Science of the Total Environment

An International Journal for Scientific Research into the Environment and its Relationship with Humankind

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Mapping of drinking water research: A bibliometric analysis of research output during 1992–2011

Hui-Zhen Fu, Ming-Huang Wang, Yuh-Shan Ho *

Department of Environmental Sciences, Peking University, Beijing 100871, People's Republic of China
Trend Research Centre, Asia University, Taichung 41354, Taiwan

HIGHLIGHTS
► Drinking water research was characterized based on SCI-Expanded during 1992–2011.
► Research emphases were obtained from title, author keywords and KeyWords Plus.
► Ozonation, chlorination and adsorption were common techniques and are getting popular.
► Emerging contaminants concerned arsenic, nitrate, fluoride, lead, and cadmium.

ARTICLE INFO
Article history:
Received 13 September 2012
Received in revised form 15 November 2012
Accepted 16 November 2012
Available online xxxx
Keywords:
Drinking water
Keyword
Global research trend
SCI-Expanded
Scientometrics

ABSTRACT
A bibliometric analysis based on the Science Citation Index Expanded from the Web of Science was carried out to provide insights into research activities and tendencies of the global drinking water from 1992 to 2011. Study emphases included performance of publication covering annual outputs, mainstream journals, Web of Science categories, leading countries, institutions, research tendencies and hotspots. The results indicated that annual output of the related scientific articles increased steadily. Water Research, Environmental Science & Technology, and Journal American Water Works Association were the three most common journals in drinking water research. The USA took a leading position out of 168 countries/territories, followed by Japan and Germany. A summary of the most frequently used keywords obtained from words in paper title analysis, author keyword analysis and KeyWords Plus analysis provided the clues to discover the current research emphases. The mainstream research related to drinking water was water treatment methods and the related contaminants. Disinfection process and consequent disinfection by-products attracted much attention. Ozonation and chlorination in disinfection, and adsorption were common techniques and are getting popular. Commonly researched drinking water contaminants concerned arsenic, nitrate, fluoride, lead, and cadmium, and pharmaceuticals emerged as the frequently studied contaminants in recent years. Disease caused by contaminants strongly promoted the development of related research.

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1. Introduction
Drinking water has long been of concern. In the beginning of the 19th century, the early research in drinking water focused on the contaminants nitrite (Spiegel, 1900), Bacillus coli (Savage, 1902), and toxicogenic germs (Vaughan, 1904). Purification of drinking water by ozone (Thomae, 1900), UV radiation (Sommerfeld, 1910), and chlorine (Ditthorn, 1915) for the removal of these contaminants was also reported. In the 1970s, the occurrence of organohalides in chlorinated drinking waters (Bellar et al., 1974; Rook, 1976) attracted scientists’ attention. A modern parallel of attention on drinking water occurs when sufficient water is available but is so polluted or brackish that its uses are restricted (Sundstrom and Klei, 1979). Since the Industrial Revolution, consequent pollution problems have occurred and steadily increased for a long period of time. Since there has been a tremendous growth in manufacturing and the use of synthetic chemicals from World War II (Manahan, 1991), many of these chemicals, for example, insecticides and herbicides, appeared and accumulated in the environment as run off from agricultural land. For hundreds of years, drinking water related research has become a multidisciplinary field which covers a wide spectrum including studies on environmental sciences (Kolpin et al., 2002; Wang et al., 2010), biochemistry and molecular biology (Bohl et al., 1997), and medicine research (Mackenzie et al., 1994). Today, there are also many problems in drinking water, although the control of environmental pollution has been investigated and legislated on for a long time (Bove et al., 1995; Järup, 2003). In the last decade, the removal of organic contaminants (Kolpin et al., 2002), pharmaceutical (Heberer, 2002), heavy metals (Järup, 2003), and arsenic
(Berg et al., 2001) from drinking water has attracted attention. It is helpful to portray the global trend of the research fields that sustain human life.

