



## 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<sup>1</sup>. 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<sup>2</sup>. 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<sup>3</sup>, global drinking water research output during 1992–2011 period<sup>4</sup>, lead in drinking water field from 1991 to 2007 period<sup>5</sup>, research on arsenic in drinking water during the 1992–2012 period<sup>6</sup>, drinking water research in Africa<sup>7</sup>, pharmaceutical wastewater treatment<sup>8</sup>, soil and water conservation in the Loess Tableland-Gully Region of China<sup>9</sup>, water security research<sup>10</sup>, advances in water use efficiency in agriculture<sup>11</sup>, sustainable water use in agriculture<sup>12</sup>, desalination research<sup>13</sup>, water footprint research<sup>14</sup>, wastewater irrigation<sup>15</sup>, ecohydrology in lakes and reservoirs<sup>16</sup>, integrated water assessment and modelling<sup>17</sup>, Nanomaterials for treating emerging contaminants in water by adsorption and photocatalysis<sup>18</sup>, interbasin water transfers<sup>19</sup>, water research based on MODIS images<sup>1</sup>, scientific coverage in water governance<sup>20</sup>, sustainable water resources management<sup>21</sup>.

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<sup>22</sup>. 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<sup>23</sup>. 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<sup>24</sup>. 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 analysed<sup>25</sup>. Highly Cited Papers in Library and Information Science (LIS): Authors, Institutions, and Network Structures<sup>26</sup>.

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

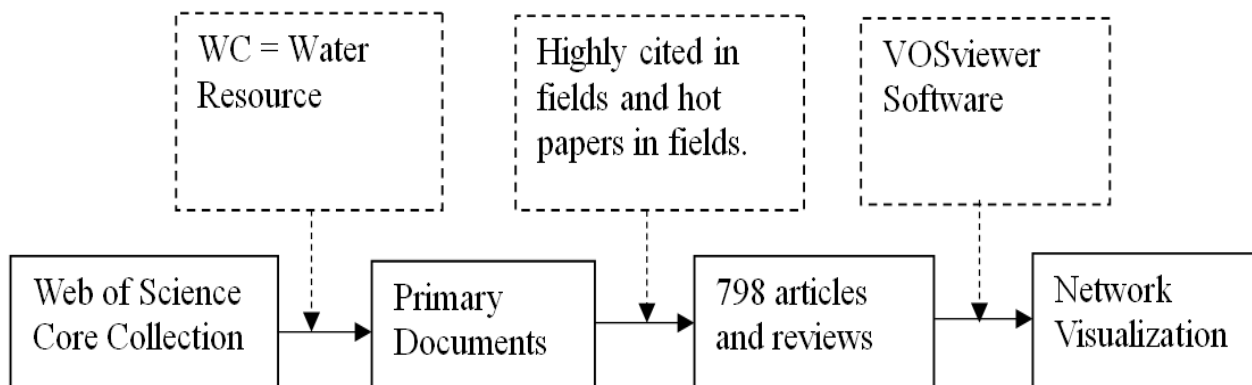


Fig. 1 — A framework of search criteria for Web of Science Category: Water Resource

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<sup>27</sup>. VOSviewer is widely used for showing maps of global scientific collaboration<sup>28-30</sup>, medical big data research<sup>31</sup>, Advances in water use efficiency in agriculture and Sustainable Water Use in Agriculture<sup>11,12</sup>, global research on biosimilars<sup>32</sup>, Bibliometric mapping of microbiology research topics<sup>33</sup>, mapping of the world rice research<sup>34</sup>; bibliometric analysis of research on the maize based on top papers during 2009–2019<sup>35</sup>; Bibliometric and mapping of top papers in the subject category of green and sustainable science and technology<sup>36</sup>. 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

