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

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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.

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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.

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 runoff 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

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(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 subfield 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 research ideas and results (Ho et al., 2010). Altogether 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

Table 1
Characteristics by year of publication outputs from 1992 to 2011.

Year	TP	AU	AU/TP	PG	PG/TP	NR	NR/TP
1992	701	2600	3.7	5661	8.1	17,182	25
1993	724	2678	3.7	5909	8.2	18,881	26
1994	725	2878	4.0	6032	8.3	20,209	28
1995	836	3329	4.0	6969	8.3	23,720	28
1996	978	3748	3.8	8024	8.2	28,240	29
1997	973	4089	4.2	8109	8.3	27,780	29
1998	1012	4212	4.2	8166	8.1	29,173	29
1999	1130	4634	4.1	9465	8.4	33,150	29
2000	1209	5076	4.2	10,439	8.6	37,498	31
2001	1219	5127	4.2	10,501	8.6	37,467	31
2002	1382	6002	4.3	12,100	8.8	43,178	31
2003	1377	6006	4.4	12,253	8.9	44,872	33
2004	1549	6700	4.3	13,488	8.7	50,939	33
2005	1718	7787	4.5	14,906	8.7	57,682	34
2006	1896	8710	4.6	16,565	8.7	64,527	34
2007	2216	10,316	4.7	19,063	8.6	75,820	34
2008	2368	11,113	4.7	20,280	8.6	80,525	34
2009	2641	12,523	4.7	22,299	8.4	94,085	36
2010	2814	13,452	4.8	24,943	8.9	105,784	38
2011	3129	15,625	5.0	27,731	8.9	121,676	39
Average			4.5		8.6		33

TP: total articles; AU: author number; AU/TP: author number per article; PG: page count; NR: cited reference count; PG/TP: page count per article; NR/TP: cited reference count per article.