Bibliometrics is a useful tool to map the literature around a research field, which has been used in many global studies of specific fields recently (Vergidis et al., 2005; Falagas et al., 2006). It refers to the research methodology employed in library and information sciences, which utilizes quantitative analysis and statistics to describe distribution patterns of articles within a given topic, field, institution, and country. In order to analyze the global trends of research productivity in tropical medicine, the contribution of the different world regions to research and the articles published in the main journals of tropical medicine during the period of 1995–2003 were revealed (Falagas et al., 2006). Statistical methods have been employed to describe the worldwide alcohol-related research from 1992 to 2003 (Rajendram et al., 2006). An assumption is made in these studies that the number of publications of a country in a certain scientific sub-field reflects its commitment to the state of science and is a reasonable indicator for the research and development efforts in that field. However, traditional bibliometric analysis in scientific research fields has many deficiencies: their original data are usually insufficient. Many studies only select several journals or categories to represent global research trends of a topic (Mela and Cimmino, 1998; Klein and Hage, 2006). h-index introduced in 2005 (Hirsch, 2005), now automatically provided by scientific databases, could enrich the contents of the article. The change in the citations or publication counts of countries and organizations cannot completely indicate the development trend or future orientation of the research field (Chiu and Ho, 2007). More information, closer to the research itself, including source title, author keyword, KeyWords Plus, and abstracts (Xie et al., 2008; Li et al., 2009a; Zhang et al., 2010) should be introduced in the study of the research trend.

Drinking water related research during the past 20 years was analyzed to provide a basis for a better understanding of the global research situation, establishing medium and long term strategies of this field. The analyzed aspects covered not only the quantitative description of publications: annual outputs, mainstream journals, Web of Science categories, and leading countries, and institutions, but also the research tendencies and hotspots obtained from the analyses of words in paper title, author keywords, and KeyWords Plus.

2. Methodology

The methodology used in this research was similar to other bibliometric studies (Hsieh et al., 2004; Chiu et al., 2004). Data were obtained from the online version of SCI-Expanded databases of the Web of Science from Thomson Reuters on 11 July, 2012. According to Journal Citation Reports (JCR) of 2011, it indexed 8336 journals with citation references across 176 Web of Science categories in the science edition. “Drinking water” was searched in terms of topic within the publication year limitation from 1992 to 2011. The citations related to drinking water, which stands for “drinking water,” “drinking waters,” “drinkable water,” “drinkable waters,” and “drinking waterborne,” were downloaded. In total, 37,078 publications met the selection criteria. Journal articles were used for further analysis because they represented the majority of document types that also included whole books, articles, proceedings, and book chapters. An overall total of 30,597 original articles (88%) were used for further analysis.

Downloaded information included names of authors, contact address, title, year of publication, author keywords, KeyWords Plus, abstract, Web of Science categories of the article, and names of journals publishing the articles. The records were downloaded into spreadsheet software, and additional coding was manually performed for the number of authors, country of origin of the collaborators, and impact factors of the publishing journals (Chuang et al., 2007). Impact factors (IF) were taken from the JCR published in 2011. h-Index is defined by the h of Np papers having at least h citations each and the other (Np – h) papers have h citations each (Hirsch, 2005). Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Articles from Hong Kong were included under the heading of China. Contributions of different institutions and countries were estimated by the affiliation of at least one author to the publications. Collaboration type was determined by the addresses of the authors (Ho, 2007), where the term “single country article” was assigned if the researchers’ addresses were from the same country. The term “internationally collaborative article” was designated to those articles that were coauthored by researchers from multiple countries. The term “single institution article” was assigned if the researchers’ addresses were from the same institution. The term “inter-institutionally collaborative article” was assigned if authors were from different institutions (Malarvizhi et al., 2010).

3. Performance of publication

3.1. Publication outputs

To obtain an overview of drinking water research, the annual number of articles during 1992–2011 was displayed in Table 1. The number of drinking water publications increased from 701 in 1992 to 3129 in 2011. The most number of authors of a single article was 52, for an article published in Neurology, 1994, which conducted research on the health and aging-risk-factors for Alzheimer’s disease in Canada (McDowell et al., 1994). An increasing number of journals published research papers related with drinking water. The average article lengths fluctuated slightly, with an overall average of 8.6 pages. Twenty-five references were cited per article in 1992, comparing to 39 references per article in 2011, with slight increases throughout the 20 years.

