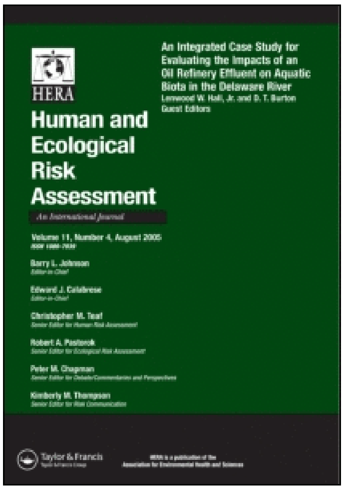

Human and Ecological Risk Assessment: An International Journal
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713400879

A Bibliometric Study of the Trend in Articles Related to Risk Assessment Published in *Science Citation Index*

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Online publication date: 23 August 2010

To cite this Article Mao, Ning , Wang, Ming-Hung and Ho, Yuh-Shan(2010) 'A Bibliometric Study of the Trend in Articles Related to Risk Assessment Published in *Science Citation Index*', Human and Ecological Risk Assessment: An International Journal, 16: 4, 801 — 824

To link to this Article: DOI: 10.1080/10807039.2010.501248
URL: http://dx.doi.org/10.1080/10807039.2010.501248

Human and Ecological Risk Assessment, 16: 801–824, 2010

ISSN: 1080-7039 print / 1549-7860 online
DOI: 10.1080/10807039.2010.501248

A Bibliometric Study of the Trend in Articles Related to Risk Assessment Published in *Science Citation Index*

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ABSTRACT

In this study, a bibliometric method was used to evaluate the global scientific production of risk assessment research for the last 16 years and provide insights into the characteristics of the risk assessment research activities and tendencies that may exist in the papers. Data were obtained on the online version of SCI, Web of Science from 1992 to 2007. Two important respects of the paper characteristics were analyzed: (i) performance of publication and (ii) research tendency and hotspots. The main results were as follows: English-language articles took the majority of all the publications. Number of articles in this field increased from 1 in 1968 to 1037 in 2007. *Human and Ecological Risk Assessment* published the most papers in this field, taking 3% of all. Research tendency was investigated by statistically analyzing the distribution of paper title, author keyword, and keyword plus. Furthermore, a new method named "word cluster analysis" was successfully applied to find the research hotspots of this field. Research hotspots of risk assessment mainly focused on three subject categories: environmental science, ecology, and epidemiology. This new bibliometric method can help relevant researchers realize the panorama of global risk assessment research, and establish the further research direction.

Key Words: risk assessment, SCI, scientometrics, trend, research hotspots, Keywords, h-index, word cluster analysis.

INTRODUCTION

Risk assessment, as a practical method, can find its applications in many fields. In earlier years, radiation assessment for nuclear engineering (Penland 1974; Schauer and Shinozuka 1975; Smith and Kastenberg 1976; Albert and Williams 1978; Burns 1978) had been investigated. In 1975, *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, WASH-1400 was published by the U.S.

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Nuclear Regulatory Commission, which put forward the typical accident risk assessment system (Hu 2000). In the 1980s, many environment pollution accidents happened; for example, the Chernobyl nuclear power plant accident. These accidents stimulated the related research of risk assessment (Mao and Liu 2003). Carcinogenic risk assessment was also a hotspot at that time when a series of articles were published in the prestigious scientific journals *Science* and *Nature* (Brown *et al.* 1978). Risk assessment, as a regulatory tool, developed during virtually all of the 20th century and the first milestone in the revolution of risk assessment was the *1906 Food and Drug Act,* which marked the beginning of risk assessment as a regulatory tool (Doull 2003). In terms of the regulatory evolution of risk assessment, the National Research Council (NRC) and U.S. Environmental Protection Agency (USEPA) made a lot of prominent efforts, which significantly changed the conception and principles of risk assessment (Johnson and Reisa 2003). In 1983, the publication of the NRC's report, *Risk Assessment in the Federal Government: Managing the Process* (Red Book) was a monument in the development of risk assessment and risk management practices and policies because the recommendations on how to improve institutional practice of risk assessment and management helped shape risk policy and practices at regulatory agencies such as the USEPA (Goldman 2003; Johnson and Reisa 2003). Besides, the "Red Book" created a framework for incorporation of toxicology into environmental decision-making, which has withstood the test of time (Goldman 2003). Ever since, the four-step risk assessment frame, hazard identification, dose–response assessment, exposure assessment, and risk characterization, came into being, which had a far-reaching influence over the whole development of risk assessment (Council 1983). The NRC has published many volumes on risk assessment since the "Red Book" appeared. These volumes were focused on particular risks issues, some of which had noteworthy methodological contributions, such as *Improving Risk Communication* (1989), *Human Exposure Assessment for Airborne Pollutants* (1991), *Science and Judgment in Risk Assessment* (1994), and *Understanding Risk: Informing Decisions in a Democratic Society* (1996). Under the guidance of these publications, scientific articles on risk assessment have demonstrated an exponental increase in quantity over the past several decades, and a number of papers presenting the latest research achievements have been published in the authoritative scientific journals such as *Nature* and *Science* (Williams *et al.* 1992; Harkness *et al.* 1993; Martonen *et al.* 1994; Deportes *et al.* 1995; Perera 1997; Quensen *et al.* 1998; Scancar *et al.* 2000; Tsai *et al.* 2001; Kolar and Lodge 2002; Weston *et al.* 2004; Loffler *et al.* 2005; Li *et al.* 2007).

A common research tool for this analysis are the bibliometric methods that have already been widely applied for the scientific production and research trends in many disciplines of science and engineering (Zitt and Bassecoulard 1994; Tang and Thelwall 2003; Keiser and Utzinger 2005; Xie *et al.* 2008). Furthermore, the *Science Citation Index* (SCI) from the Institute for Scientific Information (ISI) Web of Science databases are the most important and frequently used source databases of choice for a broad review of scientific accomplishment in all research fields (Bayer and Folger 1966; Braun *et al.* 2000; Li *et al.* 2009). Conventional bibliometric methods often evaluate the research trend by the publication outputs of countries, research institutes, journals, and research fields (Braun *et al.* 1995; Colman *et al.* 1995; Ugolini *et al.* 1997; Ho 2008) or by the citation analysis (Cole 1989; Schutz and Six 1994;

Li and Ho 2008). However, merely depending on 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. More information, closer to the research itself (*e.g.*, distribution of paper title, author keyword, and keyword plus), in different periods should be introduced in the study of the research trend (Xie *et al.* 2008; Li *et al.* 2009). Arrue and Lopez (1991) evaluated the growth pattern of conservation tillage research based primarily on abstracts published in *Soils and Fertilizers*. In addition, in recent years, distribution of keywords in different periods was applied to evaluate research trend (Xie *et al.* 2008; Li *et al.* 2009).

In this study, we aim to synthetically use the traditional method, study field and country analysis, and the innovative method, paper title, author keyword, keyword plus analysis together with a new method called the "word cluster analysis," mapping the trends of global risk assessment research during the period of 1992–2007. It would help researchers to realize the panorama of global risk assessment research, and establish the further research direction.

