Thirty years (1984–2014) of groundwater science teaching and research in China: A dissertation-based bibliometric survey

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Abstract: In order to track the footprint of groundwater science teaching and research in China during the past years, a bibliometric analysis was conducted based on the database of China National Knowledge Infrastructure (CNKI), which covered the time span from 1984 to present and included more than 2.6 million master and doctoral dissertations from hundreds of institutions of Mainland China. The bibliometric analysis summarized output, geographical, and institutional patterns, as well as research directions and hotspots in groundwater studies in China in the period of 1984-2014. A total of 1 396 groundwater-related dissertations including 1 161 master dissertations and 235 doctoral dissertations, contributed by 128 institutions distributed in 53 cities nationwide, were searched out in the database. It can be seen obviously that, the groundwater science teaching and research in China has experienced a notable growth in the past three decades especially during 2000-2014. Groundwater modeling, resource, and exploitation were the top three major subject categories; China University of Geosciences (Beijing), Jilin University and Chang'an University were the top three productive institutions together accounting for more than one third of the total dissertations and 50% of the doctoral dissertations, which further prompted the cities (Beijing, Changchun, and Xi'an) to become the top three productive cities. The dissertations generally covered all the international research topics, which indicated that hydrogeologists in China have tracked the international frontier closely during the past decades. The keywords analysis revealed that, (1) numerical modeling was still the hottest topic and PHREEQC, MODFLOW, GMS, and FEFLOW were the four most used softwares; (2) the topics related with groundwater pollution and quality developed steadily and rapidly; (3) environmental isotopes and GIS were frequently used tools for hydrogeological condition analysis, and spatial data processing respectively; and (4) the unsaturated zone as an integral part of aquifers attracted more and more attentions from hydrogeologists focus on saturated zone.

Keywords: Groundwater; Hydrogeology; Research hotspot; Scientometrics; Bibliometrics analysis; China National Knowledge Infrastructure (CNKI)

Introduction

Groundwater, which has been a source of water supply since the dawn of recorded history of human settlement and agricultural activity (ZHOU Yu *et al*. 2011), is an active component of the hydrologic cycle and widely recognized as a critical and vulnerable resource (NIU Bei-bei *et al*. 2014). During the past decades, people worldwide have witnessed increasing speed of groundwater table depression, deterioration of water quality, saline intrusion, ecological degradation, geologic hazard such as land subsidence and ground fracture,

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etc. (Gleeson *et al*. 2012b; Fang *et al*. 2013; ZHAI Yuan-zheng *et al.* 2013; Chamine, 2015). Meanwhile, in the last decades, the number of dissertations about groundwater science teaching and research has increased steadily, and covered a variety of topics, such as hydrogeochemical and hydrological processes, groundwater and soil pollution control and remediation, flow dynamics in saturated and unsaturated zone, interactions among groundwater, surface water, land use, climate change and human activities in different scales, groundwater-related engineering problems and disasters, techniques for groundwater modeling and assessment, environmental tracing techniques, and groundwater management and policies, *etc*. (Gleeson *et al.* 2012a; NIU Bei-bei *et al.* 2014; ZHAI Yuan-zheng *et al.* 2014).

Groundwater-related studies have been reviewed from different viewpoints worldwide (Welch *et al.* 2000; Schwartz and Ibaraki, 2001; Scanlon *et al.* 2002; Mandal and Suzuki, 2002; Bohlke, 2002; Schwartz *et al.* 2005; NIU Bei-bei *et al.* 2014; Gorelick and ZHENG Chun-miao, 2015). However, the previous studies mainly focused on the groundwater-related studies from global view and were mainly based on English journals worldwide, which excluded Chinese journals and dissertations. As far as we know, China has played a rising role in the groundwater science teaching and research during the past decades especially after 2000 (ZHAI Yuan-zheng *et al.* 2014), and has produced a lot of articles and dissertations written in Chinese and published in China. A general statistics and review of the groundwater science related research in China is urgently needed to reflect the significant developments and achievements in the academia of China. In 2014, we investigated the groundwater-related scientific projects funded by the National Natural Science Foundation of China (NSFC) in the whole funded period (1997-2013) (ZHAI Yuan-zheng *et al.* 2014). In this study, we used comprehensive statistics of dissertations included in the database of China National Knowledge Infrastructure (CNKI), which is the biggest database for scientific publications in China, to reflect the development of groundwater science in China (1984-2014). Specifically, this paper aims at (1) making a statistics for the master and doctoral dissertations included in the database of CNKI; (2) evaluating civic and institutional research outputs; and (3) summarizing the national research characteristics and hot issues, through which related scientists and managers at home and abroad can realize the teaching and research profile of groundwater of China.

1 Data source and methods

1.1 Data source

The data analyzed in this paper were collected from the database of China National Knowledge Infrastructure (CNKI, http://epub.cnki.net/kns/brief/result.aspx?dbPrefix=CDMD), which was sponsored by Tsinghua University and Tsinghua Tongfang Company Limited in June 1996. CNKI, as the biggest and leading database of journals and dissertations in China, covers multiple disciplinary fields, such as basic subjects, engineering technologies, agricultural sciences, medical sciences, philosophy, humanity sciences, social sciences, earth sciences, environmental sciences, and so on, most of which were written in Chinese with English titles, keywords, and abstracts. Master dissertations and doctoral dissertations included in CNKI (China Master's Theses Full-text Database and China Doctoral Dissertations

Full-text Database, respectively) come from 670 and 423 teaching and research institutions in Mainland China, respectively, which cover the time span from 1984 to present and the number have reached 2 604 824 when we searched in June 2015.

