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Mapping of top papers in the subject category of Water Resources based on the Essential Science Indicators

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Based on the Essential Science Indicators (ESI) database, this study analyzed 798 top papers in the subject category of Water Resources from 2008 to 2018. The 798 top papers include 797 highly cited papers and 21 hot papers in the field. Distributions of document type, language of publication, scientific output, and publication of journals are reported in this article. Co-authorship network visualization of author, organizations and countries, co-occurrence network visualization of all keywords was visualized using VOS viewer software. Results showed that 798 papers, all written in English, were from 2,845 authors, 80 countries/territories and 1,107 organizations, listed in 49 journals in the field of water resources. Top 5 core journals with higher impact factor ranked as *Water Research*, *Journal of Hydrology*, *Desalination*, *Catena* and *Advances in Water Resources*. Top 5 countries and regions were USA, China, Australia, England and Germany. Top 5 organizations were Chinese Academy of Sciences, University of California System, Helmholtz Association, Delft University of Technology and Eth Zurich. Based on the analysis of network map of VOSviewer, there is cooperation for authors, organizations and countries or regions. The analysis of keywords showed that the research of water resource was separated 6 clusters. This study demonstrates that there are more top papers come from journals with the higher IF and higher rank in Category of Water Resources. Therefore, authors can choose their ideal Journal with a high impact factor to publish papers in the English language related to this research field.

Keywords: Bibliometric analysis; Essential Science Indicators; Top papers; VOSviewer; Water Resources.

Introduction

Water is essential for life as it provides drinking water and food for humans and animals. Among the existing natural resources on Earth's surface, water is the most extensive as it covers more than 70% of the Earth[1]. With the water pressures brought by population growth and climate change, nearly 80% of the world's population is currently exposed to high levels of threat to water security[2]. The security of water resource is an important factor for human socio-economic sustainable development.

According to category description for Water Resources in the Scope Notes of Science Citation Index Expanded (SCIE), Water Resources covers resources concerning a number of water-related topics. These include desalination, ground water monitoring and remediation, hydrology, irrigation and drainage science and technology, water quality, hydraulic engineering, ocean and coastal management, river research and management, waterways and ports. In the subject category of water resources, research articles that are listed in the ESI undoubtedly are of important significance.

Bibliometric analysis is a method assessing the status and trends of a particular research field and thus providing ideas and directions for future research. Bibliometrics technique has been adopted in various water research such as river water quality[3], global drinking water research output during 1992–2011 period[4], lead in drinking water field from 1991 to 2007 period[5], research on arsenic in drinking water during the 1992–2012 period[6], drinking water research in Africa[7], pharmaceutical wastewater treatment[8], soil and water conservation in the Loess Tableland-Gully Region of China[9], water security research[10], advances in water use efficiency in agriculture[11], sustainable water use in agriculture[12], desalination research[13], water footprint research[14], wastewater irrigation[15], ecohydrology in lakes and reservoirs[16], integrated water assessment and modelling[17], Nanomaterials for treating emerging contaminants in water by adsorption and photocatalysis[18], interbasin water transfers[19], water research based on MODIS images[1], scientific coverage in water governance[20], sustainable water resources management[21].

Top papers are the sum of hot papers and highly cited papers, based on Clarivate Analytics' ESI. Highly cited paper is a paper that belongs to the top

1% of papers in a research field published in a specified year. Hot paper is a paper published in the past two years that received a number of citations in the most recent two-month period that places it in the top 0.1% of papers in the same field. This total discounts duplicates, so that a paper that is both hot and highly cited is counted only once. Zhang Nan et al. (2018) analyzed 2140 highly cited papers during period of 2005-2014 in the field of Economics and Business from 4499 authors, 914 universities, and 64 countries/territories[22]. Highly cited papers serve as a proxy for excellence, Noorhidawati et al. (2017) identify Malaysia's highly-cited papers and explore the characteristics of these papers[23]. To provide an overview of the characteristics of research in China, a bibliometric evaluation of highly cited papers with high-level representation was conducted during the period from 1999 to 2009 based on the Essential Science Indicators (ESI) database[24]. High-impact papers were presented in the subject category of water resources in the essential science indicators database of the institute for scientific information was analysised[25]. Highly Cited Papers in Library and Information Science (LIS): Authors, Institutions, and Network Structures[26].

The purpose of this paper was to use bibliometric methods to analyze ESI papers in the subject category of water resources during 11 years period from 2008 to 2018, hoping to gain a deeper understanding on research status through analyzing their publication year, category, author, affiliations, country, journals, all keywords and other key features. The co-authorship network visualization of author, organizations and countries, and co-occurrence network visualizations of all keywords were done by VOSviewer software.

Data and methodology

This paper is based on two main steps, namely, data collection and preprocessing, which gathers citation datasets from major online database, and bibliometric analysis based on the resulting data.

WoS and Essential Science Indicators (ESI)

Clarivate Analytics's Web of Science (WoS) is the world's leading scientific citation search and analytical information platform. It is used as both a research tool supporting a broad array of scientific tasks across diverse knowledge domains as well as a dataset for large-scale data-intensive studies. Based on Clarivate Analytics, Essential Science Indicators (ESI) is a unique compilation of performance statistics and trends extrapolated from counts of articles published in scholarly journals and the citations to those articles. The Essential Science Indicators database has been updated as of March 14, 2019, to cover an 11 year period, January 1, 2008 – December 31, 2018. Data is updated bi-monthly (six times a year). This is the sixth (and the last) bi-monthly update of 2018.