MATERIALS AND METHODS

The data were based on the online version of the *Science Citation Index* (SCI) Web of Science. SCI is a multidisciplinary database of the Institute for Scientific Information (ISI), Philadelphia, USA. According to *Journal Citation Reports* (JCR) it indexes 6426 major journals with citation references across 172 scientific disciplines in 2007. The online version of SCI was searched under the keywords "risk assessment," and "risk assessments" as a part of title, abstract, author keywords, and keywords plus to compile a bibliography of all papers related on risk assessment research. Document information included names of authors, contact address, title, year of publication, author keywords, keywords plus, subject categories, and names of journals publishing the articles. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Collaboration type was determined by the addresses of the authors, where the term "single country" was assigned if the researchers' addresses were from the same country. The term "international collaboration" was designated to those articles that were coauthored by researchers from multiple countries. The term "single institute publication" was assigned if the researchers' addresses were from the same institute. The term "inter-institutionally collaborative publication" was assigned if authors were from different institutes. The impact factor of a journal was determined for each document as reported in the JCR 2007. h-index was a good indicator of the impact of a scientist or journal and had the advantage of being objective (Kinney 2007). It was defined as the number of papers with citation number greater than or equal to h (Hirsch 2005). More specifically, a scientist has index h if h of his or her Np papers have at least h citations each and the other (Np-h) papers have $\leq$h citations each. Hirsch suggests that h-index has a better predictive power than commonly used indexes, such as (i) number of publications; (ii) total number of citations; (iii) average citation number per publication; (iv) total number of citations; or (v) number of citations of the highly cited publications (Hirsch 2007). In this study, h-index was calculated for different document types, languages, journals, subject categories, research institutes, and countries to evaluate the achievements, respectively.

PERFORMANCE OF PUBLICATION

Document Type and Language of Publication

There were 24,258 publications that met the selection criteria mentioned earlier, including 17 document types. Article (15,862) was the most frequently used document type, comprising 65% of the total production with its h-index 117, which was relatively the highest. Details of different document types are shown in Table 1. As journal articles represented the majority of document types that were also peer-reviewed within this field, 15,862 articles were identified and further analyzed in this study. The emphasis of the following discussion is to determine the pattern of scientific production, research activity trends that consisted of authorship, the institutes, countries, and the trends in the research subjects addressed. Ninety-seven percent of all these journal articles were published in English with its h-index 117. Several other languages also appeared. The other top six languages were German (242 articles, h-index: 10), French (109; 6), Spanish (30; 4), Japanese (14; 1), Russian (11; 1), and Chinese (6; 1).

Characteristics of Publication Outputs during 1992–2007

The total amounts of SCI articles including "risk assessment," and "risk assessments" in title only during the last 100 years were counted and displayed in Figure 1.

Table 1. Distribution of document type and their h-indices.

Document type	TP	%	h-index
Article	15,862	65	117
Proceedings paper	3762	16	57
Review	2132	8.8	85
Meeting abstract	1172	4.8	4
Editorial material	804	3.3	28
Letter	239	1.0	9
News item	90	0.37	1
Correction	61	0.25	3
Note	60	0.25	15
Reprint	28	0.12	4
Book review	19	0.078	1
Addition correction	13	0.054	2
Discussion	8	0.033	4
Software review	4	0.016	1
Bibliography	2	0.0082	2
Biographical-item	1	0.0041	0
Database review	1	0.0041	0
Total	24,258	100	

TP: publications in the study period; (%): the percentage of the document type.

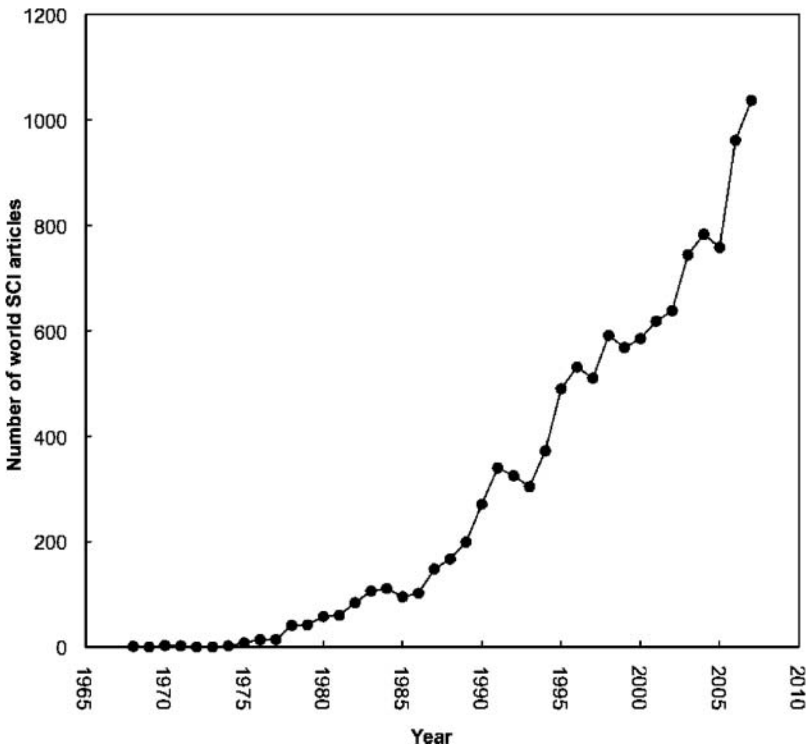

Figure 1. Number of SCI articles referring to "risk assessment" and "risk assessments" in the title only during the last 100 years.

The risk assessment research developed exponentially over the last century, especially in the recent two decades. Articles increased from 1 SCI article in 1968 to 1037 articles in 2007. As a whole, the development of risk assessment can be divided into two phases in terms of the increasing speed of SCI journal articles. The first phase is between 1968 and 1985, in which number of articles goes up slightly. This phase is representative of the very beginning of the risk assessment research. The second phase lasts from 1986 to now. The number of articles begins to rocket and maintains its increase, which is more evident especially in the 21st century. During this phase, risk assessment has drawn more attention for the sake of keeping pace with the increasing need of human health.

Distribution of Output in Subject Categories and Journals

Based on the classification of subject categories in JCR, the publication output data of risk assessment research was distributed in 169 SIC subject categories during the last 16 years. The top 20 productive subject categories and their h-indices are statistically analyzed in Table 2. Moreover, the annual publications of the top 5 productive subject categories are analyzed in Figure 2. The number of scientific articles per category exhibited sustaining growth during the time period covered, which indicates that risk assessment research had been steadily developed in various categories. In terms of the number and increasing speed of articles, the risk

Table 2. Top 20 productive subject categories of articles and their h-indices during 1992–2007.

Subject category	TP	%	h-index
Environmental Sciences	4202	15	60
Toxicology	2975	11	58
Public, Environmental & Occupational Health	1568	5.7	52
Pharmacology & Pharmacy	940	3.4	44
Environmental Engineering	787	2.8	35
Food Science & Technology	594	2.1	32
Water Resources	566	2.0	25
General & Internal Medicine	542	2.0	49
Oncology	529	1.9	47
Biotechnology & Applied Microbiology	526	1.9	35
Cardiac & Cardiovascular Systems	460	1.7	46
Civil Engineering	432	1.6	16
Ecology	421	1.5	35
Genetics & Heredity	398	1.4	38
Multidisciplinary Geosciences	370	1.3	19
Legal Medicine	312	1.1	24
Microbiology	302	1.1	41
Industrial Engineering	290	1.0	21
Veterinary Sciences	286	1.0	18
Entomology	280	1.0	23

TP: Number of articles;%: the percentage of articles from different subject categories in total publications.

assessment–related subject categories can be roughly classified into three groups. Environmental science is holding primacy all through the study period except for the first 4 years, and can hardly be exceeded by other study fields. Toxicology and public, environmental, and occupational health follow. Publication of these subject categories increases moderately. Pharmacology and pharmacy together with environmental engineering compose the third group, whose increasing speed is relatively the slowest. The reason might fall into two respects. On one hand, risk assessment is a sociopolitical measure. It could be influenced by policy and funding issues to a great extent (Paul 2003). More specifically, a lot of risk assessment has been conducted because national policies require such an assessment; the public require such an assessment. Therefore, as the public perceptions paid more and more attention to the environment and toxicants, policy framework was made gradually and money was invested into the related research and papers booming in these fields was the direct result of them. On the other hand, as the use of statistics in any scientific discipline can be considered a key element in evaluating its degree of maturity, the result provided a current view of the risk assessment research emphases of this topic (Palmer *et al.* 2005). To be specific, the high increasing speed of environmental science papers might indicate that it was a “rising” subject category.