The research results of master and doctoral dissertations of groundwater analyzed in this paper are obtained by inputting "P641" (hydrogeology discipline code formulated by Chinese Library Classification) in the "Entering search criteria" dialog box under the inputting condition of "Chinese Library Classification".

1.2 Statement

In order to facilitate the analysis and avoid misunderstanding, a statement was presented as follows:

(1) According to the Chinese Library Classification, only those dissertations marked P641 were searched and analyzed in this paper.

(2) All groundwater-related dissertations can be searched in the database of CNKI but with other Chinese Library Classification (not P641, which were chosen and determined by the authors freely) were not included in this paper, because it's very difficult to distinguish them and cover all of them due to the blurry boundary between disciplines.

(3) Dissertations produced in institutions of Hongkong, Macao and Taiwan were not included in the database of CNKI.

(4) As far as we know, minority institutions can't be found in the database of CKNI, and not all dissertations of some institutions were included in the database (such as Chinese Academy of Sciences). Therefore, the searched results were not comprehensive.

(5) Those institutions ever suffered recombination (such as Changchun College of Geosciences, being a part of Jilin University now) or renaming (such as Ocean University of China, ever called Ocean University of Tsingtao) were considered and discussed with the present names.

(6) All the regions, institutions, and researchers involved were only discussed for scientific research without any bias.

(7) Above all, the main purpose of this paper was only to track the development process of the groundwater science teaching and research and what the scientists were interested in and doing in China, but not to represent the complete blueprint of the groundwater research in China, because the dissertations couldn't cover all, not to mention that the database of CNKI were not comprehensive and some groundwater-related dissertations in the database were not marked by P641.

1.3 Methods

Bibliometric approaches, which were first introduced as an application of mathematical and statistical methods to books and other media of communication (Pritchard, 1969) and have been widely applied in various fields in recent years (Persson *et al.* 2004; WANG Ming-huang *et al.* 2010; SUN Jin-shui *et al.* 2012; NIU Bei-bei *et al.* 2014), were used to quantitatively and qualitatively investigate the groundwater research in this study.

The original data and extractive data were mainly disposed by using the Microsoft Excel 2013 software. The institutional distribution and geographic distribution were analyzed and presented by using the ArcGIS 10.0 software. The network diagram describing the relationships among keywords was drawn by using the Gephi software for free (http://gephi.org/), the operation of which can be seen in detail in Leydesdorff and

Rafols (2012).

2 Results and discussion

2.1 General output description

In the same study period of this paper (1984-2014), 2 544 366 dissertations including 2 283 489 master dissertations (accounting for 90%) and 260 877 doctoral dissertations (accounting for 10%) can be found in the database of CNKI (Fig. 1). Only seven dissertations including one master dissertation and six doctoral dissertations accomplished in the earliest year (1984), while the same number for the last year (2014) is 274 661 composed of 254 615 for master dissertations and 20 046 for doctoral dissertations. Generally speaking, it can be seen from the figure that, the quantity of dissertations in the study period experienced a sharply increasing process with the maximum (318 265 in 2013) being 4.5×10^4 times of the minimum (seven in 1984). The rapid increasing of dissertations were radically benefited from the rapid development of the higher education during the past three decades in China (Cyranoski *et al.* 2011), especially after entering the new century, which can be approved largely by the available data of masters and doctors incepted during 1997-2013 (Fig. 2).

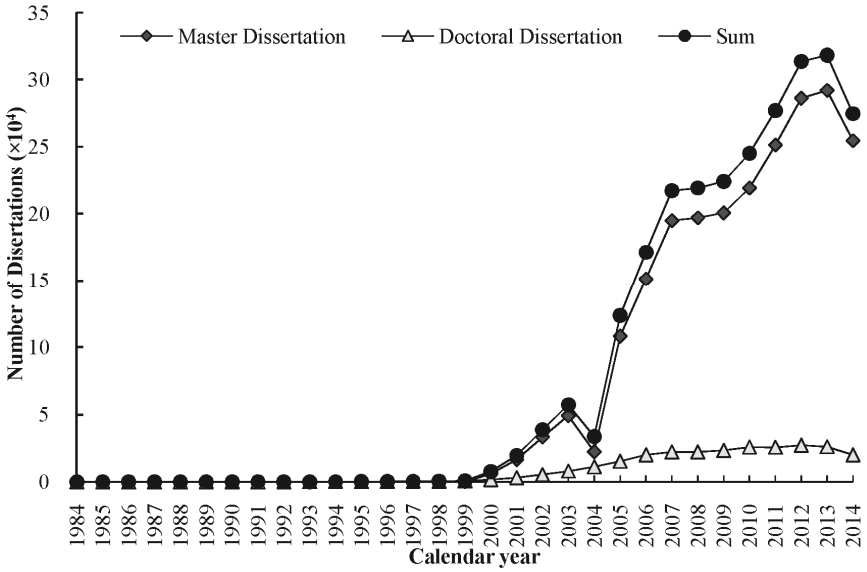

Fig. 1 Number of dissertations during the study period (1984-2014)

With respect to the groundwater-related dissertations, there are a total of 1 369 dissertations including 1 161 master dissertations and 235 doctoral dissertations according to the searched results (Fig. 3). All the master dissertations were accomplished during 2000-2014. The earliest doctoral dissertation was accomplished in 1988 by ZHOU Yang-xiao from Chinese Academy of Geological Sciences (CAGS): Groundwater management model of Wuwei Basin in Shiyang River catchment, followed by two doctoral dissertations accomplished in 1992 and 1994, respectively, before 2000. It's safe to say, almost all of the dissertations were accomplished during 2000-2014 with the maximum (216 in 2013) being 36 times of the minimum (six in 2000). It also indicated that the teaching and research of groundwater science in China experienced a very rapid development processes from 2000 to 2014, which reflected the social need and the rigorous

reality of China: Water shortage (Varis and Vakkilainen, 2001; FENG Kui-shuang *et al.* 2014; TAO Tao and XIN Kun-lun 2014) and water pollution (Schwarzenbach *et al.* 2010; QIU Jane, 2011; LU Yong-long *et al.* 2015; Nixdorf *et al.* 2015).

