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A historical review and bibliometric analysis of research on lead in drinking water field from 1991 to 2007

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ABSTRACT

A bibliometric analysis based on Science Citation Index (SCI) published by Institute of Scientific Information (ISI) was carried out to identify the global research related to lead in drinking water field from 1991 to 2007 and to improve the understanding of research trends in the same period. The results from this analysis indicate that there have been an increasing number of annual publications mainly during two periods: from 1992 to 1997 and from 2004 to 2007. United States produced 37% of all pertinent articles followed by India with 8.0% and Canada with 4.8%. *Science of the Total Environment* published the most articles followed by *Journal American Water Works Association* and *Toxicology*. Summary of the most frequently used keywords are also provided. "Cadmium" was the most popular author keyword in the 17 years. Furthermore based on bibliometric results four research aspects were summarized in this paper and the historical research review was also presented.

1. Introduction

It is well known that lead (Pb), as a kind of heavy metals, is a dangerous and important environmental pollutant. Lead has been used for thousands of years and its poisoning effects have been recognized for several centuries. Lead can cause pathophysiological changes in several organ systems including central nervous, renal, hematopoietic, and immune system (Goyer, 1986; Beliles, 1994). Among these damages, a very important issue is that lead can strongly affect intelligence development of children. Many studies indicated that neurodevelopment (Fulton et al., 1987; Needleman, 1991; Chiodo et al., 2004; Surkan et al., 1993) and cognitive development (Bellinger, 1991; Garavan et al., 2000; Troesken and Geddes, 2003; Fewtrell et al., 2004) of children were adversely affected by low level lead exposure. For example, Canfield et al. found a decrease of 4.6 intelligence quotient (IQ) point corresponding to every 10 μg/dL increase in blood Pb level (Canfield et al., 2003). Lanphear et al. (2000) also found that deficits in cognitive and academic skills associated with lead exposure occurred at blood lead concentrations lower than 5 μg/dL.

The lead sources in daily life are mainly lead paint and dust (Kaplan and Shaull, 1961; Baker et al., 1977), leaded gas (Nriagu and Pacyna, 1988; Nriagu, 1990) and lead in drinking water (Dudi et al., 2005; Triantafyllidou et al., 2007). Among them, lead in drinking water is a very important lead source. In fact, for instance, in USA, the average national contribution of drinking water to blood lead is currently believed to be on the order of 7%–20% (Shannon and Graef, 1989; Guidotti, 2004).

For decades, the research related to lead in drinking water field has become a multidisciplinary field which covers a wide spectrum including studies in environmental sciences (Wasserman et al., 2004), toxicology (Adonaylo and Oteiza, 1999), water resources (Gharaibeh et al., 1998), pharmacology and pharmacy (Cohn et al., 1993), and biochemistry and molecular biology (Sewerynek et al., 1995). Although serious problems with lead pollution of drinking water were largely considered historical, some lead problems still emerged in recent years (Edwards and Dudi, 2004). Therefore, it is urgent to portray the global trend of research on lead in drinking water field in order to sustain human life.

Bibliometrics refers to research methodology employed in library and information sciences, which utilizes quantitative analysis and statistics methods to describe distribution patterns of articles with a given topic (Almind and Ingwersen, 1997), field (Campanario et al., 2006), institute (Moed et al., 1985), or country (Schubert et al., 1989). These methods have been used to investigate research trends of

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specific fields recently (Vergidis et al., 2005; Falagas et al., 2006; Kumari, 2006). In order to analyze global trends of research productivity in tropical medicine, Falagas et al. studied the contribution of different world regions to research published in main journals of tropical medicine during the period of 1995–2003 (Falagas et al., 2006). Rajendram et al. used statistic methods to describe the worldwide alcohol-related research from 1992 to 2003 (Rajendram et al., 2006). An assumption is made in these studies that the research publications of a country in a certain scientific subfield reflects its commitment to the state of science and is a reasonable indicator for research and development efforts in that field. However, traditional bibliometrics analysis in scientific research fields has two universal deficiencies: first, the original data are usually insufficient. Many studies only select several journals or categories to represent global research trends related to a certain topic (Mela and Cimmino, 1998; Klein and Hage, 2006). Second, the change in citations or publication counts of countries and organizations cannot completely indicate the development trend or future orientation of research field (Chiu and Ho, 2007). More information, closely related to research itself, i.e. source title, author keyword, keyword plus, and abstracts have also been introduced in study of research trend (Xie et al., 2008; Li et al., 2009; Zhang et al., in press).