In total, 15,862 articles were published in 2690 journals, including not only specialty journals, but also journals of other disciplines. The top 20 productive journals

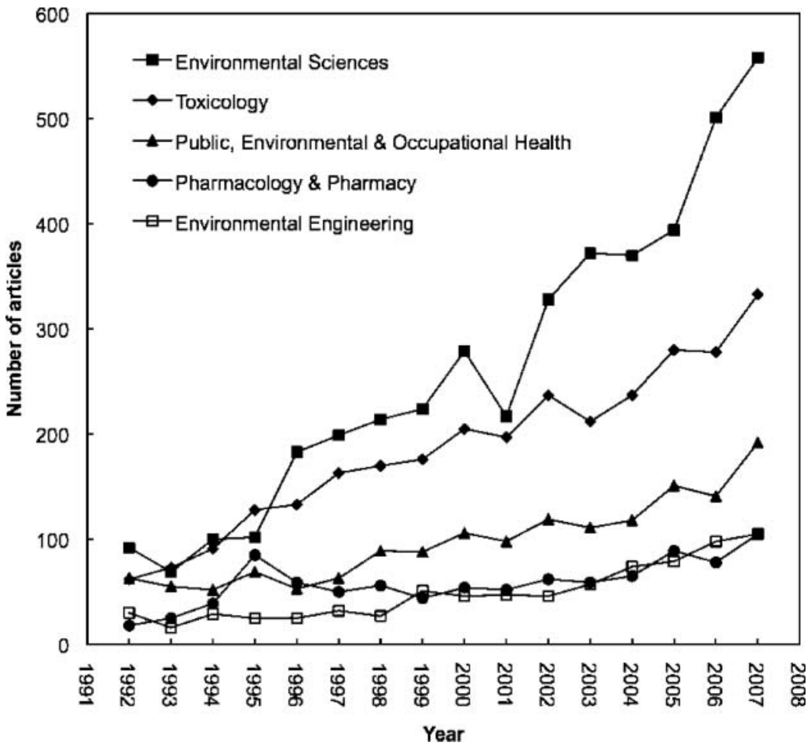

Figure 2. Comparison of the growth trends of the top five productive subject categories during the last 16 years.

through the recent 16 years are presented in Table 3. As the leading journal of this particular research field, *Human and Ecological Risk Assessment* published the most articles with 481 publications comprising 3% of all the articles, followed by *Environmental Toxicology and Chemistry* and *Regulatory Toxicology and Pharmacology*, contributing 2.6% and 1.9% of all the journal articles, respectively. In contrast, as regards the impact factor and the h-index, the rank of journals changed. *Environmental Health Perspectives* won first place with the highest impact factor (5.636) and h-index (34). *Environmental Science and Technology* and *Environmental Toxicology and Chemistry* had the same h-index (31) but the impact factor of the former journal (4.363) was higher than the latter one (2.309).

Moreover, Bradford's Law of Scattering (Bradford 1934) was applied. It was the most commonly used tool for studying journal productivity (Chen and Leimkuhler 1987). Bradford's law was used to estimate the exponentially diminishing returns of extending a search for references in science journals. One formulation of Bradford's Law is that if journals in a field are sorted by number of articles into three zones, each with about one-third of all articles, then the number of journals in each zone will be proportional to $1{:}n{:}n^2$. The journals of zone 1 could obviously be recognized as the core journals. In this study, we sorted the journals in descending order in terms of their published articles, and the journals were divided into three "zones."

Table 3. The top 20 most published journals on risk assessment, including the ranking, respective percentages, impact factors, and h-indices.

Journal	TP (%)	IF	h-index
Human and Ecological Risk Assessment	481(3.0)	0.912	23
Environmental Toxicology and Chemistry	410(2.6)	2.309	31
Regulatory Toxicology and Pharmacology	295(1.9)	1.968	24
Chemosphere	271(1.7)	2.739	27
Environmental Health Perspectives	230(1.5)	5.636	34
Environmental Science & Technology	223(1.4)	4.363	31
Toxicological Sciences	195(1.2)	3.814	22
Risk Analysis	195(1.2)	1.784	11
Reliability Engineering and System Safety	156(1.0)	1.004	18
Toxicology	151(1.0)	2.919	21
Science of the Total Environment	142(0.90)	2.182	19
Journal of Hazardous Materials	132(0.83)	2.337	12
Environmental Pollution	122(0.77)	3.135	17
Toxicology and Applied Pharmacology	116(0.73)	3.846	26
Journal of Food Protection	98(0.62)	1.886	17
Environmental Monitoring and Assessment	95(0.60)	0.885	9
Ecotoxicology and Environmental Safety	95(0.60)	2.014	16
Archives of Environmental Contamination and Toxicology	90(0.57)	1.62	18
Food and Chemical Toxicology	90(0.57)	2.186	14
Toxicologic Pathology	82(0.52)	1.897	17

TP: Number of articles;%: the percentage of articles of journals in total publications; IF: impact factor.

Zone 1, representing the most productive third of the total articles, contained 48 journals or 1.8% of 2690 journals. Zone 2, representing the next most productive third of total articles, contained 319 journals or 12% of 2690 journals. Zone 3, representing the least productive third of total articles, contained 2323 journals or 86% of 2690 journals. The number of journals of three zones approximately followed the Bradford's law. To reiterate, the number of journals was approximately $1{:}n{:}n^2$. From the article's distribution in journals, we can draw the conclusion that the most productive journals have their roots in environmental science, toxicology, and pharmacology, which is consistent with the conclusion we drew from subject categories analysis.

Distribution of Institutes and Countries

During the study period, there are 10,594 institutes devoted to the risk assessment–related research, from which the USEPA was worthy of the flagship in terms of its best outputs. It published the most articles (554) and completed the most independent and cooperative publications. Moreover, the first authored and corresponding authored articles of the USEPA were the most. Furthermore, which is more important, its h-index (40) is the highest among all the institutes. Harvard University followed distantly, as its publications (212) were less than half of USEPA's. All of the measurements mentioned above ranked second with the exception of the single publication (ranked 6th) and h-index (ranked 3rd). The top 20 most productive institutes and their respective outputs are displayed in Table 4.

The contribution of different countries/territories was estimated by the location of the affiliation of at least one author of the published papers. There were 176 articles without any author address information on the ISI Web of Science. Of all the 15,685 articles with author address, 12,971 (83%) were independent publications and 2714 (17%) were international collaborative publications. The top 20 countries/territories ranked by number of publications are listed in Table 5. Number of cooperative publications, the percentage of international cooperative publications in total country publications, together with the number and percentage of single country articles and internationally collaborated articles are also exhibited in Table 5.