3.2. Web of Science categories and journals

The category of environmental science contributed the most with 8345 articles, followed by water resources, environmental engineering, and toxicology. Environmental sciences held primacy from 1992 to 2011. Since 2006, the number of articles in water resources and environmental engineering grew quickly and ranked 2nd and 3rd in 2011
(Fig. 1). According to the category description in the Web of Science (http://admin-apps.webofknowledge.com/JCR/static_html/scope_notes/SCIENCE/2011/SCOPE_SCI.htm), environmental sciences covers resources concerning many aspects of the study of the environment, among them environmental contamination and toxicology, environmental health, environmental monitoring, environmental geology, and environmental management; environmental engineering includes resources that discuss the effects of human beings on the environment and the development of controls to minimize environmental degradation; and water resources covers resources concerning a number of water-related topics. The three most productive categories have been taking the lead, and are unlikely to be exceeded by other categories in the foreseeable future, which mainly take focus on the environmental problems of drinking water. They were also the categories with the highest growth rate and the most energy in recent years, with many kinds of treatment and protection technologies in these categories used as measures to solve problems (Mackenzie et al., 1994; Hirsch et al., 1999).

In total, 30,597 articles were published in a wide range of 3119 journals. Among these journals, 2550 (82%) journals contained less than 10 articles. Table 2 shows the top 20 productive journals, accounting for approximately 22% of the articles. Water Research published the most articles with 1288 articles (4.2%), while Environmental Science & Technology ranked second with 726 articles (2.4%). The percentage of the top productive journal was not high, which indicates the breadth of article distribution as well as the broad interest in drinking water from various research angles. This phenomenon also appears in other environment related research areas, such as Atmospheric Environment (8.7%) in atmospheric simulation (Li et al., 2009b) and Journal of Geophysical Research—Atmospheres (9.5%) in papers concerning aerosols (Xie et al., 2008). Water Research ranked on top in the category of water resources with an impact factor of 4.865 and an h-index of 64. Water Research was also the most productive journal in biosorption technology for water treatment (Ho, 2008). Environmental Science & Technology ranked third in environmental engineering with the highest impact factor of 5.228, and had the highest h-index of 72. The most commonly cited article was published in the 2nd position journal of Environmental Science & Technology with 2333 citations. It is noticeable that the 4th placer Journal of Hazardous Materials had a high impact factor of 4.173, but showed a relatively low h-index of 31 in drinking water research. The journals with the highest impact factor were CA-A Cancer Journal for Clinicians with one article (IF = 101.78), followed by New England Journal of Medicine with four articles (IF = 53.298), and Lancet with 14 articles (IF = 38.278).

3.3. Country/territory and institution

Domination in publication was not surprisingly from a small number of countries since this pattern has occurred in most scientific fields (Mela et al., 1999). Of 30,381 articles with author addresses, 25,000 (82%) were single country articles and 5381 (18%) were internationally collaborative articles. The geographical global distribution of drinking water research is shown in Fig. 2. There existed a great geographical diversity, covering 168 different countries or territories. According to their production, the 168 countries were divided into five parts. Particularly, 76 countries (45%) belonged to the first part with 1–10 articles; 74 countries (44%) belonged to the second part with 11–500 articles; 12 countries (7.1%) belonged to the third part with 501–1500 articles; five countries (Japan, China, Germany, Canada, and India) belonged to the fourth part with 1501–2500 articles; and only one country (the USA) which totally published 9494 articles, belonged to the fifth part with 2501–10,000 articles.

The top 20 countries, taking 86%, are listed in Table 3 with five indicators: total number of articles, single country articles, internationally collaborative articles, first author articles, and corresponding author articles (Malarvizhi et al., 2010). The percentage of internationally collaborative articles among the total articles for each country C% and h-index were also considered. Three American countries, ten European countries, six Asian countries, and one Oceania country, Australia, were...
ranked in the top 20 of publications. There were no African countries in the top 20. The seven major industrial countries (Canada, France, Germany, Italy, Japan, the UK, and the USA) were ranked in the top 11, whose h-indices were all higher than 50. This comes as no coinci-
dence, since the earliest drinking water research occurred in these
industrial countries and they conducted the earliest and the most rela-
tive research performances. The USA showed the greatest counts of
world publications, and also the highest h-index, followed distantly by
other countries. It also had the most-frequent partners accounting
for 43% of all the internationally collaborative articles. The publica-
tions of China and India ranked in high positions, but had relatively low
h-indices of 53 and 48.

