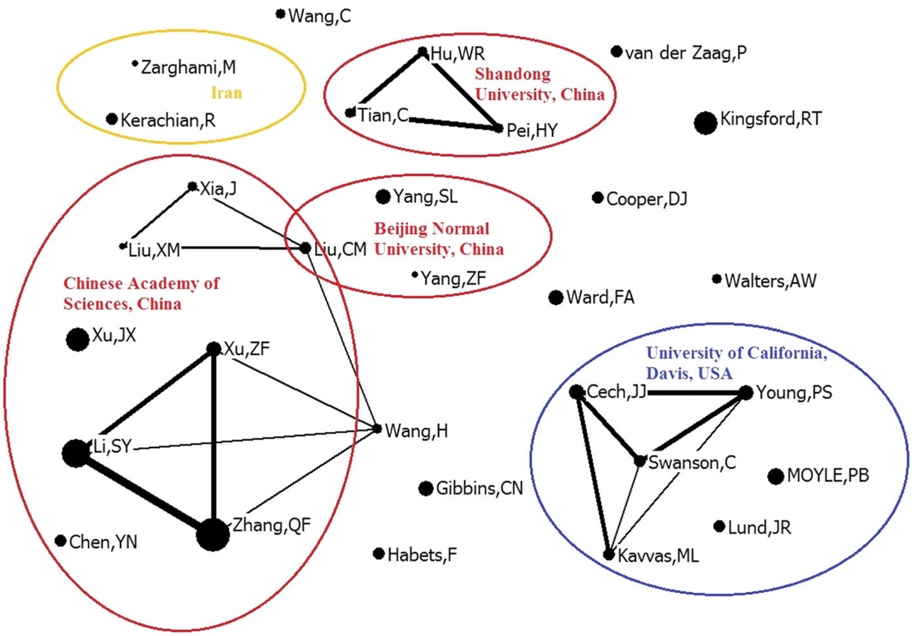

Fig. 4 Collaborative network among the thirty most prolific authors during 1991–2014. The *larger black nodes* are associated with the high *h*-index of the authors, and the *thicker lines* between nodes are associated with the larger numbers of co-authored articles

most of the world is likely to worsen in the future (Bauer et al. 2015; Li et al. 2015; Liu and Ma 1983; Loáiciga et al. 2000). Water transfer/diversion projects were commonly implemented to mitigate water resource deficits in drought-stricken regions. Recently, the three-route (East, Middle and West) South-to-North Water Transfer/Diversion Project in China has become one of the most noticeable water transfer projects the world over. Its total annual water diversion capacity of three routes would be 44.8 billion m^3 (Zhang 2009). This vast project led to many multi-disciplinary studies, such as those on construction management of the project (Liu et al. 2006; Zhong et al. 2005), the environmental geology of its Middle Route Project (Wang and Ma 1999), the protection of cultural relics along its Middle Route (Shang et al. 2003), water conservation and water purification (Yang et al. 2014), regional water security (Chen et al. 2013a, b), impact of the project on groundwater resources (Xu et al. 2013), pricing and water resource allocation scheme and policy for the project (Chen et al. 2013a, b; Jia et al. 2013), and the effect on transmission of *Oncomelania hupensis*, the intermediate host of *Schistosoma japonicum* in China (Liang et al. 2012; Wang et al. 2009).

The risk of water pollution in its water source areas and main canals is the main concern about the South-to-North Water Transfer/Diversion Project (Shen et al. 2015; Tang et al. 2014; Xie et al. 2011). The water quality in the water supply reservoirs was monitored and analyzed prior to the transfer of water by the South-to-North Project (Li et al. 2008; 2009). Keywords listed in Table 4, such as “water management”, “water quality”, “water resource/s”, “groundwater”, “water market/s”, “water supply”, “water allocation” and “eutrophication”, reflect the concern about water quality impacts of the water transfer and diversion. This indicates that water resource management and water quality protection are

Table 4 The thirty most frequent keywords in interbasin water transfer research during 1991–2014