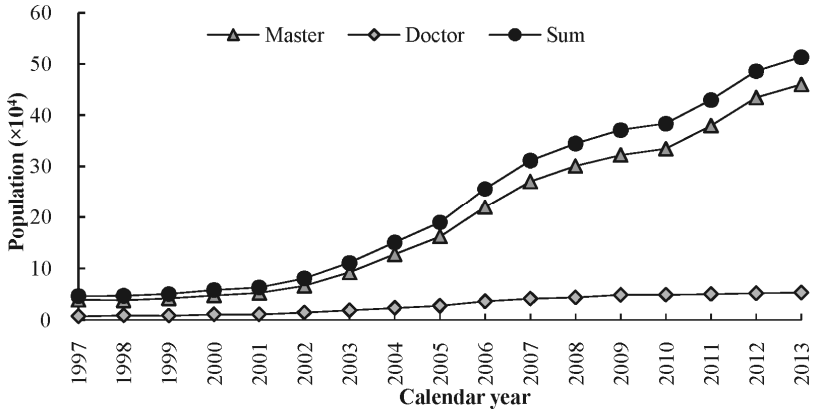

Fig. 2 Population of masters and doctors incepted during 1997-2013*

*Data were obtained from the official website of Ministry of Education of the People's Republic of China: http://www.moe.gov.cn/s78/A03/moe_560/s8492/

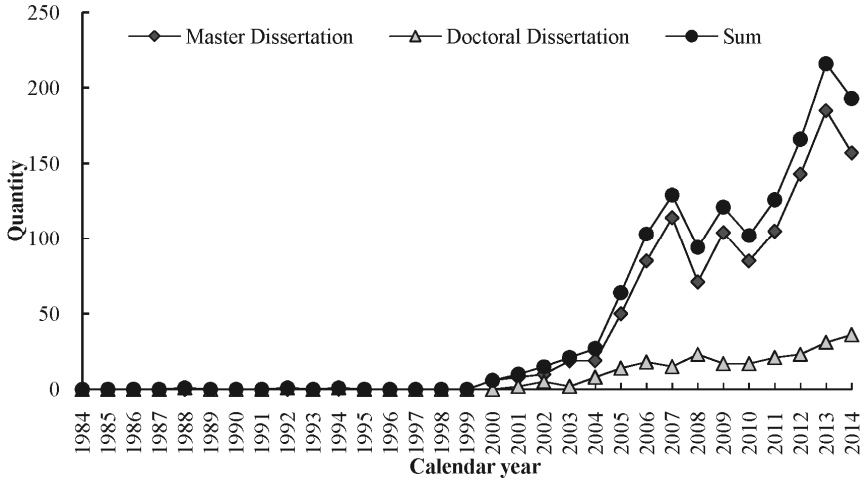

Fig. 3 Amounts of groundwater-related dissertations during the study period (1984-2014)

The relationships between dissertations and groundwater-related dissertations were shown in Fig. 4. It can be seen obviously that, there existed very good linear relationships between dissertations and groundwater-related dissertations of different types (master, doctoral, and sum of them). This finding indicated that, the teaching and research of groundwater science in China experienced the same rapid development processes during the past three decades with the postgraduate education of China, which can be seen partly from Committee on Chinese Groundwater Science (2009), Qiu (2011), NIU Bei-bei *et al.* (2014), and ZHAI Yuan-zheng *et al.* (2014). The results also indicated that, out of ten thousand dissertations annually, at least six dissertations are related with groundwater including five master dissertations and one doctoral dissertation.