The top 20 institutions were ranked by the number of articles
(Table 4). Among the top 20 institutions, 14 were in the USA, and
one each in Brazil, Canada, China, Spain, Sweden, and Taiwan. Leading
was the Environmental Protection Agency of United States (U.S. EPA)
with 832 articles and the highest h-index, which had a large disparity
with the others, and whose number of articles was more than double
to that of the Chinese Academy of Sciences in China with 350 articles.
The U.S. EPA also published the most independent, collaborative, first
authored, and corresponding authored articles. The result of the insti-
tutions’ output should be interpreted in the context of bias. The Chinese
Academy of Sciences has over 100 branches in different cities. At pres-
tent, the articles of the different branches are pooled under one heading,
and articles divided into branches would result in different rankings
(Li et al., 2009a). In addition, although the Chinese Academy of Sci-
ences and Brazil ranked 2nd and 4th with respect to publication outputs,
their h-indices were 27 and 23 respectively, which are even lower than
that of the University of Texas which holds the 13th position with an
h-index of 32.

4. Research tendencies and hotspots

4.1. Word analysis

The title and the author keywords, provide a reasonably detailed
picture of an article’s theme. The sample size of titles was the most
complete, because every article certainly has its title but does not al-
tways have author keywords and KeyWords Plus. However, the mean-
ing of the single words in titles sometimes does not make sense, and
needs referring to the author keywords for better understanding. KeyWords
Plus can be well understood independently, but they are generated independent of the title or author keywords, having an in-
direct relationship with the article’s content (Garfield, 1990). The syn-
thesized analysis of words in titles, author keywords, and KeyWords
Plus has been developed only in recent years, and has proved to be a
helpful method in revealing the research hotspots and discovering sci-
entific research trends (Chiu and Ho, 2007; Xie et al., 2008; Li et al.,
2009b). Among 30,597 articles, 22,312 articles (73%) had record informa-
tion of author keywords, while 27,829 articles (91%) with KeyWords
Plus information were analyzed. The rankings of these kinds of words
according to their frequency were considered, providing important
clues for the characteristics of hot issues. Then the method of word clus-
ter was employed to identify the trends of research hot issues.

In terms of author keywords, contaminants including arsenic (1138
articles; 5.1%), fluoride (411; 1.8%), nitrate (351; 1.6%), lead (297; 1.3%),
cadmium (274; 1.2%), and pharmaceuticals (143; 0.64%) attracted
much attention in drinking water research. Other than the searching
keyword “drinking water”, the most frequently used author keyword
was “arsenic”, which also ranked 6th in title words. Similarly, “oxidative
stress” which can be caused by chronic exposure to excessive levels
of “arsenic” in drinking water (Flora, 1999) ranked 6th in the author
keyword list and 13th in the KeyWords Plus list. Researchers paid
more attention on oxidative stress that damages cellular health and is
a culprit in the development of many diseases in the last 20 years. “Nitric
oxide” (368; 1.6%) which is closely related to oxidative stress
was also attractive, and ranked 11th in the last 20 years. Much impor-
tance on “lead” in the drinking water field is coincident with the
bibliometric analysis of research on lead by Hu et al. (2010). Also, “fluor-
ide” ranked 9th in author keywords and 23rd in words in title, as one
kind of the popular contaminants causing numerous water quality
problems especially in developing countries (Ayyob and Gupta, 2006; Du-
raiSwami and Patankar, 2011). It is noticeable that no article listed
pharmaceuticals as its author keyword until 1997, but “pharmaceuti-
cals” ranked 50th in the whole study period with respect to author key-
words. Pharmaceuticals was also included in the first nationwide
reconnaissance of the occurrence of contaminants in the most cited article
of drinking water (Kolpin et al., 2002).

Numerous water treatment methods (water treatment and drink-
ing water treatment) (588; 2.6%) have been studied in the past years.

Table 2  The 20 most productive journals with the number of articles, impact factor, h-index, and category of journals in its position.