Furthermore, information about the first authored articles, corresponding authored articles, and their h-indices are also contained in Table 5. Two North American countries, twelve European countries, four Asian countries, one South American country (Brazil), and Australia ranked in the top 20 of publications. There was still no African country getting into the top productive countries. The 7 major industrial countries (G7: Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) were the top 7 productive countries except for Japan (ranked 12) whose top place had been taken by The Netherlands. It is mainly because there are some leading institutes steering the risk assessment related research in The Netherlands. Take the National Institute for Public Health and the Environment, for example; it was a recognized leading center of expertise in the fields of health, nutrition, and environmental protection whose research results, monitoring, modeling, and risk assessment were used to underpin policy on public health, food, safety, and the environment (http://www.rivm.nl). Many influential articles came from there (Degruijl *et al*. 1993; Teunis *et al*. 1997; Liem *et al*. 2000). During the study period, it contributed 152 journal articles in all. Moreover, G7 and The Netherlands had high productivity in independent articles, first authored and corresponding authored articles, owning the percentage of 76%, 74%, and 73%, respectively. Domination in publication was not surprising from mainstream countries since this pattern has occurred in most scientific fields (Mela *et al*. 1999). To a certain extent, the number of research papers reflecting the activity and academic level of these countries were likewise high (Arunachalam and Jinandra 2000; Trajtenberg 2001). The United States exhibited its predominance in global risk assessment research and showed the greatest counts of world publications, comprising 43% of the total publications in the study period. It also had the most-frequent partners, accounting for 47% of all the international collaborative articles during the last 16 years. But the cooperative articles took only 19% of its total country publication, which was far away from European countries. In addition, the increasing speed of articles of the United States remained a high level all through, except for the period from 1996 to 1999. Furthermore, the article quality was excellent according to the h-index, which was also the highest (95) among all the countries. The United Kingdom followed distantly behind the United States, and ranked second in terms of all the measurements mentioned earlier. Comparison of the growth trends of the United States and the other

Table 4. The top 20 most productive institutes of risk assessment, including the ranking and respective percentages of publications, independent publications, cooperative publications, as first author, as corresponding author, and h-indices.

Institute	TP	TPR (%)	SPR (%)	CPR (%)	FAR (%)	RAP (%)	h-index
USEPA, USA	554	1(3.5)	1(2.3)	1(4.6)	1(2.1)	1(2.2)	40
Harvard University, USA	212	2(1.4)	6(0.58)	2(2.0)	2(0.72)	2(0.67)	33
University of North Carolina, USA	174	3(1.1)	7(0.57)	3(1.6)	3(0.59)	5(0.48)	27
University of Texas, USA	155	4(1.0)	3(0.69)	5(1.2)	5(0.57)	4(0.60)	34
National Institute for Public Health and the Environment, Netherlands	152	5(1.0)	3(0.69)	7(1.2)	4(0.58)	3(0.61)	23
University of Washington, USA	144	6(0.92)	8(0.55)	6(1.2)	6(0.50)	6(0.47)	29
University of California, San Francisco, USA	137	7(0.87)	16(0.37)	4(1.3)	7(0.47)	6(0.47)	30
Utrecht University, Netherlands	126	8(0.80)	17(0.36)	8(1.2)	10(0.43)	10(0.41)	23
Centers for Disease Control and Prevention, USA	121	9(0.77)	17(0.36)	9(1.1)	12(0.40)	20(0.31)	23
University of Maryland, USA	113	10(0.72)	9(0.51)	14(0.90)	11(0.41)	10(0.41)	22
US FDA, USA	110	11(0.70)	2(0.70)	27(0.70)	9(0.44)	8(0.45)	18
University of California, Los Angeles, USA	109	12(0.69)	5(0.68)	25(0.71)	8(0.46)	9(0.42)	21
Procter and Gamble Company, USA	101	13(0.64)	50(0.23)	11(1.0)	32(0.28)	20(0.31)	23
Johns Hopkins University, USA	99	14(0.63)	50(0.23)	13(0.97)	19(0.33)	35(0.24)	23
Karolinska Institute, Sweden	98	15(0.62)	92(0.15)	10(1.0)	37(0.26)	26(0.29)	20
University of Toronto, Canada	98	15(0.62)	62(0.19)	11(1.0)	47(0.23)	49(0.20)	18
University of Minnesota, USA	95	17(0.61)	10(0.44)	21(0.75)	14(0.38)	13(0.35)	20
NIEHS, USA	91	18(0.58)	20(0.35)	17(0.78)	13(0.38)	15(0.33)	25
University of California, Berkeley, USA	91	18(0.58)	32(0.30)	15(0.82)	14(0.38)	16(0.32)	22
University of Michigan, USA	91	18(0.58)	23(0.33)	16(0.79)	20(0.32)	27(0.28)	17

TP: Number of articles; TPR (%): Rank of publications and the percentage of articles of different institutes in total publications; SPR (%): Rank of independent publications and the percentage of articles of different institutes in total publications; CPR (%): Rank of international cooperative publications and the percentage of articles of different institutes in total publications; FAR (%): Rank of first authored publications and the percentage of articles in total publications; RAP (%): Rank of the corresponding authored publications and the percentage of articles in total publications.

Table 5. The top 20 countries/territories ranked by number of publications, including the number and percentage of single country articles and internationally collaborated articles, first authored articles, corresponding authored articles and their h-indices.

Country	TP	TPR (%)	SPR (%)	CPR (%)	FAR (%)	RPR (%)	CP	%C	h-index
USA	6806	1 (43)	1 (43)	1 (47)	1 (39)	1 (39)	1270	19	95
UK	1981	2 (13)	2 (9.7)	2 (27)	2 (9.9)	2 (9.8)	724	37	61
Germany	1330	3 (8.5)	3 (6.6)	3 (18)	3 (6.6)	3 (6.6)	480	36	52
Canada	1067	4 (6.8)	4 (5.1)	5 (15)	4 (5.3)	4 (5.2)	403	38	47
Netherlands	936	5 (6.0)	5 (3.9)	4 (16)	5 (4.4)	5 (4.4)	425	45	49
France	677	6 (4.3)	6 (2.9)	6 (11)	6 (3.1)	6 (3.2)	295	44	40
Italy	597	7 (3.8)	7 (2.7)	8 (9.2)	7 (2.8)	7 (2.8)	250	42	41
Australia	523	8 (3.3)	8 (2.6)	11 (6.7)	8 (2.6)	8 (2.7)	182	35	29
Sweden	493	9 (3.1)	10 (2.2)	10 (7.6)	9 (2.3)	10 (2.3)	207	42	38
Switzerland	476	10 (3.0)	11 (1.6)	7 (9.7)	11 (2.0)	11 (2.1)	262	55	36
Japan	426	11 (2.7)	9 (2.3)	13 (4.9)	10 (2.2)	9 (2.3)	132	31	29
Belgium	393	12 (2.5)	14 (1.3)	9 (8.3)	14 (1.6)	14 (1.7)	226	58	34
Denmark	357	13 (2.3)	13 (1.5)	12 (6.1)	12 (1.7)	12 (1.7)	165	46	30
Spain	330	14 (2.1)	12 (1.6)	15 (4.5)	13 (1.6)	13 (1.7)	121	37	26
China	273	15 (1.7)	15 (1.1)	13 (4.9)	15 (1.3)	15 (1.3)	132	48	19
Finland	204	16 (1.3)	17 (0.93)	17 (3.1)	16 (0.96)	16 (0.94)	83	41	25
Brazil	167	17 (1.1)	20 (0.76)	19 (2.5)	20 (0.83)	20 (0.85)	69	41	20
Norway	166	18 (1.1)	23 (0.61)	16 (3.2)	21 (0.72)	21 (0.75)	87	52	17
South Korea	161	19 (1.0)	19 (0.83)	22 (2.0)	18 (0.85)	18 (0.87)	53	33	14
India	160	20 (1.0)	18 (0.92)	24 (1.5)	17 (0.89)	17 (0.89)	41	26	16

TP: Number of articles; TPR (%): Rank of publications and the percentage of articles of different institutes in total publications; SPR (%): Rank of independent publications and the percentage of articles of different institutes in total publications; CPR (%): Rank of international cooperative publications and the percentage of articles of different institutes in total publications; FAR (%): Rank of first authored publications and the percentage of articles in total publications; RPR (%): Rank of the corresponding authored publications and the percentage of articles in total publications; CP: Number of cooperative articles;%C: Percentage of cooperative publications in total country publications.

top 9 most productive countries during the last 16 years is displayed in Figures 3 and 4.