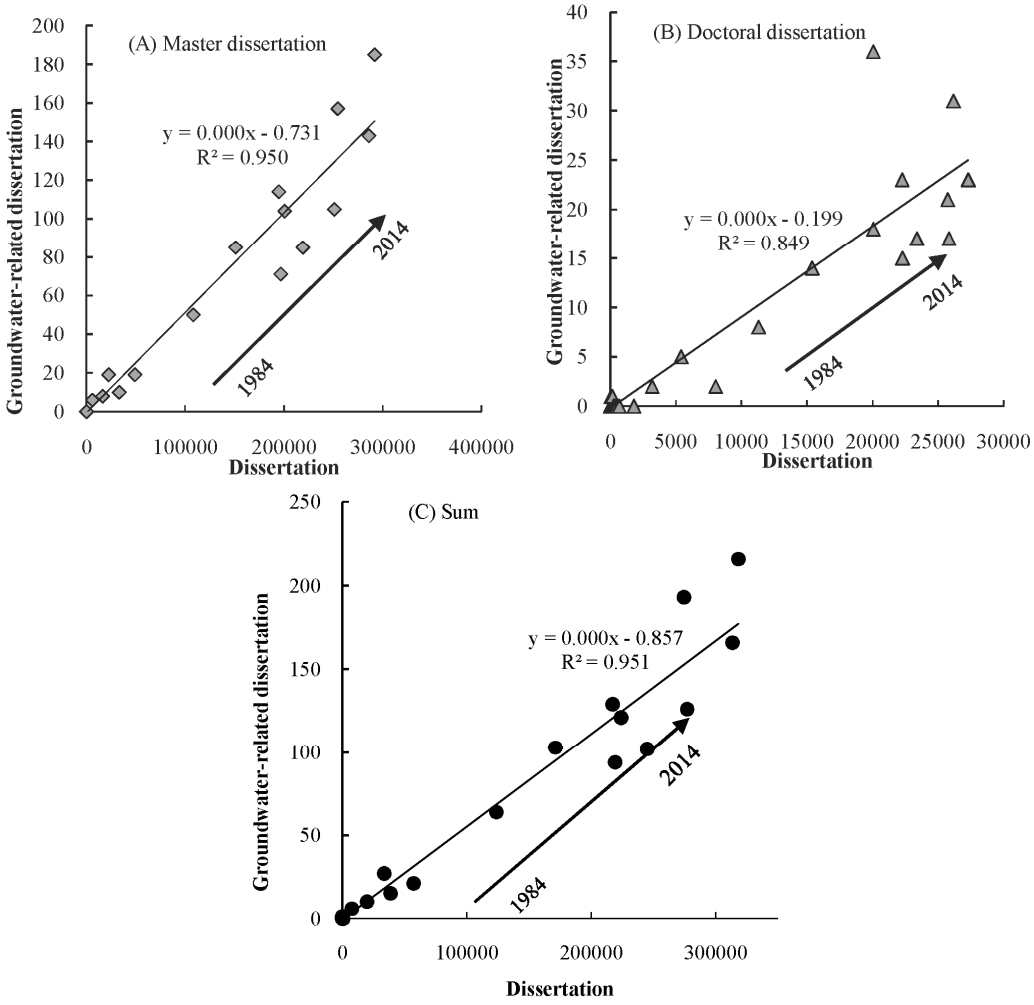

Fig. 4 Relationships between dissertations and groundwater-related dissertations for the study period (1984–2014)

2.2 Institutional distribution

According to the searched results, all the searched dissertations were produced by 128 institutions, 122 (95%) of which were universities/ colleges. Out of these institutions, more than 50% of them (52%) only produced one or two dissertations; more than 20% (23%) produced three to nine dissertations; about 10% produced 12 to 15 dissertations. The 20 most productive institutions produced 16 to 194 dissertations, with China University of Geosciences (Beijing), Jilin University, and Chang'an University being the three most productive institutions (Fig. 5). It can be seen further from Fig. 6 that, the top three productive institutions produced 34% of master dissertations, 50% of doctoral dissertations, and 37% of total dissertations; and the corresponding numbers for the top ten institutions were 54%, 79%, and 57%, respectively. *I.e.*, the majority of dissertations were concentrated in a few institutions, most of which had a relatively long history of groundwater teaching in China, such as China University of Geosciences (Beijing) in Beijing, Jilin University in Changchun, Chang'an University in Xi'an, China University of Geosciences in Wuhan, and so on. Coincidentally, this finding was very similar to the distribution characteristic of groundwater-related scientific projects funded by the National Natural Science Foundation of China (NSFC) in the period of 1997-2013 (ZHAI Yuan-zheng *et al.* 2014); and

was also similar to the distribution characteristic of authors of groundwater-related scientific articles published in Science Citation Index-Expanded (SCIE)-indexed journals in the period of 1993-2012 (NIU Bei-bei *et al.* 2014). This phenomenon clearly indicated the majority of groundwater-related dissertations as well as the majority of groundwater-related scientific projects were concentrated in a few universities/colleges; and these minority were the main forces of groundwater-related teaching and scientific research of China, and generally were also the traditional geological universities/colleges which had outstanding performances on the higher education and research of geosciences.

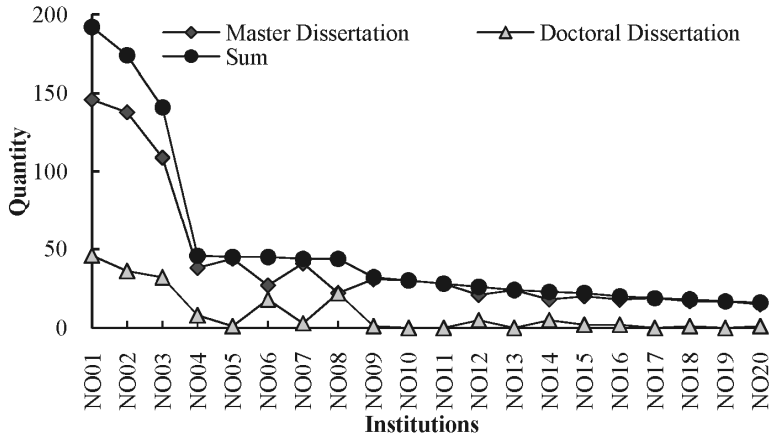

Fig. 5 The 20 most productive institutions and their outputs during the study period (1984-2014)*

*NO01: China University of Geosciences (Beijing); NO02: Jilin University; NO03: Chang'an University; NO04: Hohai University; NO05: Chengdu University of Technology; NO06: Chinese Academy of Geological Sciences; NO07: Southwest University; NO08: China University of Geosciences; NO09: HeFei University of Technology; NO10: Shijiazhuang University of Economics; NO11: Taiyuan University of Technology; NO12: Ocean University of China; NO13: Liaoning Normal University; NO14: Lanzhou University; NO15: Xi'an University of Science and Technology; NO16: Kunming University of Science and Technology; NO17: Xinjiang University; NO18: Anhui University Of Science & Technology; NO19: Henan Polytechnic University; NO20: Northwest University