In this study, bibliometric methods were used to quantitatively and qualitatively investigate research trends related to lead in drinking water field. A common research tool utilized by bibliometric practitioners includes the use of Science Citation Index (SCI), a searchable database of publications that is maintained by Institute for Scientific Information (ISI), Philadelphia, USA. Keywords may be inputted to SCI, followed by an evaluation of output to determine the impact of authors, institutes, countries, etc. in a particular discipline. Data is presented regarding the contribution of major regions of the world regarding research productivity, published during a 17-year period in all SCI journals. The results could provide a basis for better understanding the global development of research related to lead in drinking water field. Furthermore, based on bibliometric results, the historical research review was also presented in this study.

2. Data sources and methodology

The data were based on the online version of Science Citation Index (SCI), Web of Science. According to Journal Citation Reports (JCR), it indexes 6426 major journals with citation references across 172 scientific disciplines in 2007. Because before 1991, there is no abstract in articles, in order to use same standard, only articles published in the period beginning 1991 were discussed.

For bibliometric analysis, the online version of SCI was searched with keywords ("drinking water" or "drinking waters" or "drinkable water" or "drinkable waters" or "drinking waterborne" or drinking water or drinking waters) and (lead or Pb or leady or plumbean or plumbum) to compile a bibliography of all articles related to the research on lead in drinking water field. Because "lead" can also be used as a verb besides the meaning of metallic element, the articles were carefully screened to delete those in which "lead" was used as a verb. The final number of articles is 1305. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as from United Kingdom (UK). Besides, the reported impact factor (IF) of each journal was obtained from 2007 JCR. Collaboration type was determined by the addresses of authors, where the term "single country" was assigned if researchers' addresses were from the same country and the term "international collaboration" was designated to those articles which were coauthored by researchers from multiple countries.

All articles referring to the research on lead in drinking water field during the past 17 years (1991–2007) were assessed with the following aspects: document type and language of publications, characteristics of publication outputs during 1991–2007, distribution of output in subject categories and journals, publication outputs of countries and institutes and author keywords analysis.

A historical review was also performed in this research. The historical method proposes that historical phenomena can be rich and complex and a better understanding can be gained by reviewing and investigating the time(s), place(s) and context(s) in which events occur and develop. The historical method was employed in investigating the research development of lead in drinking water field as documented in publications in SCI from 1991 to 2007.

3. Results and discussion

3.1. Bibliometric analysis of research on lead in drinking water field

3.1.1. Document type, publication year and language of publications

The distribution of document types identified by ISI was analyzed. Eight document types were found in total 1305 publications during the 17-year period. Article (1113) was the most frequently used document type comprising 85% of total production, followed by proceedings paper (120; 9.2%), and review (43; 3.3%). The others showing less significance were meeting abstract (9), note (8), news item (6), letter (4), and editorial material (2). Because journal articles represented the majority of document types that were also peer-reviewed within this field, only 1113 original journal articles were used for further analysis as the relevant citable items, while all others were discarded. The distribution of annual publication output is shown in Fig. 1. It is obvious that there was an increasing number of publications mainly during two periods: from 1992 to 1997 and from 2004 to 2007.

Ninety-seven percent of all these journal articles were published in English. Several other languages also appeared, containing German (8; 0.72%), French (6; 0.54%), Japanese (6; 0.54%), Spanish (5; 0.45%), Chinese (3; 0.27%), Czech (2; 0.18%), and one for each of Croatian, Polish, Rumanian, and Russian respectively. Garfield and Welljamsdorof (1992) reported that English is the main language of microbiology research, accounting for 90–95% of all SCI papers. English remains the dominant language as it is the main language in many fields (Hsieh et al., 2004; Chen et al., 2005). It could be expected that a higher percentage of English would be used because more journals listed in ISI are published in English (Chiu and Ho, 2007).