<table>
<thead>
<tr>
<th>Journal</th>
<th>TP (%)</th>
<th>IF</th>
<th>h-index</th>
<th>Web of Science category (Position)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Research</td>
<td>262 (0.86)</td>
<td>0.935</td>
<td>15</td>
<td>Civil engineering (48/18); water resources (51/78)</td>
</tr>
<tr>
<td>Journal of Chromatography A</td>
<td>261 (0.85)</td>
<td>4.531</td>
<td>41</td>
<td>Biochemical research methods (13/72); analytical chemistry (6/73)</td>
</tr>
<tr>
<td>Environmental Science &amp; Technology</td>
<td>239 (0.78)</td>
<td>1.4</td>
<td>15</td>
<td>Environmental sciences (118/205)</td>
</tr>
<tr>
<td>Desalination</td>
<td>234 (0.76)</td>
<td>2.59</td>
<td>23</td>
<td>Chemical engineering (23/131); water resources (5/78)</td>
</tr>
<tr>
<td>Toxicology and Applied Pharmacology</td>
<td>217 (0.71)</td>
<td>4.447</td>
<td>36</td>
<td>Pharmacology &amp; pharmacy (32/261); toxicology (10/83)</td>
</tr>
<tr>
<td>Journal of Water and Health</td>
<td>206 (0.67)</td>
<td>1.367</td>
<td>12</td>
<td>Environmental sciences (120/205); microbiology (85/112)</td>
</tr>
<tr>
<td>Toxicology</td>
<td>197 (0.64)</td>
<td>3.681</td>
<td>51</td>
<td>Pharmacology &amp; pharmacy (52/261); toxicology (16/83)</td>
</tr>
<tr>
<td>Water Science and Technology</td>
<td>194 (0.63)</td>
<td>1.122</td>
<td>9</td>
<td>Environmental engineering (33/45); environmental sciences (136/205); water resources (36/78)</td>
</tr>
<tr>
<td>Environmental Health Perspectives</td>
<td>188 (0.61)</td>
<td>1.151</td>
<td>21</td>
<td>Environmental engineering (32/45); environmental sciences (134/205)</td>
</tr>
<tr>
<td>Environmental Monitoring and Assessment</td>
<td>187 (0.61)</td>
<td>4.652</td>
<td>32</td>
<td>Toxicology (9/83)</td>
</tr>
<tr>
<td>Carcinogenesis</td>
<td>180 (0.59)</td>
<td>5.702</td>
<td>44</td>
<td>Oncology (23/194)</td>
</tr>
<tr>
<td>Fluoride</td>
<td>174 (0.57)</td>
<td>0.824</td>
<td>19</td>
<td>Environmental &amp; occupational health public (127/157); toxicology (77/83)</td>
</tr>
</tbody>
</table>

TP: total articles; %: the percentage of articles of journals in total articles.
With respect to author keywords, “disinfection” (295; 1.3%), one typical unit during drinking water treatment processes, played an important role to protect human health (von Gunten, 2003; Duraiswami and Patankar, 2011), and therefore disinfection by-products (Richardson, 2003) were widely concern. “Ozone” (359; 1.6%), as an excellent disinfectant, was able to inactivate even more resistant pathogenic microorganisms (von Gunten, 2003). Because of its effectiveness in purifying and conditioning water, many municipal water companies have usually used ozonation technology to treat large quantities of water (Huber et al., 2005). Chlorination (251; 1.1%), another primary technique in traditional disinfection processes, also attracted much attention. Similarly, much concern was attracted by trihalomethanes (268; 1.2%), the toxic and cancerigenic products of chlorination in recent periods.

“Adsorption” (421; 1.9%) stood in the 8th position in both author keywords and KeyWords Plus. Adsorption was the most popular technique and is becoming a more popular topic in drinking water research. Moreover, the 6th “rat”, 14th “rats”, and 25th “mice” in author keywords, 3rd “rats”, 7th “mice”, and 9th “rat”, in words in title, and 6th “mice”, and 7th “rats” in KeyWords Plus indicated that rats and mice are usually used to determine the possible association between the toxic or life threatening concentration of contamination and human health (Komulainen et al., 1997; Heydarpour et al., 2008), indicating that human health was always the mainstream issue in drinking water research.

4.2. Hot issues

Word cluster analysis method which can overcome the weak points of the separated types of keyword analysis was employed to help identify the research issues (Mao et al., 2010). After the synthetic analysis of the three keywords, some valuable clues of the possible research hotspots related to treatment methods and contaminants could be obtained. Firstly, article titles, author keywords, KeyWords Plus and

Table 3

The top 20 most productive countries/territories.