RESEARCH TENDENCY AND HOTSPOTS

Distribution of Paper Title Analysis

Word statistical analysis technique was used to find the research tendency of this field. We divided the title, author keyword, and keyword plus into single words, and did the statistical analysis of them. The technique of statistical analysis of word in title, author keywords, and the keyword plus might be aimed at discovering directions of science (Xie *et al.* 2008; Li *et al.* 2009). In other words, the result of the statistical

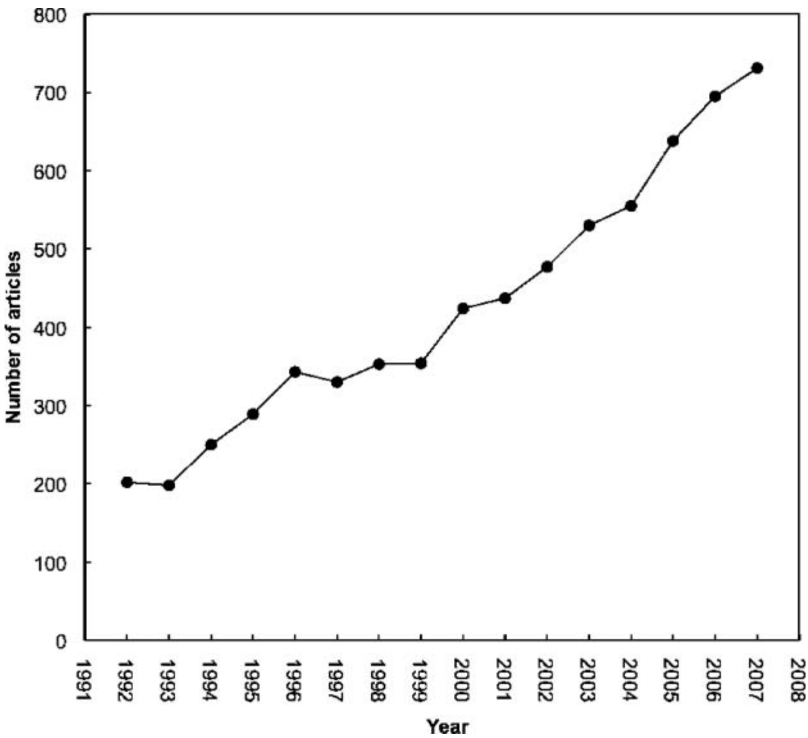

Figure 3. The growth trend of the United States during the last 16 years.

analysis may help us find the possible research trend and hotspots. Paper title analysis was one kind of the word statistical analysis. The title of an article always includes the information that an author would most like to express to their readers, because it would be seen by all the readers at first. It could be used to make inferences of the scientific literature or to identify the subjective focus and emphasis specified by authors. Xie *et al.* (2008) used the paper title, author keyword, and keyword plus analysis method to find the focus of aerosol-related research. A similar method was also applied to map the research trend in stem cell–related research (Li *et al.* 2009). In this study, we have statistically analyzed all the single words in the title of risk assessment–related articles. Some prepositions such as "of" and "in" apparently are used frequently during our study period; however, these have no useful meaning for the analysis of research trend. Therefore, all these empty words including "of," "in," "and," "the," "a," "for," "with," "by," and "to," together with the searching word "risk" and "assessment" are discarded in the paper title analysis. For the further study, after eliminating the empty words above, the 30 most frequently used single words in title, which are all substantives, are displayed in Table 6. Their appearance times-in-all through the past 16 years and each 4-year period are also exhibited. Along with the growth of the number of articles, almost all the single words' appearance time increased in the study period.

The usually used title words, except for the searching words, generally fell into three groups according to their appearing features. The first group consisted of

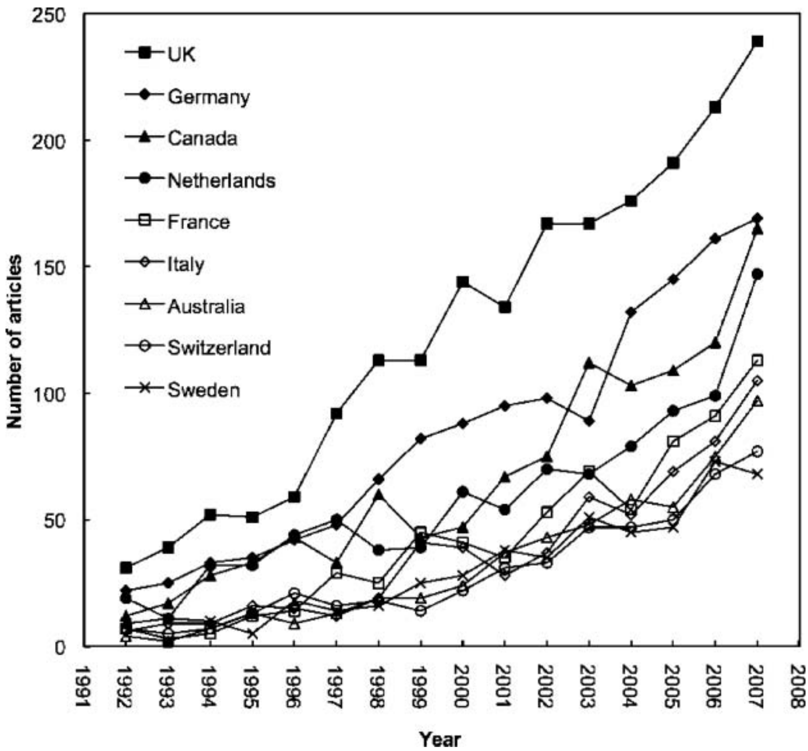

Figure 4. Comparison of the growth trends of the top 9 (except the United States) most productive countries in the world during the last 16 years.

"exposure," "analysis," and "effect." They ranked as the top three as far as the total appearance time was concerned and they implied that exposure, multifactorial analysis, and analysis method, together with the effect of different substances, no matter good or bad, were the emphasis of the risk assessment–related research. The second group was made up of "health," "cancer," and "human," whose appearance time closely followed the first group. This word group definitely pointed out that human health, especially cancer, was another mainstream of the risk assessment research. Words from the third group had a prominent character: their percentage of appearance time in the recent 4 years was all greater than 50%, which indicated that they were frequently used recently. These words probably were representative of the frontline of this field. Taking "using" for example; it indicated the practical technique was rising and was able to becoming the hotspot in the risk assessment research. "Water," whose percentage of appearance time in the recent 4 years came up to 56%, pointed out that water-related research was playing a more important role in this field.

Distribution of Author Keyword Analysis

The titles of articles and author keywords supply "reasonably" details of the articles' subject. Especially author keywords analysis could offer the information of research trend that is concerned by researchers. Bibliometric method concerning

Table 6. Top 20 most frequently used substantives in title words during 1992–2007 and 4 four-year periods.

Title words	92–07 TP	92–95 TP (%)	96–99 TP (%)	00–03 TP (%)	04–07 TP (%)
exposure	920	93 (10)	166 (18)	252 (27)	409 (44)
analysis	818	60 (7.3)	150 (18)	232 (28)	376 (46)
effects	767	51 (6.6)	143 (19)	220 (29)	353 (46)
using	762	40 (5.2)	124 (16)	213 (28)	385 (51)
study	723	33 (4.6)	122 (17)	203 (28)	365 (50)
health	700	50 (7.1)	120 (17)	222 (32)	308 (44)
cancer	681	43 (6.3)	119 (17)	207 (30)	312 (46)
human	657	74 (11)	112 (17)	180 (27)	291 (44)
model	655	59 (9.0)	101 (15)	196 (30)	299 (46)
environmental	612	67 (11)	121 (20)	191 (31)	233 (38)
evaluation	541	48 (8.9)	100 (18)	158 (29)	235 (43)
toxicity	514	58 (11)	89 (17)	148 (29)	219 (43)
patients	503	32 (6.4)	74 (15)	140 (28)	257 (51)
use	472	59 (13)	95 (20)	153 (32)	165 (35)
approach	456	44 (10)	80 (18)	105 (23)	227 (50)
management	455	44 (10)	93 (20)	124 (27)	194 (43)
data	431	39 (9.0)	73 (17)	131 (30)	188 (44)
disease	420	20 (4.8)	63 (15)	111 (26)	226 (54)
soil	396	28 (7.1)	89 (22)	108 (27)	171 (43)
ecological	388	30 (7.7)	102 (26)	134 (35)	122 (31)
water	381	9 (2.4)	56 (15)	102 (27)	214 (56)
development	346	34 (10)	72 (21)	85 (25)	155 (45)
comparison	337	31 (9.2)	73 (22)	84 (25)	149 (44)
application	326	39 (12)	65 (20)	82 (25)	140 (43)
safety	326	36 (11)	63 (19)	96 (29)	131 (40)
risks	324	26 (8.0)	62 (19)	95 (29)	141 (44)
modeling	319	41 (13)	50 (16)	82 (26)	146 (46)
based	307	26 (8.5)	60 (20)	95 (31)	126 (41)
new	296	29 (10)	49 (17)	79 (27)	139 (47)