Data collection and analysis

A multi-level bibliometric information retrieval was performed on the Web of Science (Clarivate Analytics) website. We conducted a search in the Web of Science (WoS) using the following query (Figure 1):

(WC=Water resource) AND (PY2008-2018) and document types (Article OR Review)

Then, the results were refined by top papers including highly cited papers and hot papers. Publications indexed in WoS were included: (1) articles or reviews, (2) published in journals under the

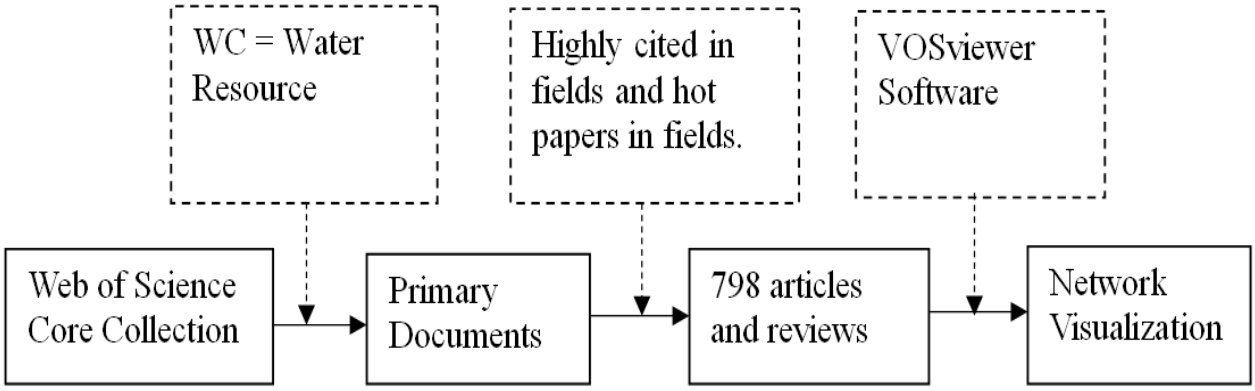

Fig. 1 — A framework of search criteria for Web of Science Category: Water Resource

JCR "water resource" category, and (3) published from 2008 to 2018. Full record and cited references of the included papers were extracted and imported into VOSviewer (Leiden University, Leiden, The Netherlands) for further citation analysis.

The "analyze results" option allows ranking the records by fields according to the record count or the selected field. The following ranks were obtained: document type, language, output, subject category, journal, country, institute, source title, all keywords were all analyzed

VOSviewer

The analysis was completed with networking maps to provide values for international collaboration and the hotspots trends for this field of study. In this work, we used VOSviewer (version 1.6.10, 2019, Leiden University, Leiden, The Netherlands) to show the international collaboration between the authors, organizations, countries and the research trends through all keywords[27]. VOSviewer is widely used for showing maps of global scientific collaboration[28-30], medical big data research[31], Advances in water use efficiency in agriculture and Sustainable Water Use in Agriculture[11,12], global research on biosimilars[32], Bibliometric mapping of microbiology research topics[33], mapping of the world rice research[34]; bibliometric analysis of research on the maize based on top papers during 2009–2019[35]; Bibliometric and mapping of top papers in the subject category of green and sustainable science and technology[36]. In this paper, default parameters values are used. These default parameters values depend on the type of map that is created.

Results and discussion

Document type and language of publication

Based on Clarivate Analytics's WoS Index, the 798 top papers were from The Science Citation Index Expanded (SCIE), 29 papers from Social Science Citation Index (SSCI) and 16 papers from Conference Proceeding Citation Index Science (CPCIS). In the ESI database, papers are defined as regular scientific articles and review articles, of the 798 papers in the ESI database, most of them were articles (619, 77.57%), followed by reviews (179, 22.43%), and papers of proceedings (16, 2.01%). All of these papers were published in English, with none in any other language.

In the 798 top papers, there are 21 hot papers and 797 highly cited paper that means 20 papers are both hot papers and highly cited papers, and one top paper is only hot paper but not the highly cited paper. This total discounts duplicates, so that a paper that is both hot and highly cited is counted only once. Currently, the ESI database is one of the most important tools in the world to evaluate the influence of researchers, universities, academic institutions, and countries.

Publication Output

With the aim of knowing the top paper research trend in water resources, a total number of 798 publications were obtained from the online version of SCIE database between 2008 and 2018. In the following subsections, the term paper refers to both document types selected from WoS (articles and reviews). In general terms, except for analysis based on dates, Figures commonly show information arranged by ranking count and in alphabetical order within the same count value. The publication trend was displayed in the Figure 2. The growth of literature can be fixed to the linear growth (R^2=0.6762). The annual number of publications is increasing over the past 11 years but with some fluctuations. The mean publication was 72.55 each year, and the highest for the articles published is 115 in the year 2018. And, the total citations were power increased from 2008 to 2018 (R^2=0.9969).

Web of Science Categories and Research Areas

Journals and books covered by Web of Science Core Collection are assigned to at least one Web of Science category. Each article indexed by the WoS belongs to one or more subject categories. There are 18 WoS subject categories of the top papers in the subject category of Water Resources in the science edition with total 264 Web of Science subject categories, and 11 research areas. Table 1 shows the research areas and WoS categories in the subject category of Water Resource. Among these, the five top categories include Water Resources (798 papers, 100% of 798 papers), Environmental Sciences (336, 42.105%), Geosciences Multidisciplinary (285, 35.714%), Engineering Environmental (268, 33.584%), and Engineering Civil (190, 23.81%). The top five research areas includes Water Resources (798 papers, 100% of 798 papers), Engineering (512, 64.16%), Environmental Sciences Ecology (339, 42.481%), Geology (285, 35.714%), Agriculture (88, 11.028%). One thing should be noticed that journals or papers may be classified in two or more categories