<table>
<thead>
<tr>
<th>Country</th>
<th>TP</th>
<th>h-index</th>
<th>TP R (%)</th>
<th>SP R (%)</th>
<th>CP R (%)</th>
<th>FP R (%)</th>
<th>RP R (%)</th>
<th>C%</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>9494</td>
<td>137</td>
<td>1 (31)</td>
<td>1 (29)</td>
<td>1 (43)</td>
<td>1 (28)</td>
<td>1 (27)</td>
<td>24</td>
</tr>
<tr>
<td>Japan</td>
<td>2151</td>
<td>75</td>
<td>2 (7.1)</td>
<td>2 (6.6)</td>
<td>7 (9.4)</td>
<td>2 (6.3)</td>
<td>2 (6.2)</td>
<td>23</td>
</tr>
<tr>
<td>China</td>
<td>1992</td>
<td>53</td>
<td>3 (6.6)</td>
<td>3 (5.7)</td>
<td>4 (10)</td>
<td>3 (5.6)</td>
<td>3 (5.8)</td>
<td>28</td>
</tr>
<tr>
<td>Germany</td>
<td>1710</td>
<td>71</td>
<td>4 (5.6)</td>
<td>6 (4.2)</td>
<td>3 (12)</td>
<td>6 (4.3)</td>
<td>6 (4.3)</td>
<td>39</td>
</tr>
<tr>
<td>Canada</td>
<td>1668</td>
<td>71</td>
<td>5 (5.5)</td>
<td>5 (4.5)</td>
<td>5 (10)</td>
<td>5 (4.5)</td>
<td>5 (4.3)</td>
<td>33</td>
</tr>
<tr>
<td>India</td>
<td>1511</td>
<td>48</td>
<td>6 (5.0)</td>
<td>4 (5.0)</td>
<td>11 (5.0)</td>
<td>4 (4.5)</td>
<td>4 (4.5)</td>
<td>18</td>
</tr>
<tr>
<td>UK</td>
<td>1430</td>
<td>67</td>
<td>7 (4.7)</td>
<td>8 (3.0)</td>
<td>2 (11)</td>
<td>8 (3.5)</td>
<td>8 (3.4)</td>
<td>47</td>
</tr>
<tr>
<td>Spain</td>
<td>1288</td>
<td>56</td>
<td>8 (4.2)</td>
<td>7 (3.7)</td>
<td>8 (6.7)</td>
<td>7 (3.7)</td>
<td>7 (3.6)</td>
<td>28</td>
</tr>
<tr>
<td>France</td>
<td>1216</td>
<td>58</td>
<td>9 (4.0)</td>
<td>9 (2.8)</td>
<td>6 (9.4)</td>
<td>9 (3.0)</td>
<td>9 (2.9)</td>
<td>42</td>
</tr>
<tr>
<td>Australia</td>
<td>901</td>
<td>53</td>
<td>10 (3.0)</td>
<td>12 (2.3)</td>
<td>9 (5.9)</td>
<td>11 (2.4)</td>
<td>11 (2.4)</td>
<td>35</td>
</tr>
<tr>
<td>Italy</td>
<td>796</td>
<td>54</td>
<td>11 (2.6)</td>
<td>14 (2.1)</td>
<td>13 (4.9)</td>
<td>13 (2.2)</td>
<td>13 (2.2)</td>
<td>33</td>
</tr>
<tr>
<td>Turkey</td>
<td>784</td>
<td>30</td>
<td>12 (2.6)</td>
<td>10 (2.8)</td>
<td>27 (1.7)</td>
<td>10 (2.5)</td>
<td>10 (2.6)</td>
<td>12</td>
</tr>
<tr>
<td>Brazil</td>
<td>769</td>
<td>35</td>
<td>13 (2.5)</td>
<td>11 (2.3)</td>
<td>17 (3.4)</td>
<td>12 (2.2)</td>
<td>12 (2.3)</td>
<td>24</td>
</tr>
<tr>
<td>Taiwan</td>
<td>646</td>
<td>47</td>
<td>14 (2.1)</td>
<td>13 (2.2)</td>
<td>22 (2.0)</td>
<td>14 (1.9)</td>
<td>14 (2.0)</td>
<td>17</td>
</tr>
<tr>
<td>South Korea</td>
<td>617</td>
<td>42</td>
<td>15 (2.0)</td>
<td>16 (1.6)</td>
<td>16 (4.0)</td>
<td>15 (1.7)</td>
<td>15 (1.8)</td>
<td>35</td>
</tr>
<tr>
<td>Netherlands</td>
<td>571</td>
<td>46</td>
<td>16 (1.9)</td>
<td>17 (1.2)</td>
<td>12 (4.9)</td>
<td>17 (1.4)</td>
<td>17 (1.4)</td>
<td>46</td>
</tr>
<tr>
<td>Poland</td>
<td>555</td>
<td>29</td>
<td>17 (1.8)</td>
<td>15 (1.8)</td>
<td>20 (2.1)</td>
<td>16 (1.6)</td>
<td>16 (1.7)</td>
<td>20</td>
</tr>
<tr>
<td>Sweden</td>
<td>550</td>
<td>51</td>
<td>18 (1.8)</td>
<td>21 (1.0)</td>
<td>10 (5.6)</td>
<td>18 (1.3)</td>
<td>18 (1.3)</td>
<td>55</td>
</tr>
<tr>
<td>Switzerland</td>
<td>486</td>
<td>55</td>
<td>19 (1.6)</td>
<td>22 (0.92)</td>
<td>14 (4.7)</td>
<td>19 (1.1)</td>
<td>19 (1.2)</td>
<td>52</td>
</tr>
<tr>
<td>Finland</td>
<td>375</td>
<td>40</td>
<td>20 (1.2)</td>
<td>19 (1.1)</td>
<td>23 (2.0)</td>
<td>20 (1.0)</td>
<td>22 (1.0)</td>
<td>28</td>
</tr>
</tbody>
</table>