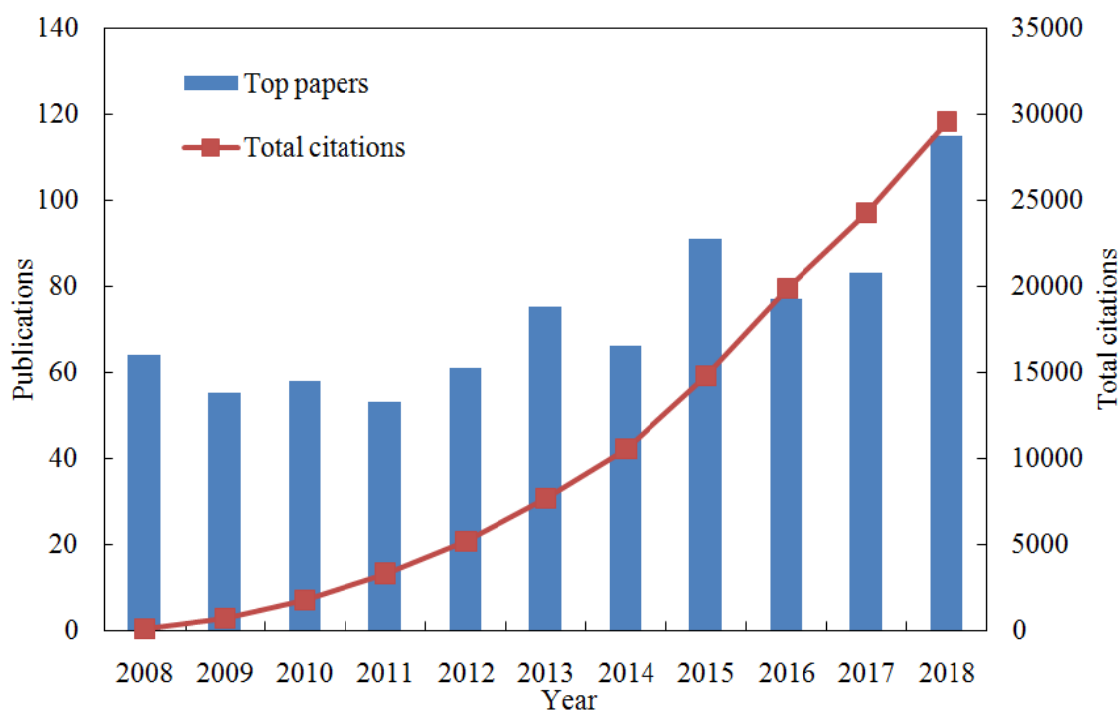


Fig. 2 — Trend number of top papers and total citations for Water Resource per year from 2008 to 2018.

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<sup>37</sup>.

### 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<sup>7</sup>. 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

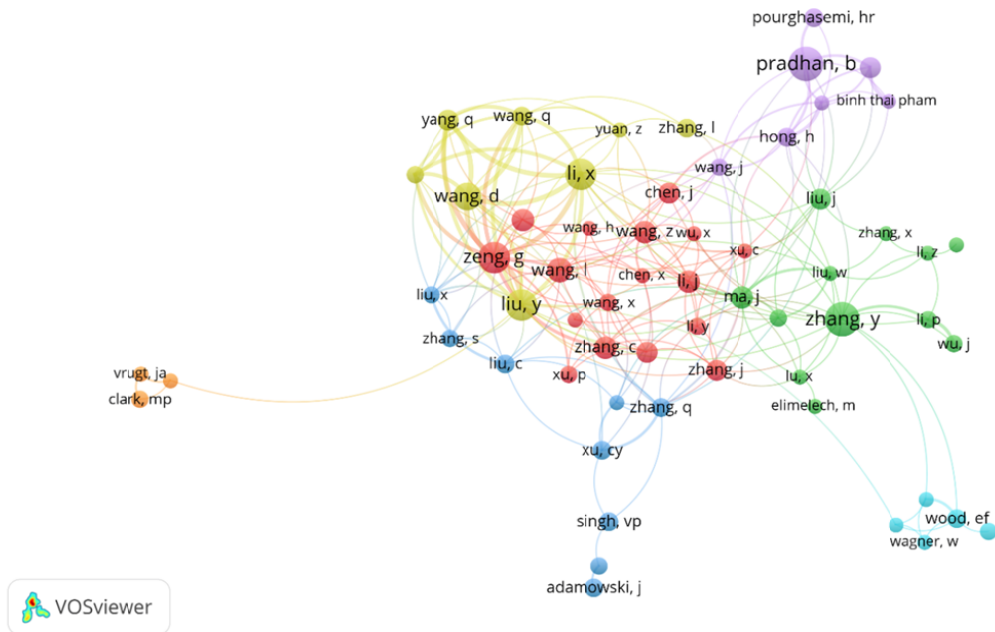


Fig. 3—Network visualization map of top authors in Water Resources from 2008 to 2018. Cooperation based on co-authorship between authors. Network visualization map of authors with minimum productivity of 5 publications in the studied field and exist within a collaborative research group.