2.3 Geographic distribution

Based on the institutional distribution of dissertations discussed above, the geographic distribution was presented in Fig. 7, in which the diameter length of the pie represented the output of dissertations relatively. It can be seen that, these institutions were distributed in 53 cities, 29 out of 34 provincial-level administrative regions of China. Out of these cities, Beijing, Xi'an and Changchun were the top three productive cities totally accounting for nearly 50 (48%) of all the dissertations. In these cities, China University of Geosciences (Beijing), Jilin University, and Chang'an University are the three most important contributors, which meanwhile were the top three productive institutions nationwide (Fig. 5). The top ten productive cities were in the order of Beijing, Xi'an, Changchun, Nanjing, Chengdu, Wuhan, Tsingtao, Chongqing, Jinan, Urumqi; and the top ten productive provincial-level administrative regions were in the order of Beijing, Shaanxi, Jilin, Shandong, Jiangsu, Sichuan, Hebei, Liaoning, Anhui, Hubei.

Based on the discussions above, the distribution characteristics can be summarized as

follows: The majority of groundwater-related teaching and scientific research of China were concentrated in a few universities in several cities.

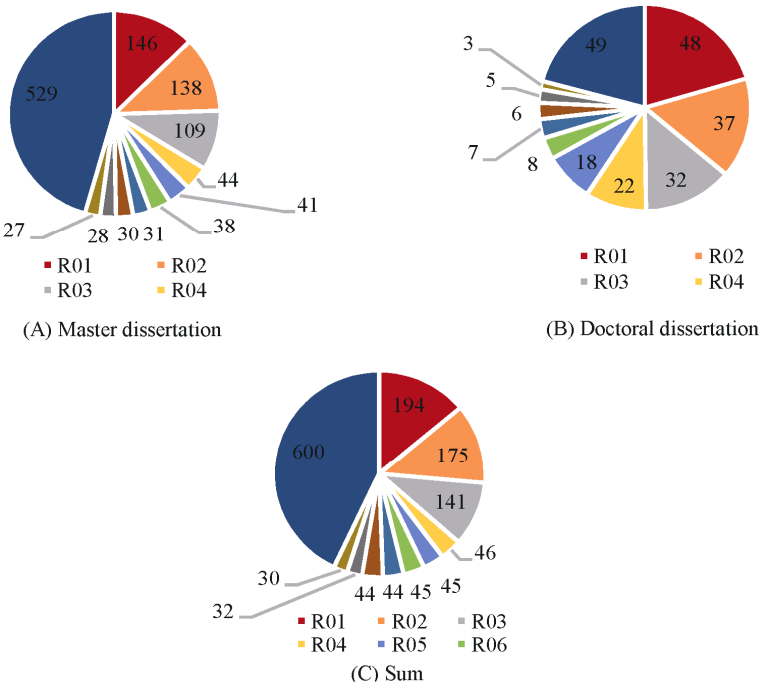

Fig. 6 The 10 most productive institutions and their contribution rates during the study period (1984-2014)*

***A:**

R01: China University of Geosciences (Beijing); R02: Jilin University; R03: Chang'an University; R04: Chengdu University of Technology; R05: Southwest University; R06: Hohai University; R07: Hefei University of Technology; R08: Shijiazhuang University of Economics; R09: Taiyuan University of Technology; R10: Chinese Academy of Geological Sciences

B:

R01: China University of Geosciences (Beijing); R02: Jilin University; R03: Chang'an University; R04: China University of Geosciences; R05: Chinese Academy of Geological Sciences; R06: Hohai University; R07: China University of Mining and Technology; R08: Lanzhou University; R09: Ocean University of China; R10: Southwest University

C:

R01: China University of Geosciences (Beijing); R02: Jilin University; R03: Chang'an University; R04: Hohai University; R05: Chinese Academy of Geological Sciences; R06: Chengdu University of Technology; R07: China University of Geosciences; R08: Southwest University; R09: Hefei University of Technology; R10: Shijiazhuang University of Economics.

2.4 Research directions and hotspots

As an interdisciplinary subject, groundwater science is associated with many subjects. According to NIU Bei-bei *et al.* (2014), the groundwater-related research covered 189 Web of Science categories, and a total of 3 164 different academic journals have published scholarly articles related to groundwater in the period of 1993-2012. The six most common categories were Environmental Sciences, Water Resources, and Multidisciplinary Geosciences, Environmental Engineering, Civil Engineering, and Geochemistry & Geophysics. In the field of bibliometrics and

statistics, keywords are usually used to identify the subjective focus and emphasis specified by authors, explore research hotspots, and discover scientific research trends (XIE Shao-dong *et al.* 2008), because keywords in articles can provide a reasonable description of an article's theme, and could reveal the profile of an author's research preferences (SUN Jin-shui *et al.* 2012). Thus, the research directions and hotspots in this study were mainly based on the keywords assisted by the titles and abstracts of the dissertations. In order to obtain the accurate and impersonal results, we (1) revised the nonstandard terms, (2) merged terms with the same meaning while using different expressions to one, (3) made an Excel information sheet including the publishing year, title, author, affiliation, locational city of the affiliation, abstract, and keywords of dissertations, and (4) downloaded all the dissertation documents with full texts.