TP: Appeared times of title words in whole study period; TP (%): Appeared times of title words in specific sub-period and its percentage in whole study period.

author keywords analysis can only be found in recent years (Ho 2007; Chiu and Ho 2007) whereas using the author keywords to analyze the trend of research is much more infrequent (Xie *et al.* 2008; Li *et al.* 2009). The technique of statistical analysis of author keywords might be aimed at discovering directions of scientific research, and prove important for monitoring development of science and programs. Examination of author keywords in this study period revealed that 27,252 author keywords were used, among which 20,578 keywords appeared only once, and 3088 keywords appeared twice. The large number of once or twice only author keywords probably indicated a lack of continuity in research and a wide disparity in research focuses (Chuang *et al.* 2007).

Author keywords appeared in the articles referring to risk assessment were calculated and ranked by total 16-year and four 4-year sub-periods. The author keywords that appeared more than 80 times in all in the last 16 years are displayed in Table 7. Synthetically analyzing these words, it could be concluded that risk assessment had infiltrated into many subject categories (*e.g.*, ecology, toxicology, and environmental science). Taking the most often used 20 author keywords, for example, "ecological risk assessment" and "bioavailability" were mainly from ecology; "epidemiology," "cancer," and "osteoporosis" came from epidemiology; "toxicity" and "pesticides" might come from toxicology; "arsenic," "heavy metals," and "exposure assessment" mainly came from environmental science, especially in the field of soil and water–related research.

Different from segmenting the title into single words in paper title analysis, in this section, we preserved the intact words that the authors want to transmit to the readers. Systemically analyzing the top 50 most frequently appearing author keywords, we could roughly draw the research trend of each sub-period. During the first sub-period (1992–1995) the research hotspot mainly focused on two branches. One was toxicology and epidemiology, especially on cancer-related research, because except for the searching keyword "risk assessment" the most frequently appearing five author keywords in this sub-period were "epidemiology (appearing 18 times)," "risk (18)," "anxiety (15)," "risk factor (13)," and "cancer (11)." As early as 1992, two cancer-related articles were published in *Science*; one was "Rodent carcinogens—Setting priorities" (Gold *et al*. 1992) and the other was "Multistep carcinogenesis—A 1992 perspective" (Sugimura 1992) that were cited 109 and 207 times, respectively, since they were published to 2007. As another evident proof, "P53—At the crossroads of molecular carcinogenesis and risk assessment" (Harris 1993) was published in *Science* in 1993, and was cited 437 times since it was published to 2007. Other frequently used author keywords, such as "ecological risk assessment (10)," "benzene (9)," "exposure (7)," and "pesticides (6)" indicated that the other research branch was ecology and environmental science. Proofs could also be found in the famous scientific journals *Science* and *Nature*. In 1993, "Insitu stimulation of aerobic PCB biodegradation in Hudson River sediments" (Harkness *et al*. 1993) was published in *Science*, and was cited 119 times until 2007. In the next year, "Genetically based n-acetyltransferase metabolic polymorphism and low-level environmental exposure to carcinogens" (Vineis *et al*. 1994) was published in *Nature*, which was also highly cited (232 times) until 2007. Compared with the first sub-period, in the next 4 years (1996–1999), "ecological risk assessment" (66) became the most frequently used author keyword except for the searching keyword, which implied that ecological risk assessment had been paid more attention to. Epidemiology, especially cancer risk assessment, remained popular during these 4 years, because "epidemiology" (31) and "cancer" (22) were still among the top 20 frequently used author keywords. In conjunction with other popular author keywords of this period, environmental and toxicological risk assessment were attracting extensive attention. The frequently used author keywords such as "benzene (15)," "heavy metals (15)," "cadmium (15)," "polychlorinated biphenyls (14)," "dioxin (12)," "mercury (11)," and "arsenic (11)" indicated that more attention had been paid on the toxicity of pollutants and their adverse effect on human health. In 1997, the article "Environment and cancer: who are susceptible?" (Perera 1997) was published in *Science*, and was cited 278 times until 2007, revealing the increasing concern of the relationship between environment and human health. In the next two sub-periods, the key

Table 7. Author keywords appeared more than 80 times during 1992–2007 and 4 four-year periods.

Author keywords	TP	92–07 R (%)	92–95 R (%)	96–99 R (%)	00–03 R (%)	04–07 R (%)
risk assessment	3440	1 (31)	1 (37)	1 (33)	1 (32)	1 (28)
risk	243	2 (2.2)	2 (2.5)	3 (2.7)	4 (1.9)	2 (2.1)
ecological risk assessment	239	3 (2.1)	8 (1.4)	2 (3.6)	2 (2.5)	3 (1.5)
risk management	190	4 (1.7)	14 (1.1)	4 (2.0)	3 (2.4)	9 (1.2)
risk factors	175	5 (1.6)	5 (1.8)	13 (1.4)	5 (1.7)	4 (1.5)
epidemiology	167	6 (1.5)	2 (2.5)	9 (1.7)	8 (1.4)	5 (1.3)
uncertainty	162	7 (1.4)	34 (0.68)	4 (2.0)	6 (1.5)	8 (1.3)
risk analysis	152	8 (1.4)	8 (1.4)	11 (1.5)	10 (1.3)	7 (1.3)
toxicity	151	9 (1.3)	11 (1.2)	11 (1.5)	7 (1.5)	10 (1.2)
exposure assessment	138	10 (1.2)	34 (0.68)	6 (1.8)	12 (1.2)	12 (1.1)
pesticides	137	11 (1.2)	21 (0.82)	6 (1.8)	8 (1.4)	15 (1.0)
exposure	134	12 (1.2)	16 (1.0)	15 (1.3)	11 (1.2)	11 (1.2)
bioavailability	116	13 (1.0)	80 (0.41)	32 (0.77)	19 (0.84)	5 (1.3)
soil	106	14 (0.94)	34 (0.68)	16 (1.2)	15 (0.87)	18 (0.94)
anxiety	105	15 (0.94)	4 (2.0)	6 (1.8)	34 (0.62)	30 (0.7)
rat	104	16 (0.93)	58 (0.54)	14 (1.4)	13 (1.0)	25 (0.77)
cancer	99	17 (0.88)	6 (1.5)	16 (1.2)	15 (0.87)	30 (0.70)
arsenic	97	18 (0.86)	80 (0.41)	41 (0.61)	20 (0.81)	14 (1.0)
heavy metals	96	19 (0.86)	382 (0.14)	25 (0.83)	34 (0.62)	13 (1.1)
osteoporosis	94	20 (0.84)	58 (0.54)	22 (0.88)	26 (0.68)	16 (1.0)
biomarkers	94	20 (0.84)	34 (0.68)	19 (1.0)	15 (0.87)	24 (0.79)
fish	87	22 (0.77)	382 (0.14)	41 (0.61)	14 (0.90)	19 (0.84)
environmental risk assessment	86	23 (0.77)	58 (0.54)	32 (0.77)	26 (0.68)	19 (0.84)
prevention	83	24 (0.74)	58 (0.54)	56 (0.50)	52 (0.56)	16 (1.0)

TP: publications in the study period; R (%): the rank and percentage of the author keywords.

research trend changed a little. Ecological and environmental risk assessment together with the related research in epidemiology still dominated this field. But research emphasis never stopped changing. For example, "bioavailability (27)" and "bioaccumulation (19)" of ecosystem was paid more attention to in these subperiods, meanwhile, "exposure assessment (39)" became more and more popular in the assessment of pollutants' toxicity.