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),

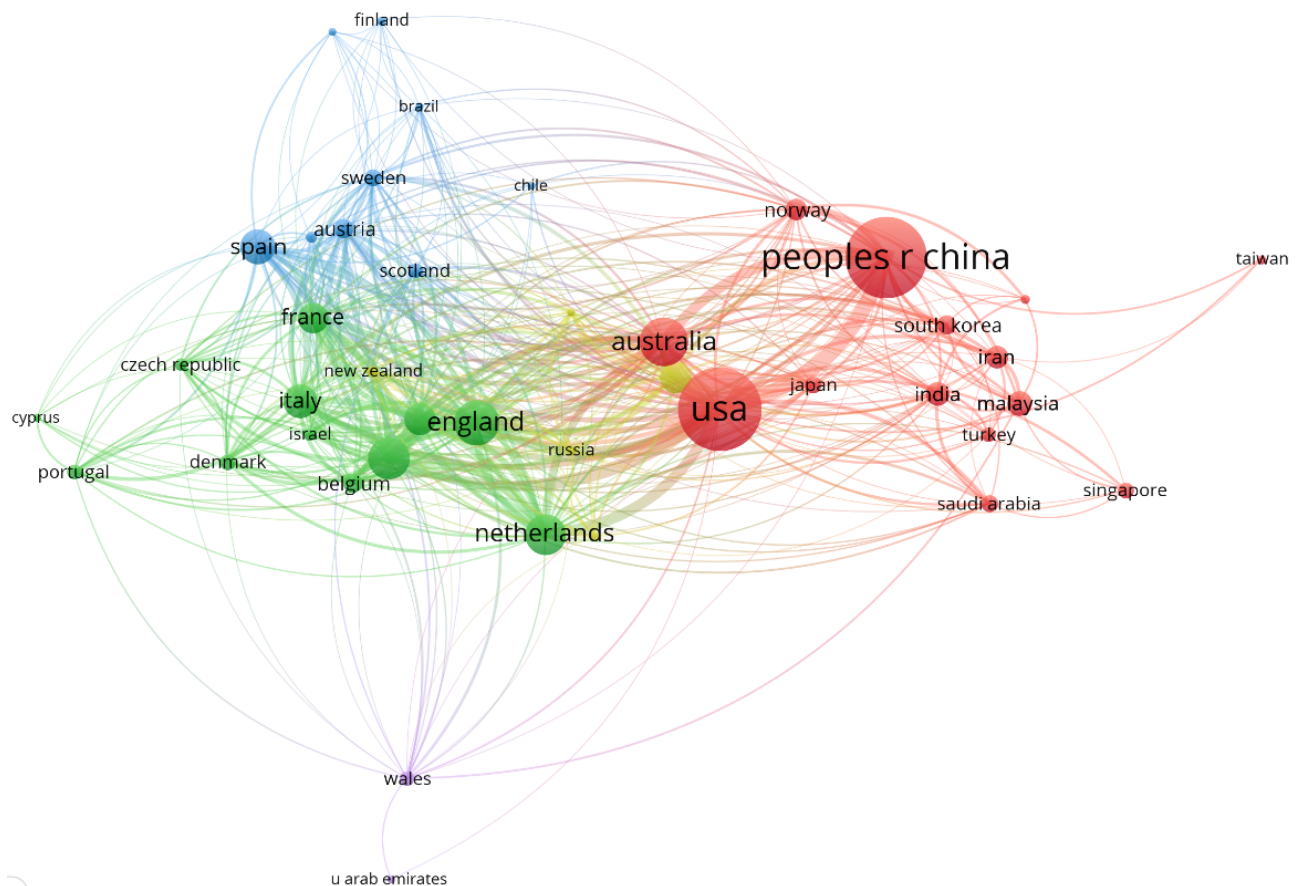


Fig. 4—The country co-authorship network of Water Resources related top papers from 2008 to 2018. The country co-authorship network map with 42 nodes and 5 clusters, the bigger nodes represented the more influential countries in this field. The distance and thickness of links represented the degree of 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<sup>38</sup>. 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<sup>39</sup>. 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            |