3.1.2. Publication distribution of countries and institutes

The contribution analysis of different countries/territories publications was based on journal articles in which the address and affiliation of at least one author were provided. There were 7 articles without any author address information on ISI Web of Science and the total article number for distribution analysis of country and institute publications was 1106. Among 1106 articles with author address, 989 (89%) were independent publications and 117 (11%) were internationally collaborative publications. The top 20 countries/territories were ranked by the number of total publications, including other information i.e. the number and percentage of single country articles and internationally collaborated articles, as well as first author and corresponding author articles (Table 1). The top 10 institutes in 17 year period are displayed in Table 2. USA, India, Canada, Turkey, and Germany are the top 5 most productive countries. However, from Table 2, no institute in Canada and Germany can be found. US EPA, University of North Carolina, and University Rochester are the top three research institutes. Furthermore, there are two Turkey and two India research institutions whose rank is in the top 10 research institutions.

3.1.3. Distribution of output in subject categories and journals

The distributions of subject categories are shown in Table 3. It indicates that "environmental sciences", "toxicology", and "public, environmental & occupational health" are the top 3 most popular

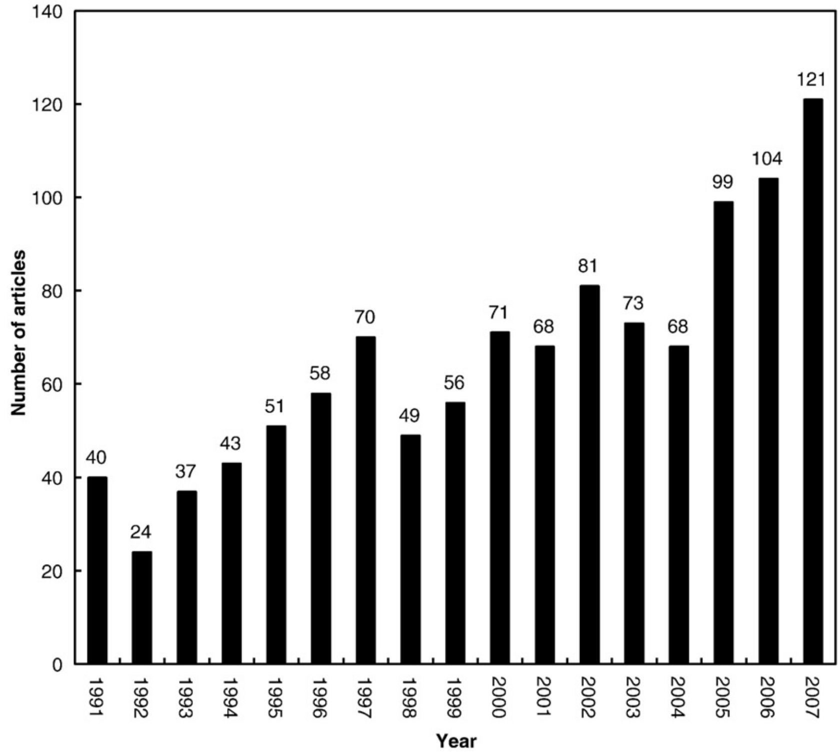

Fig. 1. Annual publication output (total publications: 1113).

subject categories. Fig. 2 shows the annual publication output in subject categories which have a total publication above 100. It can be observed that since 2003, there is a rapid increase of publications in the subject category of environmental sciences. Table 4 shows the distribution of output in journals. *Science of the Total Environment*, *Journal American Water Works Association*, and *Toxicology* are the top 3 journals with the most publications on research of lead in drinking water field.

3.1.4. Distribution analysis of author keywords

Author keywords analysis could provide the information of research trends which are concerned by researchers. Bibliometric method concerning author keywords analysis in a specific period could be found in recently years (Ho, 2007; Chiu and Ho, 2007), whereas considering the distribution of author keyword in different periods to evaluate the research trends was also presented (Xie et al., 2008; Li et al., 2009).The statistical analysis of author keywords might be aimed at discovering directions of science, and proved important for monitoring development of science and programs. Examination of

Table 1
Most productive countries/territories and institutions in research on lead in drinking water field from 1991 to 2007.