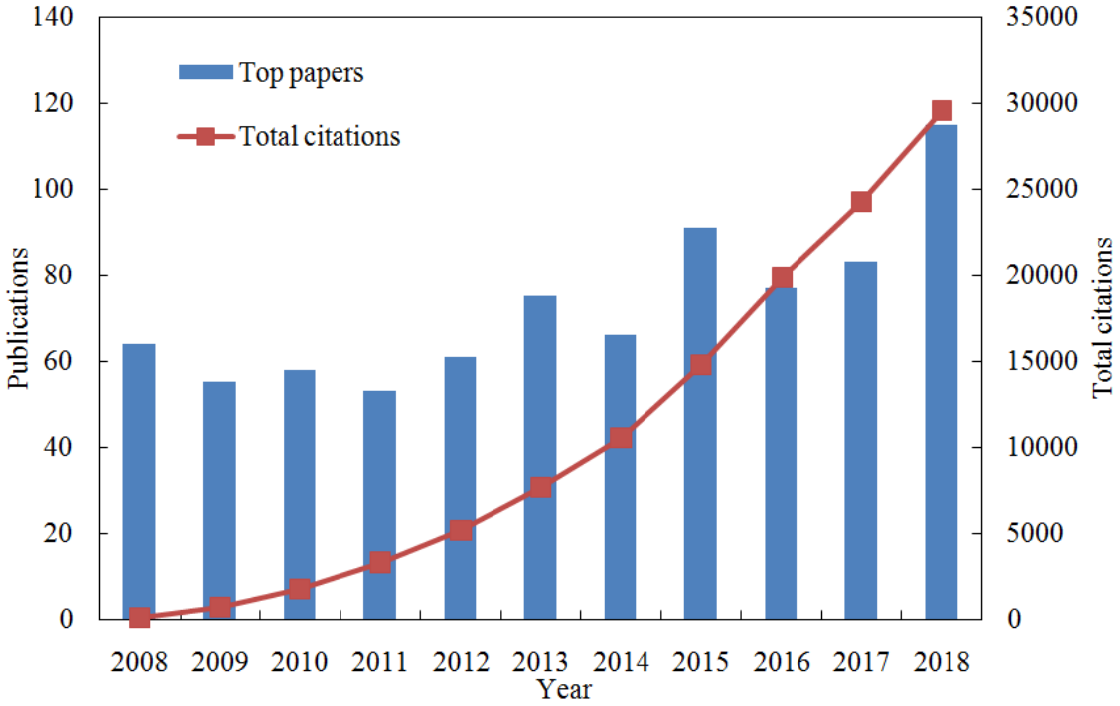

Fig. 2 — Trend number of top papers and total citations for Water Resource per year from 2008 to 2018.

Table 1 — Web of Science categories and research areas for water resources

Rank	WoS Categories	Top paper	% of 798	Research areas	Top paper	% of 798
1	Water Resources	798	100	Water Resources	798	100
2	Environmental Sciences	336	42.105	Engineering	512	64.16
3	Geosciences Multidisciplinary	285	35.714	Environmental Sciences Ecology	339	42.481
4	Engineering Environmental	268	33.584	Geology	285	35.714
5	Engineering Civil	190	23.81	Agriculture	88	11.028
6	Engineering Chemical	65	8.145	Marine Freshwater Biology	42	5.263
7	Soil Science	60	7.519	Meteorology Atmospheric Sciences	24	3.008
8	Limnology	37	4.637	Mathematics	7	0.877
9	Agronomy	28	3.509	Oceanography	3	0.376
10	Meteorology Atmospheric Sciences	24	3.008	Science Technology other Topics	2	0.251
11	Statistics Probability	7	0.877	Toxicology	1	0.125
12	Marine Freshwater Biology	5	0.627			
13	Ecology	3	0.376			
14	Oceanography	3	0.376			
15	Environmental Studies	2	0.251			
16	Green Sustainable Science Technology	2	0.251			
17	Engineering Mechanical	1	0.125			
18	Toxicology	1	0.125			

in the WoS. It also shows the multidisciplinary character of this research field[37].

Core journals

The analysis of journals is also an interesting topic, because it helps find the most possible journals to publish relevant studies. All the 798 publications were published in 49 journals. The top 15 core journals were displayed in the Table 2 with total articles each more than 7 top papers, Journal impact factor as IF2018 and IF5 year, Journal Impact Factor (JIF) Quartile in Category of Water Resources, Rank in

Table 2 — Top 15 Journal indexed using the WoS during period from 2008 to 2018.

Rank	Journal	TP	Ratio of 798(%)	IF2018	IF5year	QC	Rank in Category
1	Water Research	247	30.952	7.913	8.424	Q1	1/91
2	Journal of Hydrology	165	20.677	4.405	4.938	Q1	6/91
3	Desalination	53	6.642	6.035	6.566	Q1	2/91
4	Catena	49	6.14	3.851	4.149	Q1	9/91
5	Advances in Water Resources	42	5.263	3.673	4.49	Q1	10/91
6	Hydrology and Earth System Sciences	38	4.762	4.936	5.615	Q1	3/91
7	Water Resources Research	37	4.637	4.142	4.967	Q1	8/91
8	Agricultural Water Management	24	3.008	3.542	3.834	Q1	12/91
9	Natural Hazards	13	1.629	2.319	2.604	Q2	36/91
10	Vadose Zone Journal	10	1.253	3.634	2.839	Q1	11/91
11	Hydrological Sciences Journal (Journal Des Sciences Hydrologiques)	8	1.003	2.18	2.51	Q2	39/91
12	Water	8	1.003	2.524	2.721	Q2	29/91
13	Desalination and Water Treatment	8	1.003	1.234	1.29	Q3	66/91
14	Stochastic Environmental Research and Risk Assessment	7	0.877	2.807	2.934	Q1	22/91
15	Environmental Earth Sciences	7	0.877	1.871	2.032	Q3	51/91

Category of Water Resources, as the data from the 2018 edition of Journal Citation Reports (published in 2019). These 15 journals have produced 716 (89.726%) literature on the total of 798 top papers, the top 2 Journals and top 5 Journals published about 51.629% and 69.674% of the total of top papers, respectively. *Water Research* was the most productive journal with 247 top papers (30.952%), followed by *Journal of Hydrology* (165, 20.677%), and *Desalination* (53, 6.642%), *Catena* (49, 6.14%) and *Advances in Water Resources* (42, 5.263%), that these journals each published more than 42 papers. These top 5 journals were with higher impact factor and higher Quartile in Category of Water Resources.