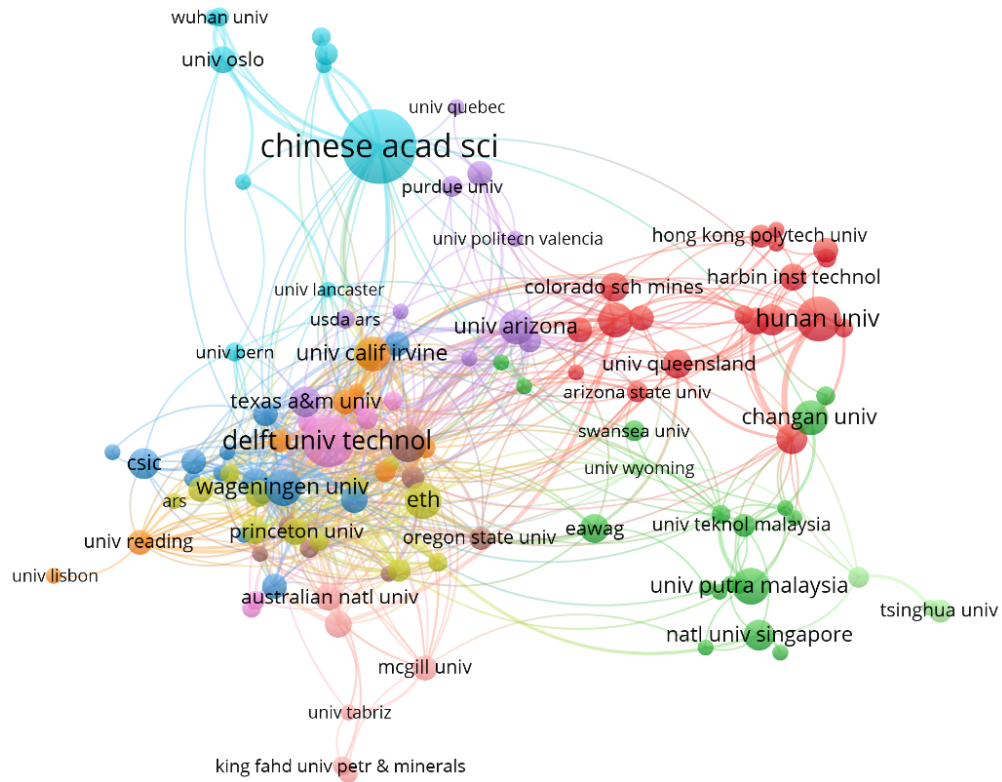


Fig. 5 — The organizations co-authorship network of Water Resource related publications from 2008 to 2018. The institutions co-authorship network map with 116 nodes and 11 clusters, the bigger nodes represented the more influential institution in this field. The distance and thickness of links represented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