Country/territory	TP (%)	SPR (%)	CPR (%)	FPR (%)	RPR (%)
USA	406 (37)	1 (32)	1 (51)	1 (33)	1 (33)
India	88 (8.0)	2 (7.3)	4 (9.0)	2 (7.4)	2 (6.2)
Canada	53 (4.8)	8 (2.8)	2 (14)	8 (3.0)	5 (3.6)
Turkey	53 (4.8)	3 (4.6)	10 (4.5)	3 (4.2)	3 (4.5)
Germany	52 (4.7)	5 (3.4)	3 (10)	4 (3.8)	5 (3.6)
Japan	44 (4.0)	6 (3.1)	7 (7.3)	6 (3.3)	7 (3.5)
Spain	42 (3.8)	4 (3.8)	22 (2.3)	5 (3.6)	4 (3.8)
China	41 (3.7)	9 (2.6)	6 (8.5)	7 (3.1)	8 (3.3)
UK	39 (3.5)	10 (2.3)	4 (9.0)	10 (2.6)	10 (2.6)
Brazil	33 (3.0)	7 (2.9)	22 (2.3)	9 (2.8)	9 (2.9)
France	29 (2.6)	11 (2.0)	8 (5.1)	13 (1.8)	13 (2.0)
Sweden	28 (2.5)	12 (1.9)	8 (5.1)	11 (2.3)	11 (2.2)
South Korea	24 (2.2)	14 (1.6)	10 (4.5)	12 (2.0)	11 (2.2)
Poland	23 (2.1)	13 (1.8)	17 (2.8)	13 (1.8)	13 (2.0)
Italy	20 (1.8)	17 (1.4)	13 (3.4)	16 (1.4)	17 (1.5)
Mexico	20 (1.8)	14 (1.6)	22 (2.3)	13 (1.8)	13 (2.0)
Argentina	18 (1.6)	18 (1.2)	13 (3.4)	19 (1.2)	23 (0.79)
Taiwan	18 (1.6)	14 (1.6)	33 (1.1)	16 (1.4)	16 (1.6)
Australia	16 (1.4)	20 (1.1)	17 (2.8)	18 (1.3)	18 (1.3)
Nigeria	15 (1.4)	18 (1.2)	28 (1.7)	19 (1.2)	18 (1.3)

TP, Total publication; SPR, Single country publication rank; CPR, International collaboration publication rank; FPR, First author publication rank; RPR, Corresponding author publication rank.

Table 2
Most productive institutions in research on lead in drinking water field from 1991 to 2007.

Institutions	TP (%)	SPR (%)	CPR (%)	FPR (%)	RPR (%)
US EPA, USA	42 (3.8)	2 (2.1)	1 (5.7)	1 (2.3)	1 (2.4)
University of North Carolina, USA	20 (1.8)	19 (0.52)	2 (3.2)	21 (0.45)	28 (0.39)
University of Rochester, USA	20 (1.8)	1 (2.9)	50 (0.57)	2 (1.6)	3 (1.3)
Erciyes University, Turkey	18 (1.6)	19 (0.52)	3 (2.9)	3 (1.4)	2 (1.7)
Industrial Toxicology Research Centre, India	15 (1.4)	2 (2.1)	50 (0.57)	4 (1.3)	4 (0.89)
University of Illinois, USA	15 (1.4)	19 (0.52)	4 (2.3)	8 (0.63)	6 (0.79)
Pamukkale University, Turkey	12 (1.1)	93 (0.17)	5 (2.1)	90 (0.18)	79 (0.20)
Defense Research and Development Establishment, India	11 (1.0)	4 (1.7)	194 (0.19)	5 (0.90)	4 (0.89)
National Institute of Environmental Health Sciences, USA	10 (0.90)	93 (0.17)	6 (1.7)	8 (0.63)	9 (0.69)
University of California, Irvine, USA	10 (0.90)	11 (0.69)	12 (1.1)	21 (0.45)	28 (0.39)

TP, Total publication; SPR, Single country publication rank; CPR, Internationally collaborative publication rank; FPR, First author publication rank; RPR, Corresponding author publication rank.

Table 3
Distributions of the subject categories.