Author keywords	TP	*R* (%)			
		1991–1996	1997–2002	2003–2008	2009–2014
Climate change	32	–	3 (4.0)	22 (1.8)	1 (5.2)
Irrigation	29	6 (4.0)	1 (5.9)	1 (5.3)	5 (2.2)
South-to-North Water Transfer/Diversion Project	28	–	–	14 (2.2)	2 (5.0)
China	23	6 (4.0)	51 (1.0)	8 (3.1)	3 (3.0)
Drought/s	22	6 (4.0)	16 (2.0)	5 (3.5)	4 (2.4)
Water management	21	1 (16.0)	–	8 (3.1)	5 (2.2)
Hydrology	20	6 (4.0)	3 (4.0)	2 (4.9)	37 (0.9)
Wetland/s	20	6 (4.0)	5 (3.0)	11 (2.7)	5 (2.2)
Dam/s	19	6 (4.0)	3 (5.0)	3 (4.4)	58 (0.6)
Water quality	19	–	16 (2.0)	8 (3.1)	5 (2.2)
Water resource/s	19	6 (4.0)	51 (1.0)	4 (4.0)	10 (1.7)
Yellow river	17	–	16 (2.0)	5 (3.5)	20 (1.5)
Groundwater	16	–	16 (2.0)	11 (2.7)	10 (1.7)
Water market/s	16	–	16 (2.0)	11 (2.7)	10 (1.7)
Water resource management	16	6 (4.0)	51 (1.0)	19 (1.8)	5 (2.2)
Environmental flow/s	15	–	5 (3.0)	31 (1.3)	10 (1.9)
Restoration	15	6 (4.0)	5 (3.0)	5 (3.5)	58 (0.6)
Simulation	14	2 (12.0)	–	19 (1.8)	17 (1.5)
Modeling/modelling	14	–	16 (2.0)	19 (1.8)	10 (1.7)
Management	12	6 (4.0)	5 (3.0)	14 (2.2)	58 (0.6)
Optimization	12	3 (8.0)	51 (1.0)	19 (1.8)	26 (1.1)
Eutrophication	11	–	51 (1.0)	134 (0.4)	10 (1.9)
Water supply	11	–	–	55 (0.9)	10 (1.9)
Macroinvertebrate/s	11	–	5 (3.0)	55 (0.9)	23 (1.3)
Water allocation	11	–	–	19 (1.8)	17 (1.5)
Runoff	10	–	5 (3.0)	134 (0.4)	23 (1.3)
Conservation	10	6 (4.0)	51 (1.0)	19 (1.8)	37 (0.9)
Human activities/activity	9	–	–	14 (2.2)	37 (0.9)
Numerical model/s	9	–	–	55 (0.9)	17 (1.5)
Remote sensing	9	–	–	19 (1.8)	26 (1.1)

TP total publications where the keywords occurred, *R* rank during the specific period, % keyword occurring frequency, – the keyword did not occur during the period of analysis

the most serious challenges facing the implementation of this vast water transfer project in China. Therefore, a long-term monitoring strategy under the supervision of the Chinese Ecological Research Network was proposed as an environmental safeguard (Zhang 2009).

It is concluded from the data listed in Table 4 and based on the keywords "modeling/modelling", "simulation", "numerical model/s", "remote sensing", "optimization", "restoration", and "conservation" that simulation and modeling of the hydrological and environmental processes affecting interbasin water transfer with spatial information technology, such as remote sensing, have been numerously proposed as part of the design optimization, water restoration, and conservation associated with water transfer projects (Wang 2013a, b; Gu et al. 2012).

Moreover, changes in interbasin water transfer research trends were detected by the statistical analysis reported in Table 4. The percentage of a few keywords obviously increased during 1991–2014. For example, keyword “South-to-North Water Transfer/Diversion Project” did not appear before 2002, but ranked 14th in 2003–2008, while ranked 2nd in 2009–2014. These results are well correlated with the attention given to the “South-to-North Water Transfer/Diversion Project” in China, which has become a top publication topic since 2002.

Conclusions

Significant interbasin water transfer research highlights were obtained from the SCIE by means of the bibliometric analysis. They are:

(1) Interbasin water transfer research grew continually and started to gain momentum in 1972, and accelerated in the past 20 years. It is predicted that the number of scientific publications on interbasin water transfer will continue to grow in the future.
(2) The USA produced the largest number of single-country and internationally collaborative articles, and the results demonstrated that China also played an important role in the field of interbasin water transfer research. There are ten, nine, and one research agencies in the USA, China, and Iran, respectively, that rank among the top 20 research institutions involved with interbasin water transfer research worldwide. The Chinese Academy of Sciences produced the largest number of publications in this topic, followed by the University of California, Davis, and the US Geological Survey.
(3) From 1991 to 1996, worldwide agency publication activity in interbasin water transfer was low and mainly limited to North America and Western Europe; however, during 2009–2014, the participating agencies grew, and Beijing, Nanjing, and Wuhan, in China, became the most active publication hotspots associated with this subject. An increasing number of agencies and scholars have joined this research field; yet, the cooperation among them could be strengthened in the future.
(4) According to the results of the keyword evolution analysis, the relation between climate change and interbasin water transfer, the South-to-North Water Transfer/Diversion Project in China, water quality and pollution risk, simulation and modeling of hydrological and environmental processes of interbasin water transfer, and the corresponding strategies for water restoration and conservation were the most published topics in the field of interbasin water transfer. It is concluded that the impacts of the South-to-North water transfer/diversion project in China and its long-term monitoring and conservation strategies may become the top discussed topics in this research field in the years ahead.

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