Based on Table 2, it can be found there are 91 journals in the category of Water Resources. In the all 49 Journals, there are 22, 17, 8 and 2 Journals ranked in Q1, Q2, Q3 and Q4 quartile in Category of Water Resources, respectively. In the 798 papers, there are 711, 59, 26 and 2 papers ranked in Q1, Q2, Q3 and Q4 quartile in Category of Water Resources, and the ratio are 89.10%, 7.39%, 3.26% and 0.25%, respectively. In the top 15 journals, there are 10 journals, 3 Journals and 2 Journals ranked in Q1, Q2 and Q3 quartile in Category of Water Resources, respectively. Of 716 top papers in the top 15 journals, there are 672 papers in the Q1 quartile in Category of Water Resources, which is 84.211% of the total 798 top papers. It can conclude that there are more top papers come from journals with the higher IF and higher rank in Category of Water Resources. According to this result, authors can choose their ideal journal to publish papers related to this research field. We have also demonstrated the importance of publishing in the English language and in a journal with a high impact factor. Citation analysis is not a measurement of scientific quality, but it is reflective of the importance that a paper has on clinical practice. It can conclude that there are more top papers come from journals with the higher IF and higher rank in Category of Water Resources. It is also a general rule that Higher Impact Factor journal will produce the high impact papers.

Authors co-authorship analysis

Collaborations among researchers, research institutions and countries play a pivotal role in contemporary science. Internationally collaborative articles had the highest visibility and scientific impact followed by inter-institutional collaborative articles, single-country articles and single-author articles, respectively[7]. Collaboration networks are used to show how authors or institutions relate to others in the field of scientific research. The most common kind of collaboration network is co-author network.

The network of authorship in the field of water resources is shown in Figure 3, each circle represents an author, and the circle sizes indicate the number of

published articles. The link connecting two circles stands for the cooperative relation between two authors, and the thickness of the link stands for the intensity of cooperation. Authors with a minimum productivity of 5 publications (default values) were visualized using network visualization map that showed research networking among active authors. Of the 2,845 authors, there were 76 authors meet the thresholds, but 15 authors are not connected to each other. The remaining 61 authors formed 7 clusters (Figure 2). Authors in the same cluster usually suggest that they work in similar fields and had close cooperation with each other.

The largest cluster consisted of seventeen authors (red color). The second cluster consisted of twelve authors (green). The third cluster consisted of nine authors (blue). The fourth cluster consisted of eight researchers (yellow). The fifth cluster consisted of seven researchers (violet). The sixth cluster consisted of five researchers (shallow blue). The seventh cluster consisted of three researchers (orange). The link strength between two nodes refers to the frequency of co-occurrence. It can be used as a quantitative index to depict the relationship between two nodes. The total link strength of a node is the sum of link strengths of this node over all the other nodes. Table 3

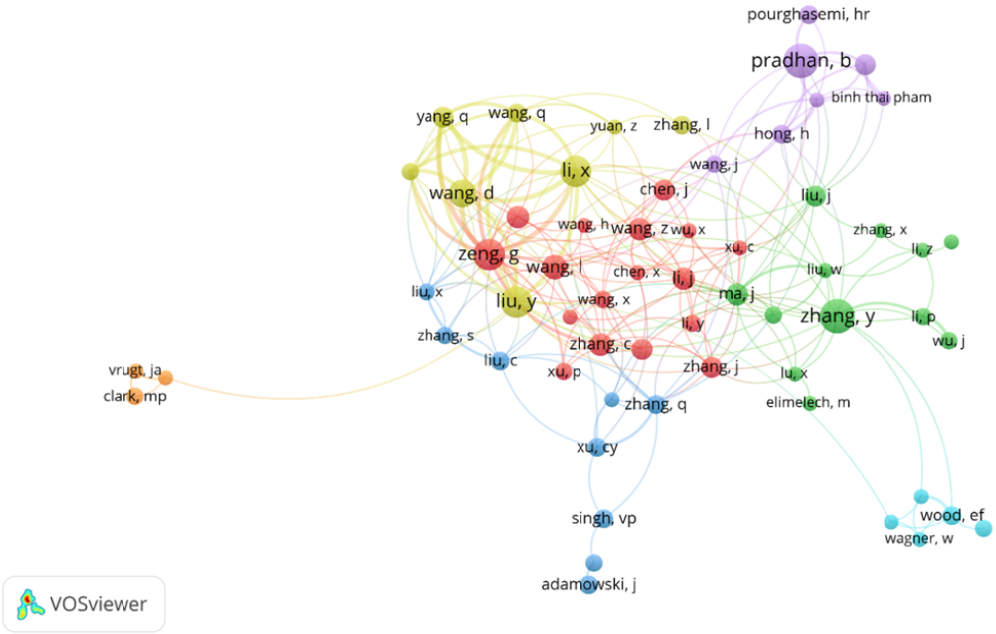

Fig. 3—Network visualization map of top authors in Water Resources from 2008 to 2018. Cooperation based on co-authorship between authors. Network visualization map of authors with minimum productivity of 5 publications in the studied field and exist within a collaborative research group.

Table 3 — The top 12 most prolific authors for Water Resource top papers

Rank	Author	Cluster	Documents	Total link strength	Citations	Avg. citations
1	Zhang, Y	2	16	16	1907	119
2	Pradhan, B	5	16	16	1855	116
3	Zeng, G	1	14	55	1050	75
4	Li, X	4	14	50	897	64
5	Liu, Y	4	14	48	977	70
6	Wang, D	4	12	44	523	44
7	Wang, L	1	10	13	825	83
8	Li, J	1	9	13	811	90
9	Wang, Y	1	9	11	460	51
10	Wang, Z	1	9	7	1095	122
11	Zhang, C	1	9	12	1168	130
12	Ma, J	2	9	18	957	106

show top 12 authors published more than 9 paper, total link strength, citations and average citations. The top 7 author with more than ten papers are Zhang, Y., Pradhan, B., Zeng, G., Li, X., Liu, Y., Wang, D., Wang, L.