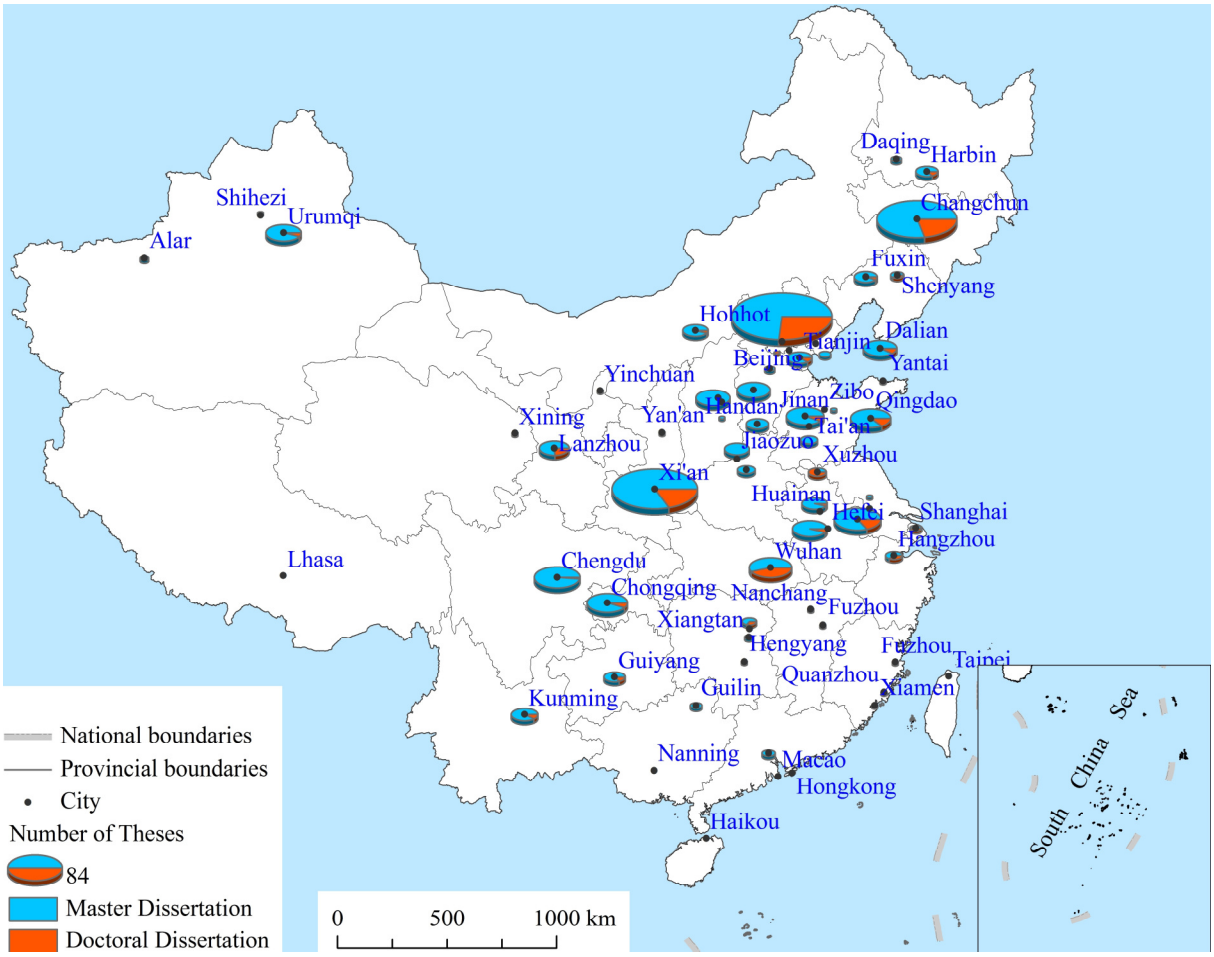

Fig. 7 National geographic distribution of groundwater-related dissertations for the study period (1984-2014)*

*The diameter of the pie represented the output relatively: The more the output, the longer of the diameter.

According to the trimmed results, 64 keywords in total appeared in the keywords lists of the dissertations, all of which were cited no less than five times by both master dissertations and doctoral dissertations. The 40 most frequently used keywords were presented in Fig. 8. The network relationships among these keywords were shown in Fig. 9. It can be seen that, the dissertations

accomplished during the study period generally covered all the international research directions, which further indicated that the scientists in China tracked the international frontier closely during the past decades.

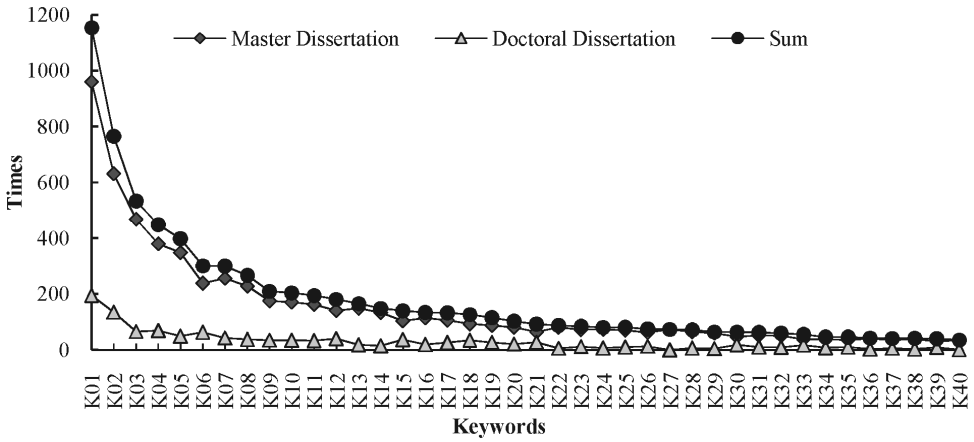

Fig. 8 The 20 most frequently used keywords during the study period (1984-2014)*

*K01: Groundwater; K02: Modeling; K03: Water resource; K04: Exploitation; K05: Water flow; K06: System; K07: Water table; K08: Aquifer; K09: Recharge; K10: Hydrochemistry; K11: Management; K12: Environment; K13: Karst; K14: Water quality; K15: Hydrogeochemistry; K16: Parameter; K17: Permeability coefficient; K18: Isotope; K19: Deep; K20: Shallow; K21: Unsaturated zone; K22: Pumping test; K23: Regime; K24: Water source; K25: Forecast; K26: Pore; K27: PHREEQC; K28: MODFLOW; K29: GIS; K30: Ecology; K31: Pollution; K32: Fracture; K33: Cycle; K34: Solute; K35: Vulnerability; K36: Saline intrusion; K37: Confined groundwater; K38: Unconfined groundwater; K39: Reservoir; K40:Hydrogeologic condition.