TP: total articles; TP R (%): rank and the percentage of total articles; SP R (%): rank and the percentage of independent articles; CP R (%): rank and the percentage of international collaborative articles; FP R (%): rank and the percentage of first author articles; RP P (%): rank and the percentage of the corresponding authored articles; C%: the percentage of internationally collaborative articles in the total articles of each country/territory.
abstracts were combined as the word base. Second, word cluster, a serious synonymic single word and congeneric phrases, were summed up by researchers using their specialized knowledge, and could represent the possible research hotspots of this field. Each word cluster was composed of several supporting words. For example, the three single words "adsorption", "sorption", and "biosorption" constitute a word cluster for a research focus of adsorption. Then the word cluster can be searched in the combined words' base to abstract the related publications. Finally, by analyzing the number of publications containing these “word clusters”, the overview of the research hotspots could be revealed (Mao et al., 2010). The possible research hotspots of methods and contaminants, the two main aspects in drinking water research, were summed up.

The possible research hotspots of treatment methods of drinking water research were "adsorption", "ozonation", and "chlorination" with the most articles. "Adsorption" (adsorption, sorption, and biosorption), "ozonation" (ozonation and ozone), and "chlorination" (chlorination,

![Fig. 3. Comparison of the trends of adsorption, chlorination, and ozonation in drinking water during 1992–2011.](image-url)
chlorine and chlorine dioxide) were classified respectively. The article number growth trends of the three different treatment methods of drinking water are compared in Fig. 3. Studies on "adsorption" rose rapidly and have taken the lead in recent years. Analysis by Water Research also shows that adsorption could be the most commonly studied technique (Wang et al., 2010). This could not only be attributed to the wide application of adsorption, but could also be partly explained by the feasibility and low cost of the experiments of this technique. Adsorption method has been employed in the treatment of drinking water for more than 40 years. The early studies of adsorption in drinking water in the 1970s mainly concerned the carbon adsorption method on phenylamine pesticides (Elidib and Aly, 1977), and organics (Bottom et al., 1976). Although ozonation and chlorination had a longer history than adsorption in drinking water, adsorption has been more widely studied in the recent two decades. The articles related to chlorination surpassed ozonation since 2001 and increased quickly in the last decade.

Besides, the development of the hotspots of contaminants including arsenic (arsenic, arsenite, and arsenate), nitrate/nitrite (nitrite, denitrification, nitrate, nitric, nitrates, nitrification, and nitrites), fluoride (fluoride, defluoridation, fluoridation, fluorides, and fluorine), lead, and cadmium in drinking water was identified in Fig. 4. All research related to these contaminants rose along with the increase of the total publications. The number of articles with arsenic showed a sharp rise with the highest growth rate from 10 in 1992 to 344 in 2011, enforcing the evidence from word analysis. Arsenic was detected in drinking water in the early 1950s (Anonymous, 1950). The relation between arsenic in drinking water and the risk of skin cancer was examined in the 1980s (Astolfi et al., 1981). In the 1990s, the association between arsenic and liver, lung, bladder and kidney was also identified (Smith et al., 1992; Chen et al., 1992). It was estimated that at 50 μg/L, the lifetime risk of dying from cancer of the liver, lung, kidney, or bladder from drinking 1 L/day of water could be as high as 13 per 1000 persons (Smith et al., 1992). Since the recognition of arsenic’s influence on human health in the 1980s and 1990s, various studies examined exposure to arsenic through groundwater in the USA (Taeger and Pesch, 2004), China (Chen et al., 2005; Liu et al., 2010), Taiwan (Xia and Liu, 2004), Argentina (Hopenhayn-Rich et al., 1998), India (Mazumder et al., 1998; von Ehrenstein et al., 2006), Chile (Yuan et al., 2007), and Bangladesh (Ahsan et al., 2000; Argos et al., 2010). In 2001, the U.S. Environmental Protection Agency (EPA) adopted an As standard of 10 μg/L in drinking water (U.S. EPA, 2001).