During the whole study period, rankings of some author keywords shifted dramatically. For instance, "sediment," which could be rarely found in the publications between 1992 and 1995, soared to "138th" in 1996–1999, "43rd" in 2000–2003, and "51st" in 2004–2007. In conjunction with other related author keywords, we could infer that the toxicity of pollutants in sediment, such as heavy metals, PAHs, and PCBs, and their adverse effect were paid more attention to. In early times of the study period, Long *et al.* (1995) pointed out the adverse biological effects of trace metals, PCBs, and pesticides in marine and estuarine sediments and gave the guidelines of them. Chapman *et al.* (1998) did some research on the cotoxicology of metals in aquatic sediments. Then the "sediment"-related articles went into a booming period. This kind of author keyword became more frequently used, including "zinc," "pharmaceuticals," "water quality," "inflammation," and "climate change." On the contrary, some author keywords were losing their research potency in the study period since they gradually disappeared in the list of frequently used author keywords. Taking "carcinogenic potency" for example, it ranked 80th in 1992–1995; fell to 284th in 1996–1999; and then straightly descended to 1029th in 2000–2003. Finally, it could not be found during 2004–2007, which indicated that it was not a popular topic any more. This kind of author keyword included "benzodiazepines," "pharmacokinetic modeling," "tetrachloroethylene," "genetic engineering," and so forth.

Distribution of Keyword Plus Analysis

The keyword plus in the SCI database supplied additional search terms extracted from the titles of articles cited by authors in their bibliographies and footnotes (Garfield 1990a,b). In paper title analysis, as we segment the title into single words, the result is not repeated and can be statistically analyzed by rule and line; however, it breaks the integrality of phrase in title, while in author keywords analysis, we preserve the intact words that the authors want to transmit. Although it makes the same single word or phrase appear in different author keywords, we can compare discrimination between author keywords, or sum up the dissimilar keywords with common phrase or single word for further study. The keyword plus analysis as an independent supplement reveals the article contents with more details. There are some similar and dissimilar trends between their statistical results in this study period. The distribution of the keywords plus with its rank and percentage in different periods is revealed in Table 8. As a whole, the research tread revealed by keywords plus was consistent with author keywords. "Toxicity," "risk," and "cancer" were also emphases of keywords plus in the study period. However, keywords plus gave special prominence to "exposure," "mortality," "in-vitro," and "drinking-water." Meanwhile, it weakened the leading status of "ecological risk assessment," which was different from author keywords.

Table 8. Top 25 frequently used keywords plus during 1992–2007 and 4 four-year periods.

Keywords plus	TP	92–07 R (%)	92–95 R (%)	96–99 R (%)	00–03 R (%)	04–07 R (%)
risk assessment	1,271	1 (9.5)	1 (14)	1 (14)	1 (14)	3 (4.6)
risk-assessment	887	2 (6.6)	N/A	689 (0.13)	60 (1.0)	1 (13)
exposure	791	3 (5.9)	2 (6.8)	2 (5.9)	2 (6.6)	2 (5.3)
toxicity	639	4 (4.8)	4 (5.2)	3 (5.7)	3 (5.1)	4 (4.2)
risk	480	5 (3.6)	12 (2.5)	9 (2.8)	4 (3.7)	5 (3.9)
model	432	6 (3.2)	20 (1.8)	7 (2.9)	5 (3.5)	6 (3.4)
mortality	410	7 (3.1)	8 (3.2)	7 (2.9)	7 (3.2)	7 (3.0)
rats	361	8 (2.7)	3 (5.4)	5 (3.8)	6 (3.2)	31 (1.5)
united-states	330	9 (2.5)	26 (1.6)	11 (2.4)	14 (2.2)	8 (2.8)
mice	327	10 (2.4)	5 (4.8)	4 (3.9)	8 (2.5)	35 (1.5)
disease	322	11 (2.4)	11 (2.8)	16 (1.9)	10 (2.3)	10 (2.5)
management	315	12 (2.3)	41 (1.2)	20 (1.7)	8 (2.5)	9 (2.6)
cancer	305	13 (2.3)	6 (3.4)	6 (3.0)	11 (2.3)	20 (1.8)
chemicals	280	14 (2.1)	13 (2.3)	10 (2.7)	15 (2.1)	21 (1.8)
women	273	15 (2.0)	56 (1.0)	18 (1.8)	13 (2.2)	14 (2.2)
water	269	16 (2.0)	32 (1.4)	13 (2.1)	20 (1.7)	11 (2.3)
health	265	17 (2.0)	20 (1.8)	15 (2.0)	12 (2.2)	19 (1.8)
prediction	259	18 (1.9)	26 (1.6)	38 (1.3)	18 (1.9)	12 (2.2)
prevalence	251	19 (1.9)	17 (1.9)	32 (1.4)	25 (1.6)	13 (2.2)
population	250	20 (1.9)	32 (1.4)	24 (1.6)	23 (1.6)	16 (2.2)
identification	244	21 (1.8)	15 (2.2)	19 (1.8)	19 (1.8)	22 (1.8)
growth	241	22 (1.8)	41 (1.2)	26 (1.6)	17 (2.0)	17 (1.8)
prevention	231	23 (1.7)	121 (0.55)	35 (1.3)	26 (1.5)	14 (2.2)
metabolism	229	24 (1.7)	9 (2.9)	12 (2.3)	22 (1.6)	43 (1.3)
soil	227	25 (1.7)	36 (1.3)	20 (1.7)	20 (1.7)	23 (1.8)

N/A: not applicable
TP: publications in the study period; R (%): the rank and percentage of the keywords plus.

Keywords plus as additional search terms are usually more concerned about the novel research direction than the mature direction in the field (Garfield 1990a,b). For example, "in-vitro" method could reduce or replace the use of animals, or lessen the distress and discomfort of laboratory animals, which was a rapidly developing direction in toxicology. Lots of risk assessment research had adopted the "in-vitro" method (Lamb and Chapin 1992; Goldberg *et al.* 1993; Wester *et al.* 1993). Other words, such as "exposure," "mortality," and "drinking-water," were all closely correlative to the health of human beings, which reflect that one purpose of risk assessment was to provide a normalized process to evaluate human, animal, and ecological responses associated with exposure to some environmental agents (Anderson and Hilaire 2004).