Subject categories	TP	*R* (%)
Environmental sciences	363	1 (18)
Toxicology	263	2 (13)
Public, environmental and occupational health	122	3 (6.2)
Water resources	118	4 (6.0)
Pharmacology and pharmacy	116	5 (5.9)
Analytical chemistry	108	6 (5.5)
Environmental engineering	102	7 (5.2)
Neurosciences	73	8 (3.7)
Civil engineering	54	9 (2.7)
Biochemistry and molecular biology	51	10 (2.6)

TP, Total publication; R, Rank.

author keywords in this study period revealed that 2396 author keywords were used. Among them, 1937 (81%) keywords appeared only once, and 234 (10%) keywords appeared twice. Only 9% of all author keywords (225) were used more than 3 times. The large number of once-only author keywords probably indicated a lack of continuity in research and a wide disparity in research focuses (Chuang et al., 2007). Table 5 shows the top 30 most frequently used author keywords appeared in articles on lead in drinking water field from 1991 to 2007. Except for "lead" and "drinking water" which were searching keywords in this study, the two most frequently used keywords were "cadmium" and "heavy metals". Furthermore, "zinc" and "copper" which belong to heavy metals were also frequently used keywords. Cadmium is a kind of heavy metals which is also very harmful to human body (Bae et al., 2001). Besides, it usually exists in drinking water (Melgar et al., 1997). Therefore, in the research related to health effect and toxicology of lead in drinking water, lead release into drinking water and determination of lead level in drinking water, cadmium was also often involved in investigation (Fang et al., 1991; Bae et al., 2001). Therefore, it made "cadmium" as the most frequently used keyword in the research on lead in drinking water field.

Table 4
Distributions of the output in journals.

Journals	TP	*R* (%)	IF
Science of the Total Environment	40	1 (3.6)	2.182
Journal American Water Works Association	26	2 (2.3)	0.605
Toxicology	25	3 (2.2)	2.919
Neurotoxicology	24	4 (2.2)	3.009
Water Research	20	5 (1.8)	3.427
Environmental Health Perspectives	18	6 (1.6)	5.636
Environmental Science & Technology	17	7 (1.5)	4.363
Toxicology Letters	17	7 (1.5)	2.826
Environmental Geochemistry and Health	16	9 (1.4)	1.086
Environmental Geology	16	9 (1.4)	0.722
Toxicological Sciences	16	9 (1.4)	3.814
Toxicology and Applied Pharmacology	16	9 (1.4)	3.846
Analytica Chimica Acta	15	13 (1.3)	3.186
Neurotoxicology and Teratology	15	13 (1.3)	2.444
Archives of Environmental Contamination and Toxicology	13	15 (1.2)	1.62
Environmental Monitoring and Assessment	13	15 (1.2)	0.885
Water Air and Soil Pollution	13	15 (1.2)	1.224
Biological Trace Element Research	12	18 (1.1)	0.95
Human & Experimental Toxicology	12	18 (1.1)	1.122
Journal of Hazardous Materials	12	18 (1.1)	2.337

TP, Total publication; R, Rank; IF, Impact Factor.

3.2. Research trends of lead in drinking water field

The research on lead in drinking water field has a very long history. If just searching "lead" and "drinking water" in article title, the first article published in SCI journals was in 1914 (Stainthorpe, 1914). Based on the bibliometric results, the research on lead in drinking water field is roughly consisted of 4 aspects as follows: health effect caused by lead in drinking water, lead release in drinking water, determination of lead level in drinking water and lead removal from drinking water. From Fig. 1, it can be found that the number of publications was increased mainly during two periods: from 1992 to 1997 and from 2004 to 2007.