Countries/regions co-authorship analysis

The contributions of different countries/territories were estimated by the location of the affiliation of at least one author of the published paper. There are 80 countries contributing the 798 top papers in this study. We developed the international country co-authorship network map using VOSviewer software. In Figure 4, a circle represents a country/region. The size of each circle represents the number of articles of each country, denotes the activity of the country/region. A line is established when two countries/regions have a collaborative relationship. The thickness of each line reflects the tightness of cooperation and the number of collaborations between countries/regions. We set the minimum threshold as 5 (default values), then there are 42 countries/regions of the 80 countries meeting the requirement. The VOSviewer software divides these 42 nodes into 5 clusters. The different colors group, the different clusters formed by sets of countries. One color represents one cluster.

As we can see from Figure 4, USA, China, Australia, England and Germany are the biggest circles. The first cluster consisted of 14 countries and regions (red color), The USA, Peoples Republic of China, Australia, Malaysia, India, Iran, Norway, South Korea, Saudi Arabia, Japan, Singapore, Turkey, Vietnam and Taiwan. The second cluster consisted of 12 countries (green color), England, Germany, Netherlands, Italy, Switzerland, France, Belgium, Denmark, Portugal, Czech Republic, Israel and Cyprus. The third cluster consisted of 9 countries (blue color), Spain, Austria, Sweden, Scotland, Greece, Finland, Brazil, Chile and Romania. The fourth cluster consisted of 5 countries (yellow color),

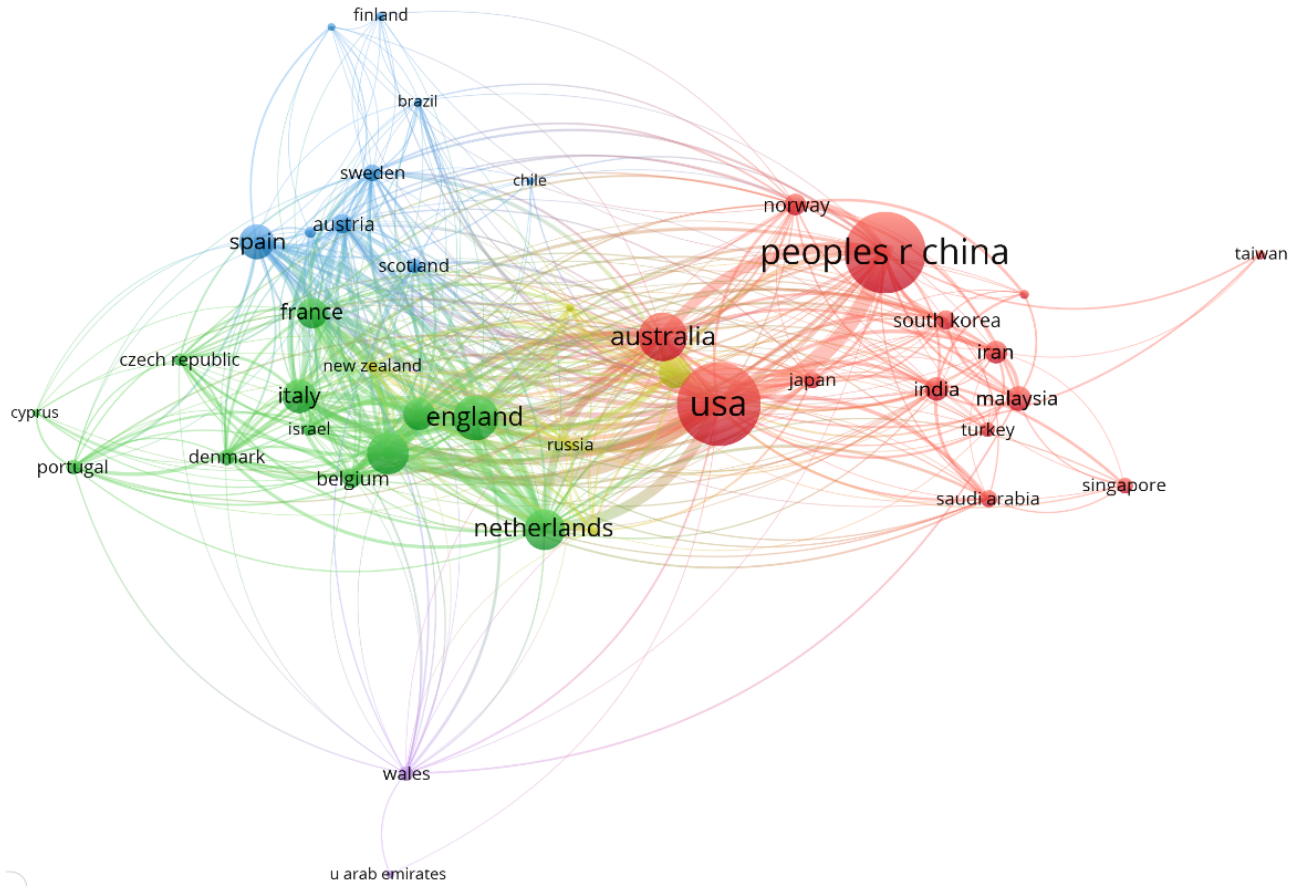

Fig. 4—The country co-authorship network of Water Resources related top papers from 2008 to 2018. The country co-authorship network map with 42 nodes and 5 clusters, the bigger nodes represented the more influential countries in this field. The distance and thickness of links represented the degree of cooperation among countries.

Canada, New Zealand, Poland, Russia and South Africa. The fifth cluster consisted of 2 countries (violet color), Wales and United Arab Emirates. Taiwan, as a region and province of Peoples R China, shows the stronger research ability in the field of Information Science & Library Science.

Figure 4 showed that the United States was not only the research center but also closely cooperated with many countries, such as China, Australia, England, Netherland and Japan. More cooperation could bring more advanced achievements in scientific research. Therefore, geographical location is an important factor that determines international cooperation. Nowadays, increasing international exchanges have promoted academic communications. An increasing number of scholars have chosen to go abroad for further studies and academic visits, especially between the China with USA and Australia[38]. USA is the largest producer of S&T articles in the world and due to its large number of scholarly articles. So, it is apparent and certified that US will have more collaborative partners all over the globe.