Research Hotspot Analysis

A completely new method named the "word cluster analysis" was successfully used to analyze the research hotspot in the field of risk assessment. It was a continuation of

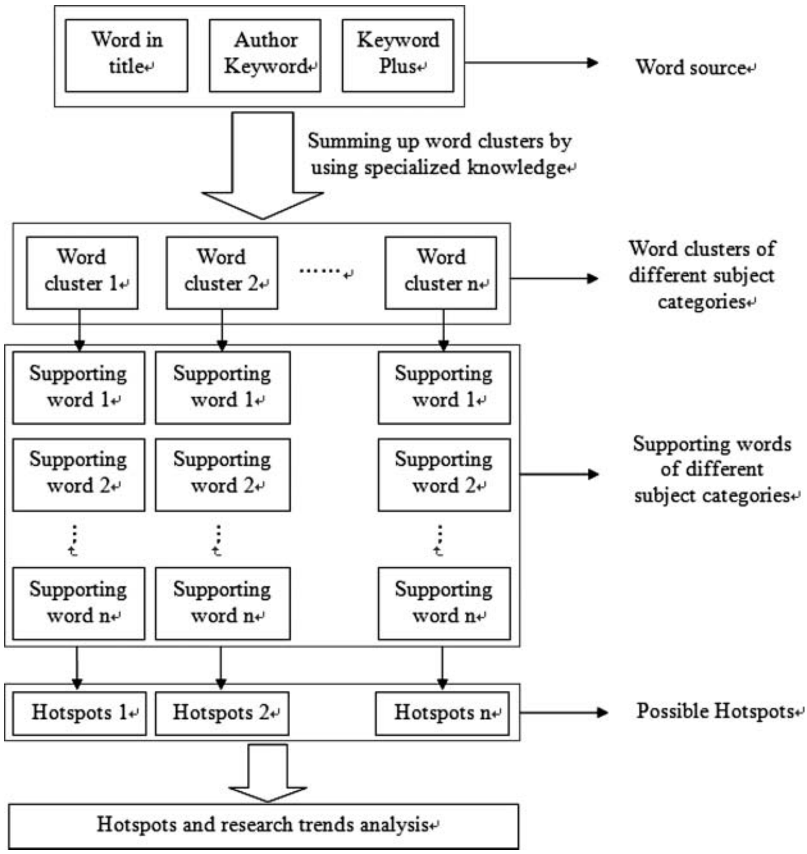

Figure 5. Sketch map of the "Word Cluster Analysis" approach.

the three key words (word in title, author keyword, and keyword plus) analysis. The approach of doing "word cluster analysis" was as follows. After systematically analyzing the distribution of the three keywords, researchers could get some valuable clues of the possible research hotspots. First, paper title, author keyword, and keyword plus were combined together as the "word source." Then, researchers had to use their specialized knowledge to distill "word cluster" of different subject categories from the word source. The "word cluster" was a series of synonymic words or congeneric phrases (called supporting words) that 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. Distilling "word clusters" was the most important step of doing the "word cluster analysis." In this step, researchers had to adequately use their specialized knowledge and the valuable clues that were gotten by analyzing the three keywords. At last, by analyzing the number of articles containing these "word clusters" researchers could get an outline of the research hotspots. A sketch map of the "word cluster analysis" approach is shown in Figure 5.

Taking risk assessment research, for example, after synthetically analyzing the distribution of the three keywords, we summed up the research hotspot into three subjects: environmental science, ecology, and epidemiology, especially cancer-related research. Generally speaking, hotspot of environmental science lies in exposure, PCBs, dioxin, and "metal" related research. Each hotspot was supported by a single word or word cluster. For example, exposure was supported by "exposure assessment," "occupational exposure," "environmental exposure," and "dietary exposure." PCBs' supporting words was composed of "PCBs," "polychlorinated biphenyls," and "PCB congeners." "Metal," "heavy metal," "arsenic," "lead," "plumbum," "copper," "cuprum," "zinc," "zincum," "cadmium," "selenium," "mercury," "hydrargyrum," "chromium," and "nickel," together with the element symbol of each metal mentioned above comprised the supporting word cluster of metal. Supporting words of dioxin were composed of "dioxin," "PCDD," "PCDF," "polychlorinated dibenzofuran," and "polychlorinated dibenzo-p-dioxin." Hotspots of ecology were classified into two sub-groups. One was biological-related research, whose supporting word cluster included "bioavailability," "biomarker," "bioaccumulation," "biomonitoring," "biodiversity," "biological," "bioassays," "bioindicator," "bioremediation," "bioconcentration," and other words and phrases containing "biological." The other was ecological-related research, whose supporting words contained "ecotoxicology," "ecotoxicity," "ecosystem," and "ecological." Cancer and carcinogen related research

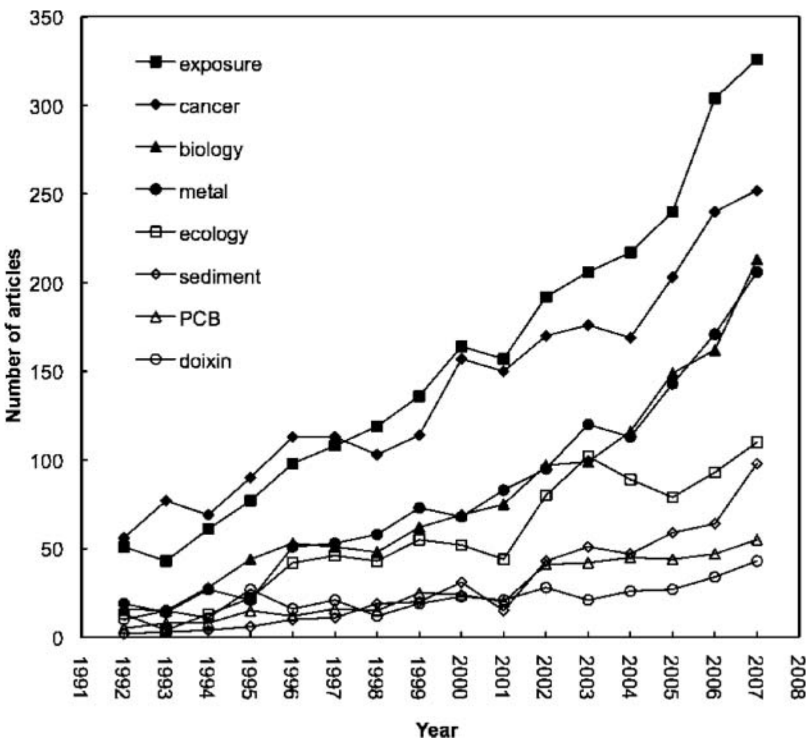

Figure 6. Growth trends of hotspot-related articles in the recent 16 years.

was supported by "cancer," "tumor," "carcinoma," and "carcinogen." Articles concerning these supporting word clusters were analyzed and the distribution of these articles is displayed in Figure 6. Generally, the hotspots mentioned earlier could be reflected by some highly cited articles. Taking exposure-related research for example, exposure assessment method was adopted by Hayes *et al.* (2002) in order to determine the effect of herbicide atrazine at low ecologically relevant doses on frogs. Chlebowski *et al.* (2003) used the exposure assessment method to determine the influence of estrogen plus progestin on breast cancer.

CONCLUSIONS

In this study dealing with risk assessment SCI papers, we obtained some significant points on the worldwide research trends throughout the period from 1992 through 2007. The effort provided a systematically structural picture, as well as clues to the impacts of the risk assessment topic. English was by far the dominant language, while 17 other languages were also used. It indicated that risk assessment became more globally connected. Apparently more and more authors, institutes, and countries engaged in the research over the 16 years. The USEPA was the pioneer in the field of risk assessment, as it had the most independent/cooperative/first authored/corresponding authored publications. Furthermore, the h-index of the USEPA was the highest. The G7, together with The Netherlands, owned a long research tradition in this field. They had not only the absolute ascendancy of publication, but also the most-frequent research partners and high h-indices. Overall 27,634 articles were published in 2690 journals in 204 subject categories with a great diversity. The number of journals publishing three parts of articles approximately followed the Bradford's law. The mainstream of risk assessment research was in environmental science, toxicology, and public, environmental, and occupation health related fields. Systematically analyzing the distribution of paper title, author keyword, and keyword plus, it could be concluded that application of risk assessment mainly focused on two branches. One was toxicology and epidemiology, especially on cancer-related research, and the other was ecology and environmental science. By using the "word cluster analysis" method, we could infer that the hotspots of risk assessment–related research mainly focus on environmental science, ecology, and epidemiology (especially cancer-related research). The result analysis by using this new bibliometric method can help relevant researchers realize the panorama of global risk assessment research, and establish the further research direction.

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