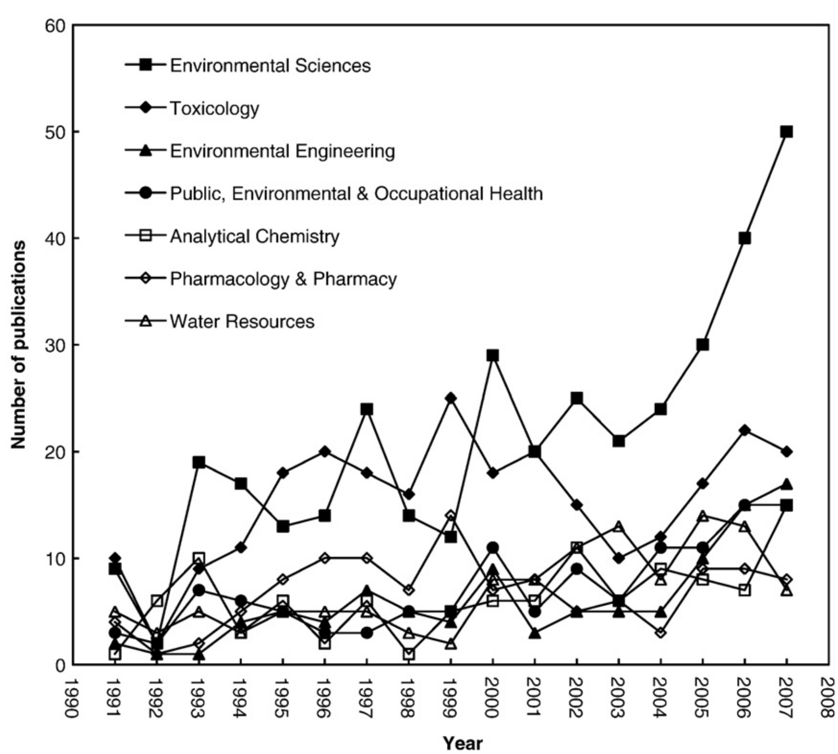

Fig. 2. Annual publication output in the top 7 subject categories.

Table 5
Top 30 frequency of author keywords used.

Author keywords	TP	*R* (%)
Lead	221	1 (28)
Drinking water	86	2 (11)
Cadmium	66	3 (8.5)
Heavy metals	59	4 (7.6)
Arsenic	41	5 (5.3)
Rat	40	6 (5.1)
Zinc	27	7 (3.5)
Copper	26	8 (3.3)
Rats	24	9 (3.1)
Groundwater	22	10 (2.8)
Lead acetate	20	11 (2.6)
Preconcentration	19	12 (2.4)
Trace metals	19	12 (2.4)
Water	19	12 (2.4)
Lead toxicity	18	15 (2.3)
Trace elements	18	15 (2.3)
Water quality	18	15 (2.3)
Children	17	18 (2.2)
Hippocampus	17	18 (2.2)
Oxidative stress	17	18 (2.2)
Heavy metal	16	21 (2.1)
Development	15	22 (1.9)
Neurotoxicity	15	22 (1.9)
Adsorption	14	24 (1.8)
Atomic absorption spectrometry	14	24 (1.8)
Brain	14	24 (1.8)
Lead exposure	14	24 (1.8)
Nickel	14	24 (1.8)
Nitric oxide	14	24 (1.8)
Liver	13	30 (1.7)

TP, Total publication; R, Rank.

3.2.1. Health effect and toxicology of lead in drinking water

It is well known that lead can cause pathophysiological changes in several organ systems including the central nervous, renal, hematopoietic, and immune system (Goyer, 1986; Beliles, 1994). For instance, 10 μg/dL lead can cause 4.6 pts IQ drop (Canfield et al., 2003). Since Cory-Slechta and Widzowski examined the impact of lead exposure on dopaminergic (DA) function in 1991 (Cory-Slechta and Widzowski, 1991), the research about health effect and toxicology of lead in drinking water increased very rapidly during the period from 1992 to 1997 (Ronis et al., 1996; Rodrigues et al., 1996; Watson et al., 1997). This is the main reason that the number of total publications continuously increased in this period. The main research focus during this period was how human or animal functions were affected by lead exposure. Because low level lead exposure can strongly affect human's intelligence, many researches were focused on the effect of lead exposure to the function of brain (Cohn and Cory-Slechta, 1993; Bielarczyk et al., 1994; Gilbert et al., 1996). Besides, there were also some researches about other functions, such as kidney (Oberley et al., 1995; Moser et al., 1995). In recent years, the research focus was transferred to the mechanism of damage effect (Adonaylo and Oteiza, 1999; Carmignani et al., 2000; Vaziri et al., 2003). Besides, in many researches, rats were usually used for investigation (Cory-Slechta et al., 1992; Kala and Jadhav, 1995). This is the reason that “rat” and “rats” were very frequently used author keywords (Table 5).