There are 80 countries contributing the 798 top papers in this study, and the top 10 and top 15 most productive countries producing 1,032 (129.324%) and 1,208 (151.378%) of all articles 798 (202.504%). Table 4 lists the top 15 countries/regions that the publications were above 27 top papers ranked by the number of total publications, and also list the cluster, total link strength, citations and average citations.

Organizations co-authorship analysis

The contribution of different institutes was estimated by the institute of the affiliation of at least one author of the published papers. Organization co-authorship analysis reflects the degree of communication between institutions as well as the influential institutions in this field[39]. Of the 1,107 organizations, there were 117 organizations meet the thresholds of 5, but 1 organization no connected to each other. The remaining 116 organizations formed 11 clusters with different colors (Figure 5). Each circle represents one organization, the size of each circle represents the number of articles of each organization, denotes the activity of the organization. A line is established when two organizations have a collaborative relationship, the thickness of each line reflects the tightness of cooperation and the number of collaborations between organizations, the closer the circles the closer the collaboration. The top 3 Organizations each published more than 20 papers, Chinese Academy of Sciences is the first organization with 41 publications, followed by Delft University of Technology (25) and Hunan Univ (20). Table 5 lists the top 11 organizations and institutions that the publications were above 14 papers ranked by the number of total publications, and also show the total link strength, citations and average citations.

Keywords co-occurrence analysis

Figure 6 shows the network map that links the keywords to the entire sample of the articles analyzed.

Table 4 — Top 15 countries/regions publishing top papers in the field of Water Resources

Rank	Countries/Regions	Records	Ratio(%) of 798	Cluster	Total link strength	Citations	Avg. citations
1	USA	236	29.574	1	365	41492	176
2	Peoples R China	228	28.571	1	184	24432	107
3	Australia	102	12.782	1	242	16579	163
4	England	90	11.278	2	260	16110	183
5	Germany	79	9.900	2	270	13664	173
6	Netherlands	76	9.524	2	226	12749	168
7	Spain	60	7.519	3	133	9603	160
8	Italy	57	7.143	2	189	8889	156
9	Switzerland	53	6.642	2	174	9190	177
10	Canada	51	6.391	4	134	7998	157
11	France	49	6.14	2	176	8421	172
12	Malaysia	35	4.386	1	47	5807	166
13	India	34	4.261	1	63	4969	146
14	Iran	31	3.885	1	50	3903	126
15	Norway	27	3.383	1	70	2723	101

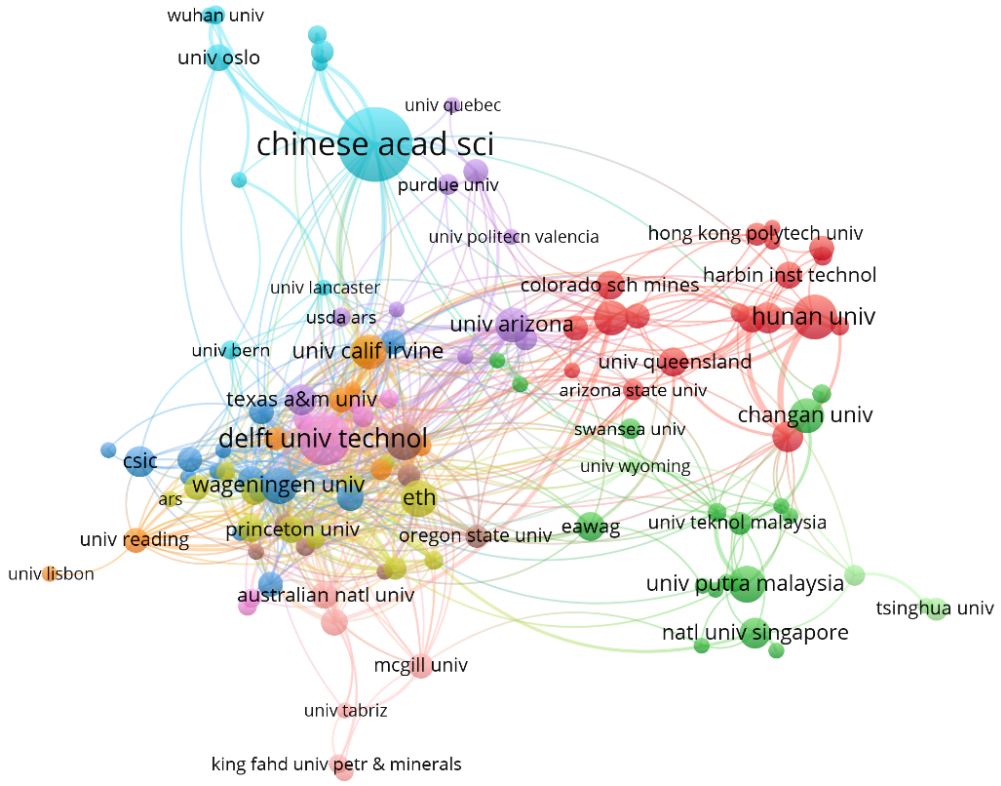

Fig. 5 — The organizations co-authorship network of Water Resource related publications from 2008 to 2018. The institutions co-authorship network map with 116 nodes and 11 clusters, the bigger nodes represented the more influential institution in this field. The distance and thickness of links represented the degree of cooperation among organizations.

Table 5 — Top 11 organizations publishing top papers in the field of water resources

Rank	Organizations	Cluster	Documents	Link strength	Total link strength	Citations	Avg. citations
1	Chinese Acad Sci	6	41	26	40	4020	98.05
2	Delft Univ Technol	9	25	38	57	5625	225.00
3	Hunan Univ	1	20	9	20	1546	77.30
4	Univ Putra Malaysia	2	15	6	9	2211	147.40
5	Wageningen Univ	3	15	28	36	1218	81.20
6	Eth Zurich	4	15	29	39	2570	171.33
7	Natl Ctr Atmospher Res	8	15	42	76	2572	171.47
8	Univ New S Wales	1	14	18	28	2965	211.79
9	Changan Univ	2	14	4	7	549	39.21
10	Univ Arizona	5	14	22	35	3096	221.14
11	Univ Calif Irvine	7	14	20	29	1656	118.29

Keywords were extracted from titles and abstracts of 6,124 studies and then analyzed by VOSviewer software. Keywords appearing more than 5 times were 351 included in the map. For the keywords map, full counting method was used, meaning that each co-occurrence link carried the same weight. The default “association strength method” was used for normalization of the co-occurrence matrix with default values of attraction and repulsion. The size of the circle represents the number of articles in which each keyword appears and the color represents the cluster in which the keyword is included based on the number of co-appearances. In general, the larger size of a circle, the more frequently the key word appears. And a small distance between two terms represent that a large number of co-occurrences of the terms.