With the exception of "groundwater", which reflected the microscopic discipline itself, the three most frequently used keywords were "numerical modeling", "water resource", and "exploitation". It can be seen through this fact that, the direction of groundwater resource and its exploitation attracted the greatest attention in groundwater research, with numerical modeling probably being the most frequently used method. The followed keywords, such as "water flow", "system", "water table", "aquifer", "recharge", "regime", "water source", "cycle", "reservoir", and so on were also directly associated with the resource function of groundwater closely (Fig. 9), the most important one of which were as a vital source of drinking water worldwide especially in arid and rural areas (Eschauzier *et al.* 2013; Von Bromssen, 2014). In the worldwide context, with rivers in critical regions already exploited to capacity and groundwater overdraft as well as large-scale contamination occurring in many areas, we have entered an era in which multiple simultaneous stresses will drive water "management" (Gorelick and ZHENG Chun-miao, 2015). Groundwater resources are taking a more prominent role in providing freshwater supplies. As to China, because the North China Plain, Ordos Basin, and Northwest China were the nation's, even the world's most water-scarce areas (FAN Yu-bing *et al.* 2014), a lot of dissertations devoted to study and resolve the water shortage problem in these areas, including estimating the groundwater recharge and sustainable yield, evaluating the water resources, revealing and forecasting the regime and water table fluctuation of groundwater, and exploring the relationship between the limited groundwater resource and the vulnerable "ecology".

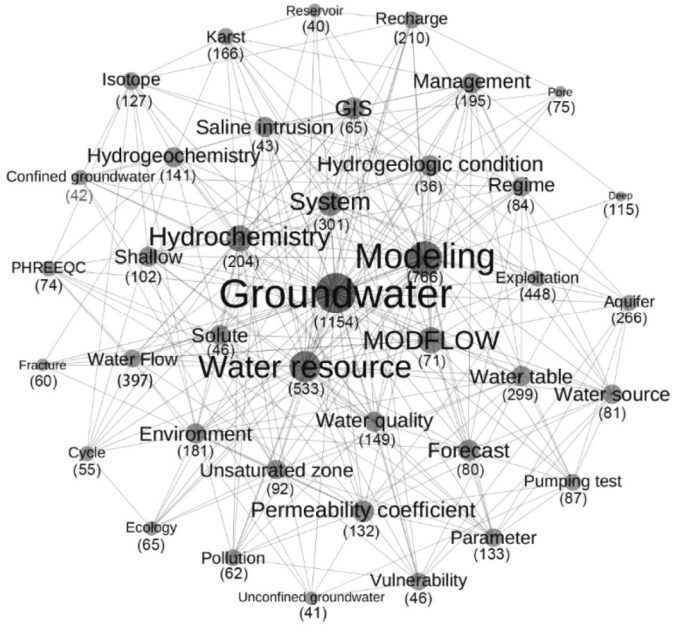

Fig. 9 The network diagram describing the relationships among the frequently used keywords during the study period (1984-2014)*

*The numbers in parentheses under keywords were the total times appeared in the keywords lists of dissertations.

With regard to the numerical modeling tools, the appearances and locations of "PHREEQC", "MODFLOW", "GMS", and "FEFLOW" in the keywords list indicated that they were the four most frequently used softwares, which were already very familiar with hydrogeologists. Numerical modeling is an important means in the groundwater research, especially in "forecast" of groundwater regime under different conditions. With an increasing need to better understand the environmental processes and manage water resources, the future of groundwater numerical modeling is bright and exciting. In China, groundwater numerical modeling has been introduced from abroad and developed rapidly in the past decades, to which about 30% of the groundwater-related scientific projects funded by the NSFC during 1997-2013 were related directly (ZHAI Yuan-zheng *et al*. 2014). The numerical modeling was used to model the mass transport in groundwater, visualize the hydrogeological process, simulate the multiphase flow in stratum, model the integrated simulation of groundwater in the saturated zone and unsaturated zone, model the interaction of surface water and groundwater, and so on. In addition, concern about the uncertainty of the groundwater modeling has aroused in the past years domestic and overseas (WU Ji-chun and ZENG Xian-kui, 2013; SHI Xiao-qing *et al*. 2014; ZHAI Yuan-zheng *et al*. 2014). Generally, numerical modeling was still the most important means used in the groundwater research in China with only a few commercial softwares were used widely.