3.2.2. Lead release into drinking water

The lead release into drinking water is also a very important research aspect of research on lead in drinking water field. Because lead source of drinking water is mainly lead-bearing plumbing materials, the research of lead release was mainly focused on two aspects as follows: corrosion behaviors and mechanisms of lead-bearing plumbing materials (Subramanian and Connor, 1991; Isaac et al., 1997; Korshin et al., 2000) and corrosion control of lead in drinking water (Chen et al., 1994; Lin et al., 1997). From 2001, Edwards have conducted many researches about lead corrosion in drinking water distribution system (Kvech and Edwards, 2001; Edwards and McNeill, 2002). In 2004, Edwards and Dudi found that a switch from free chlorine to chloramine disinfectant triggered problems with excessive lead in Washington, D.C., drinking water (Edwards and Dudi, 2004). Since then, lead corrosion in drinking water became a very active research aspect and many articles on it were published (Dudi et al., 2005; Tang et al., 2006; Vasquez et al., 2001). It resulted in a large increase of publications during the period from 2004 to 2007 (Fig. 1) and a rapid publication increase in the subject category of environmental sciences since 2003 (Fig. 2).

3.2.3. Determination of lead level in drinking water

Lead is harmful for human health and usually lead concentration in drinking water is very low. Therefore, the measurement of low level lead in drinking water is very important. During the period from 1991 to 1999, the main measurement techniques included flame atomic absorption and potentiometric stripping analysis (PSA). Fang et al. used flame atomic absorption to determine lead, cadmium and copper in drinking water (Fang et al., 1991). Soylak et al. (1997) investigated a simple method for atomic absorption spectrometric determination of lead in drinking water samples after preconcentration by sorbing 1-(2-pyridylazo) 2-naphthol (PAN) complex of lead on an activated carbon column. Wang et al. (1992) investigated the utility of mercury-coated screen-printed electrodes for stripping voltammetric and potentiometric measurements of lead. Furthermore, Wang and Tian (1993) replaced the mercury-based screen-printed electrodes with gold-coated ones for the measurement of lead by potentiometric stripping analysis (PSA) to avoid environmental contamination. After entering 21st century, the measurement techniques continuously developed, and some new techniques were applied to measure lead concentration in drinking water, such as reversed-phase high-performance liquid chromatography (RP-HPLC) (Hu et al., 2002) and inductively coupled plasma (ICP) (Cheng et al., 2004).

3.2.4. Lead removal from drinking water

Because of the toxicology of lead, for decades, the methods of lead removal from drinking water were investigated (Gulson et al., 1997; Gharaibeh et al., 1998). The most popular methods were adsorption (Orumwense, 1996; Ho and McKay, 2000; Sublet et al., 2003) and ion exchange (Komgold et al., 1996; Vaaramaa and Lehto, 2003). It makes “adsorption” as a frequently used keyword in publications (Table 5).

4. Conclusion

To gain a clearer insight into research trends, forecasts and contributions on lead in drinking water field, historical review and bibliometric methods were applied in this research. This study reveals that research on lead in drinking water field is roughly consisted of 4 aspects as follows: health effect caused by lead in drinking water, lead release in drinking water, determination of lead level in drinking water and lead removal from drinking water. The results from this analysis indicate that there are an increasing number of annual publications mainly during two periods: from 1992 to 1997 and from 2004 to 2007. The increase of the first period was mainly resulted from the rapid increase of research on health effect and toxicology of lead in drinking water, and the increase of research on lead release into drinking water was the main reason which caused the number of annual publications increased in the second period. It can be predicted that the number of scientific articles on the topic of lead in drinking water field will be still growing at a high rate in the future. Results indicated that author keywords analysis was an effective approach for mapping global research on lead in drinking water field during the period from 1991 to 2007. Based on author keywords analysis results, it can be concluded that “cadmium” and “heavy metals” were the most frequently used author keywords in the period 1991–2007. In addition, "zinc" and "copper" which belong to heavy metals were also frequently used keywords.

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