The 2nd position holder nitrate held 3219 articles during 1992–2011 and 276 articles in 2011. Cyanosis in infants caused by nitrates in well water has first been investigated in JAMA—Journal of the American Medical Association (Comly, 1945). Two cases of infant methemoglobinemia, also known as blue baby syndrome with blue-gray skin color, in Columbia County during June 1998 and Grant County during April 1999 were associated with water from private wells which contained nitrate-nitrogen (Knobeloch et al., 2000). The relation between nitrate in drinking water and the risk of cancer has also been discussed among scientists for more than 30 years (Jensen, 1982; Powlson et al., 2008). Since the risk of nitrate in drinking water was recognized, more than 3000 articles have been published in the last two decades, only behind the research related to arsenic. In terms of the following frequently studied contaminant, 1375 articles were published on fluoride during 1992–2011, and in 2011 there were 192 related articles. The removal of fluoride in drinking water has been studied since the 1930s (Boruff, 1934). The research related to fluoride in drinking water was mainly conducted in public environmental occupational health (Featherstone, 1999), dentistry oral surgery medicine (Magalhaes et al., 2008), and environmental sciences (Srimurali et al., 1998). Lead increased from 11 articles in 1992 to 117 in 2011, with 1003 articles in total. Lead at a low level of exposure affects the intelligence development of children (Fulton et al., 1987; Chiodo et al., 2004). The research related to lead in drinking water has become a multidisciplinary field with various studies in toxicology (Gurer et al., 1998), environmental

![Fig. 4. Comparison of the trends of arsenic, nitrate, fluoride, lead, and cadmium in drinking water during 1992–2011.](image-url)
sciences (Clement et al., 2000), pharmacology and pharmacy (Bryant, 2004), water resources (Tang et al., 2006), analytical chemistry (Grahek et al., 2006), and neurosciences (Villeda-Hernandez et al., 2001). Following lead, cadmium had 773 articles in 1992–2011, and 86 articles in 2011. In a previous study of lead in drinking water, cadmium was the most popular hotspot, together with lead (Hu et al., 2010). Cadmium exposure could induce itai-itai disease, the most serious disease first found in Japan (Tsuchiya, 1976; Satagur and Moore, 2004). Arsenic, lead, and cadmium, as the toxic environmental heavy metals, were detrimental to health and attracted much attention (Ryan et al., 2000; Järup, 2003).

5. Conclusions

An overview of the research in the drinking water field was presented with the information related to annual publications, categories, journals, institutions, countries, research emphases and tendencies. Drinking water researches increased sharply during 1992–2011. Many studies in the categories of environmental sciences, water resource, environmental engineering, and toxicology have been taken to seek for protection measures of drinking water crisis. Canada, France, Germany, Italy, Japan, the UK, and the USA had high productivity in both independent and internationally collaborative articles, especially the USA. The U.S. Environmental Protection Agency took the leading position of the institutions in total publications. The impact factor is usually used to evaluate a journal’s relative importance, especially when compared to others in the same field (Bena vent et al., 2004). The indicators of first author articles, corresponding author articles, and h-index could provide more characteristics of classical bibliometric indicators, compared to others in the same field. The contaminants including arsenic, nitrate, fluoride, lead, and cadmium are the most common research focuses and are still gaining popularity. In particular, fears about oxidative stress which can be caused by excessive levels of arsenic have arisen dramatically from 1992 to 2011. Pharmaceuticals, as the quickly increasing concern, can be caused by excessive levels of arsenic have arisen dramatically and are not similar with each other in a degree to enforce the results, but also could complement one another to minimize one’s shortage. This method has been proved to be an effective approach for mapping global drinking water research, and could also be adapted in other studies for the characterization of a given research field.

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