After keywords analysis, there are 6 main clusters that represent 6 different viewpoints on water

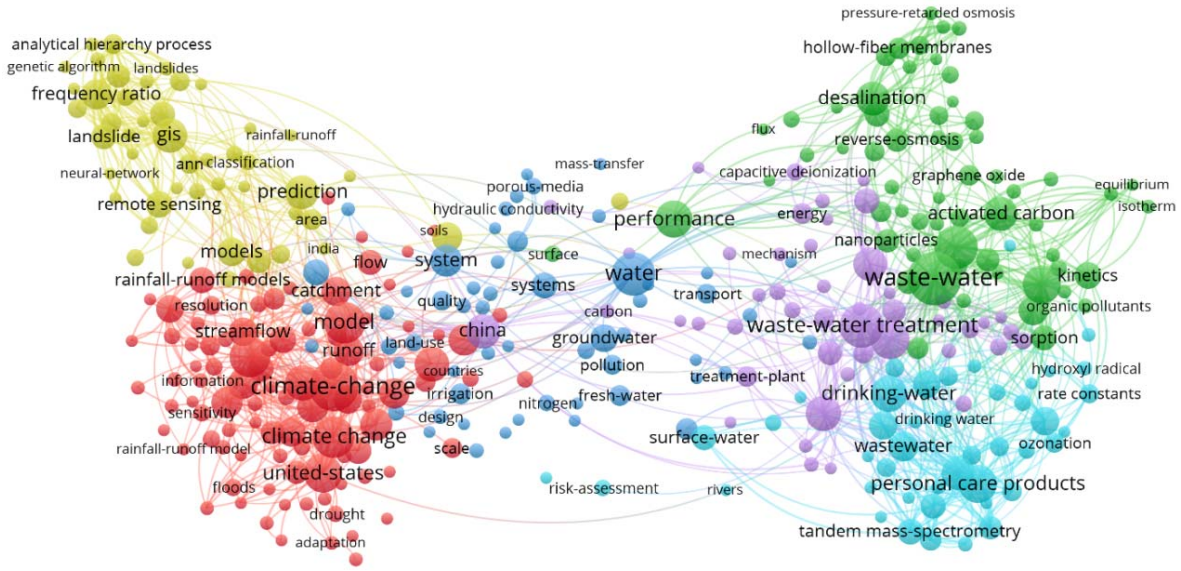

Fig. 6—VOSviewer co-occurrence Network visualization mapping of most frequent all keywords (minimum of 5 occurrences) in Water Resource. Co-occurrence network of all keywords including author keywords and keywords plus.

resources, and also show the relations of the six clusters. VOSviewer co-occurrence network visualization mapping of most frequent all keywords (minimum of 5 occurrences) in water resource shows a shape like a butterfly, the left map including the first and the fourth cluster focused on the climate-change on water resource and water resource prediction, the right map including the second, fifth and sixth clusters represent the waste-water and water treatment, personal care products of water, the map center is third cluster focused on water system which connected the map left and map right.

The first cluster (Red) is focused on climate-change on water resource aspects, including keyword terms as climate change, model, precipitation, United-States, river-basin, management, climate, impact, uncertainty, variability, rainfall, runoff, temperature, catchment, streamflow, soil-moisture, hydrology, calibration, simulation, rainfall-runoff models, et.al.

The second cluster (Green) represents the waste-water and water treatment, keyword terms ranked as waste-water, adsorption, aqueous-solution, performance, desalination, activated carbon, water treatment, kinetics, sorption, seawater desalination, heavy-metals, reverse-osmosis, nanoparticles, aqueous-solutions, and hollow-fiber membranes, escherichia-coli, natural organic-matter, graphene oxide, membrane, forward osmosis, et al.

The third cluster (blue) is focused on water system, including keyword terms as water, system, groundwater, validation, systems, environment, irrigation, fresh-water, carbon-dioxide, transport, quality, pollution, water quality, land-use, resources, porous-media, nitrogen, flows, use efficiency, spatial variability, et al.

The fourth cluster (yellow) represents water resource prediction aspects, keyword terms ranked as GIS, prediction, river, frequency ratio, models, remote sensing, support vector machine, landslide, time-series, logistic-regression, area, support vector machines, artificial neural-networks, Ann, analytical hierarchy process, spatial prediction, reference evapotranspiration, remote-sensing data, Iran, fuzzy-logic, et al.

The fifth cluster (violet) is focused on waste-water treatment, including keyword terms as waste-water treatment, removal, activated-sludge, China, membrane fouling, bacteria, extracellular polymeric, substances, treatment-plant, energy, oxidation, membrane bioreactor, waste activated sludge, sewage-sludge, capacitive deionization, anaerobic digestion, water treatment plants, nitrogen removal, nitrate, methane production, anammox, et al.

The sixth cluster (shallow blue) is focused on personal care products of water, keyword terms ranked as personal care products, drinking-water, pharmaceuticals, wastewater, treatment plants, advanced oxidation processes, degradation, tandem mass-spectrometry, surface-water, solid-phase extraction, aquatic environment, sewage-treatment

plants, ozonation, antibiotics, toxicity, rate constants, fate, emerging contaminants, disinfection by-products, biodegradation, et al.

The most frequently cited papers

The total citation count was obtained from WoS Core Collection, and this shows the total number of times that a particular article was cited by the journals listed in the SCIE database. Although a great many articles have been published, a relatively small number of individuals account for a large proportion of the citations within the period. Table 6 shows the top 10 papers of total citations more than 600 times, six papers are from *Water Research*, two papers are each from *Journal of Hydrology*, one paper is each from *Desalination* and *Water Science and Technology*.