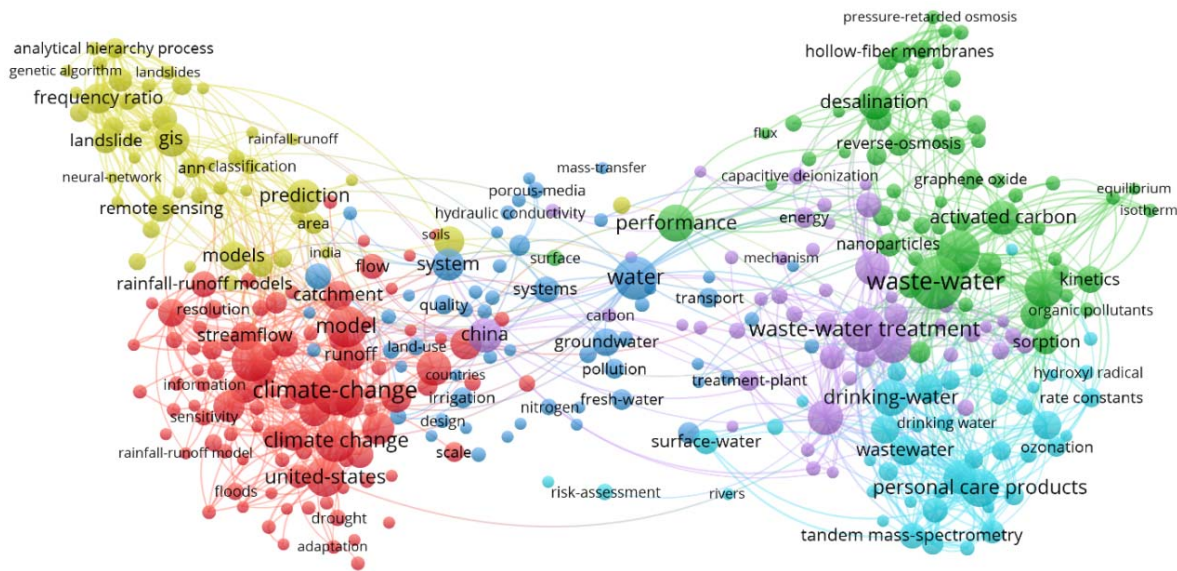


Fig. 6—VOSviewer co-occurrence Network visualization mapping of most frequent all keywords (minimum of 5 occurrences) in Water Resource. Co-occurrence network of all keywords including author keywords and keywords plus.

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)<br>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)<br>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)<br>4591-4602  | 1124            | 93.67            |
| 4    | A review of drought concepts  | Mishra, Ashok K.; Singh, Vijay P.   | Journal of Hydrology         | 2010             | 391(1-2)<br>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)<br>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)<br>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)<br>80-91    | 721             | 65.55            |
| 8    | Membrane distillation: A comprehensive review   | Alkhudhiri, Abdullah; Darwish, Naif; Hilal, Nidal   | Desalination                 | 2012             | 287(S1)<br>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)<br>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)<br>927-934     | 687             | 62.45            |

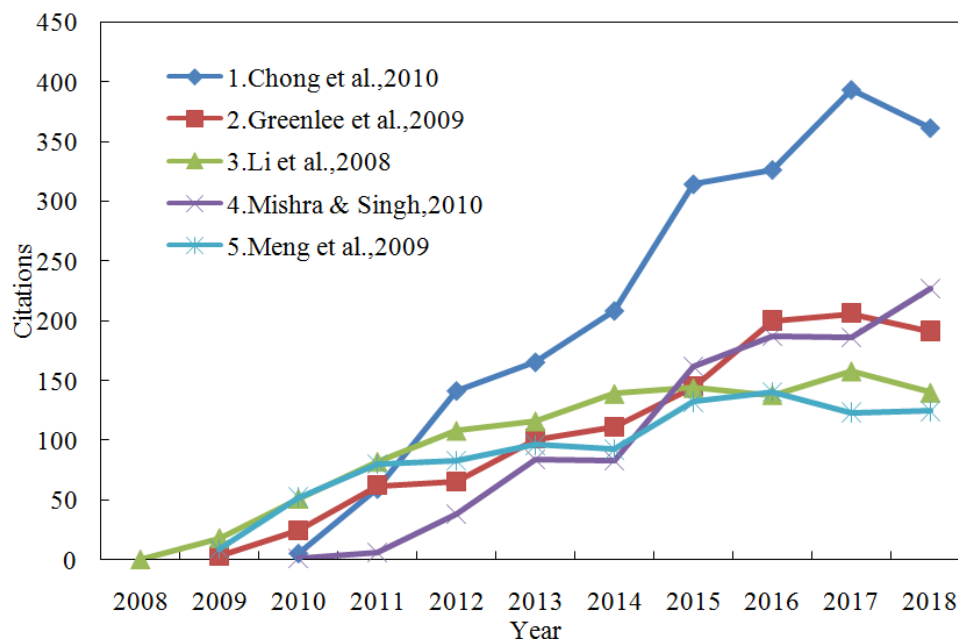


Fig. 7 — Comparison of the citations of the top five papers from their initial publications to March 22, 2019

## 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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