Some keywords in the list related with groundwater pollution and quality directly, such as "hydrochemistry", "environment", "water quality", "hydrogeochemistry", "pollution", "solute", "vulnerability" and so on. Due to the complexities of the groundwater pollution and quality direction, it's not strange that so many related keywords were found in the list, because the direction involved various topics, such as (1) the mechanisms of groundwater pollution, (2) the control, reduction,

evaluation, remediation and simulation of pollutants' migration in soil and groundwater, (3) the detection of all kinds of emerging contaminants, multiple pollutants, their interactive effects, and their interactions with surrounding media, (4) the study of chemical, biochemical and biogeo-chemical processes in soil and groundwater, (5) their overall influence on human health and the environment, and so on (Committee on Chinese Groundwater Science, 2009). For the groundwater pollutants appeared in the dissertations, heavy metals (such as Mn, Cr, Pb and Cd), As, N, F, petroleum, BTEX, petroleum hydrocarbon, PAHs, DNAPLs (Dense Non-Aqueous Phase Liquids), PPCPs (Pharmaceuticals and Personal Care Products), nitrobenzene, and pesticides were the hot pollutants studied. Out of the studied pollutants, nitrate was the hottest topic during the study period, which was consistent with the scientific projects funded by the NSFC (ZHAI Yuan-zheng *et al.* 2014) as well as the academic articles published in SCIE-indexed journals (NIU Bei-bei *et al.* 2014). This situation was radically attributed to the increasing groundwater nitrate pollution being alarmingly in various parts of the world due to increased usage of nitrogenous fertilizers, changes in land-use patterns, and increased recycling of domestic wastewater (GU Bao-jing *et al.* 2013; Jasper *et al.* 2014). In regard to the remediation technologies, both of ex-situ remediation and in-situ remediation were ever studied, and the latter mainly included PRB (permeable reactive barrier) and aeration technology, and materials used included biology, microorganism, nanoscale zero-valent iron, attapulgite clay and so on. The contaminated bodies include both aquifers (saturated zones) and unsaturated zone.

As tools for gaining basic groundwater information for researching groundwater-related scientific problems, environmental "isotopes" and "Geographic Information System (GIS)" methods were found frequently. Environmental tracing with isotopes as an effective technique in groundwater research has two kinds of effects, tracing the source and the hydrological process of groundwater and subsequently determining the groundwater recharge quantitatively (Bethke and Johnson, 2008; Edmunds, 2009; McCallum *et al.* 2014; Lamontagne *et al.* 2015), and tracing the process of mass transportation of pollutants in groundwater/soil (Sidle, 1998; Cook, 2013). During the study period, the environmental tracers ever been used included ^{2}H, ^{18}O, ^{3}H, ^{36}Cl, ^{18}O of NO_3^-, ^{15}N of NO_3^-, SF_6, CFCs, ^{17}O and ^{18}O of SO_4^{2-}, ^{81}Br, ^{85}Kr, SF_5CF_3, $^{87}Sr/^{86}Sr$, ^{222}Rn, ^{226}Ra, and so on, in inorganic/organic substances in waters in saturated/unsaturated zones. GIS provides unique capabilities (especially for spatial analysis and visualization) in the assessment and management of groundwater resources, contamination, and environmental impacts (Scibek and Allen, 2006; NIU Bei-bei *et al.* 2014).

Unsaturated zone as an essential media of groundwater interacting with the surface environment was also studied, as the topics include soil properties, seepage processes, the movement of contaminants through it, and combined studies of soil water and groundwater. Groundwater vulnerability, termed as the possibility of percolation and diffusion of contaminants from the ground surface into natural water table reservoirs under natural conditions, can be made for geogenic anthropogenic sources of contamination depending on the need and data availability (Brindha and Elango, 2015). Along with the deterioration of groundwater environment, the available ground-water for drinking has become less and less in China during the past decades. Thus, groundwater

vulnerability assessment was essential for groundwater source protection (HUAN Huan *et al.* 2015), and a certain number of dissertations during the study period took it as the study target, the majority of which used the index system method, such as the best known DRASTIC method (Brindha and Elango, 2015) or its modified editions (Kazakis and Voudouris, 2015). Apart from groundwater vulnerability assessment, the index system method was also usually used as a study means for other issues.

3 Conclusions

An evaluation of national groundwater science teaching and research situation of China during 1984-2014 was obtained by statistical analysis of dissertations accomplished during the same period and included in the database of China National Knowledge Infrastructure (CNKI), which covered the time span from 1984 to present and included more than 2.6 million master and doctoral dissertations from hundreds of institutions of Mainland China. The output, geographical, and institutional patterns, as well as research directions and hotspots in groundwater studies were summarized for the study period. A total of 1 396 dissertations including 1 161 master dissertations and 235 doctoral dissertations, contributed by 128 institutions distributed in 53 cities nationwide, were searched out with an obviously sharp increasing characteristic especially during 2000-2014 with time, the shape of which was very similar to that of dissertations included in CNKI. It can be seen obviously that, the groundwater teaching and research in China has experienced a notable growth in the past three decades especially during 2000-2014. Groundwater modeling, resource, and exploitation were the top three major subject categories; and China University of Geosciences (Beijing), Jilin University, and Chang'an University were the top three productive institutions together accounting for more than one third of the total dissertations and 50% of the doctoral dissertations, which further prompted the three locational cities (Beijing, Changchun, and Xi'an) to become the top three productive cities. The dissertations generally covered all the international research directions, which further indicated that hydrogeologists in China have tracked the international frontier closely during the past decades. The keywords analysis revealed that, (1) numerical modeling was still the hottest direction and the most important means with PHREEQC, MODFLOW, GMS, and FEFLOW were the four most active softwares; (2) the directions related groundwater pollution and quality developed rapidly; (3) environmental isotopes and GIS were frequent used tools for hydrogeological condition analysis, and spatial data processing, respectively; and (4) the unsaturated zone as an integral part of generalized aquifers and an essential media attracted more and more attentions from hydrogeologists whose focuses were mainly limited to the saturated zone in the early stage. Based on the work of this paper, we hope that related scientists and managers domestic and abroad can find out the teaching and research profile of groundwater science in China.

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