Five most frequently cited articles have been cited more than 966 times since their initial publication to March 22, 2019, the total citations and the average citations per year for five papers were showed in Table 6. The annual citations of the five papers showed a trend to increase during their citation history after the published year that is over the cited half-life about 5-6 years based on JCR 2018. The time dependence of a single paper is called its history. In the beginning year (zero year here), this was lower because all papers appeared in that published year. From Figure 7, it can be found that the citation per year of the papers increased till to 2018, but the increase rate is different.

Table 6 — Top 10 most highly cited papers with citation more than 600 times.

Rank	Title	Authors	Source Title	Publication year	Volume, Pages	Total Citations	Average per Year
1	Recent developments in photocatalytic water treatment technology: A review	Chong, Meng Nan; Jin, Bo; Chow, Christopher W. K.; Saint, Chris	Water Research	2010	44 (10) 2997-3027	2080	208
2	Reverse osmosis desalination: Water sources, technology, and today's challenges	Greenlee, Lauren F.; Lawler, Desmond F.; Freeman, Benny D.; Marrot, Benoit; Moulin, Philippe	Water Research	2009	43(9) 2317-2348	1168	106.18
3	Antimicrobial nanomaterials for water disinfection and microbial control: Potential applications and implications	Li, Qilin; Mahendra, Shaily; Lyon, Delina Y.; Brunet, Lena; Liga, Michael V.; Li, Dong; Alvarez, Pedro J. J.	Water Research	2008	42(18) 4591-4602	1124	93.67
4	A review of drought concepts	Mishra, Ashok K.; Singh, Vijay P.	Journal of Hydrology	2010	391(1-2) 204-216	1026	102.6
5	Recent advances in membrane bioreactors (MBRs): Membrane fouling and membrane material	Meng, Fangang; Chae, So-Ryong; Drews, Anja; Kraume, Matthias; Shin, Hang-Sik; Yang, Fenglin	Water Research	2009	43(6) 1489-1512	966	87.82
6	Application of layered double hydroxides for removal of oxyanions: A review	Goh, Kok-Hui; Lim, Teik-Thye; Dong, Zhili	Water Research	2008	42(6-7) 1343-1368	748	62.33
7	Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling	Gupta, Hoshin V.; Kling, Harald; Yilmaz, Koray K.; Martinez, Guillermo F.	Journal of Hydrology	2009	377(1-2) 80-91	721	65.55
8	Membrane distillation: A comprehensive review	Alkhudhiri, Abdullah; Darwish, Naif; Hilal, Nidal	Desalination	2012	287(S1) 2-18	718	89.75
9	Environmental fate and toxicity of ionic liquids: A review	Thi Phuong Thuy Pham; Cho, Chul-Woong; Yun, Yeoung-Sany	Water Research	2010	44(2) 352-372	713	71.3
10	Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batch assays	Angelidaki, I.; Alves, M.; Bolzonella, D.; Borzacconi, L.; Campos, J. L.; Guwy, A. J.; Kalyuzhnyi, S.; Jenicek, P.; van Lier, J. B.	Water Science and Technology	2009	59(5) 927-934	687	62.45

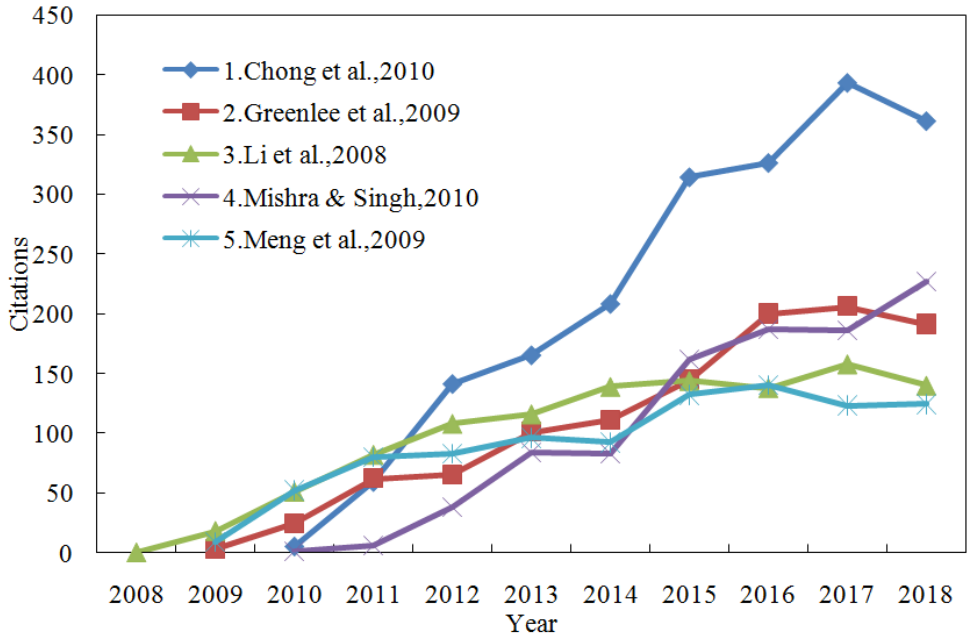

Fig. 7 — Comparison of the citations of the top five papers from their initial publications to March 22, 2019

Conclusions

The 798 top papers include 797 highly cited papers and 21 hot papers in the field. Results showed that 798 papers, all written in English, were from 2,845 authors, 1,107 organizations and 80 countries/territories, listed in 49 journals in the field of water resources. Based on the analysis of network map of VOSviewer, there is cooperation for authors, organizations and countries or regions. The analysis of keywords showed that the research of water resource was separated six clusters. This work would be useful to the researchers to know the trends in water resource research. In addition, this study demonstrates that there are more top papers come from journals with the higher IF and higher rank in Category of Water Resources. Therefore, authors can choose their ideal journal with a high impact factor to publish papers in the English language related to this research field.

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