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Bibliometric analysis of global environmental assessment research in a 20-year period

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ABSTRACT

Based on the samples of 113,468 publications on environmental assessment (EA) from the past 20 years, we used a bibliometric analysis to study the literature in terms of trends of growth, subject categories and journals, international collaboration, geographic distribution of publications, and scientific research issues. By applying thresholds to network centralities, a core group of countries can be distinguished as part of the international collaboration network. A frequently used keywords analysis found that the priority in assessment would gradually change from project environmental impact assessment (EIA) to strategic environmental assessment (SEA). Decision-theoretic approaches (i.e., environmental indicator selection, life cycle assessment, etc.), along with new technologies and methods (i.e., the geographic information system and modeling) have been widely applied in the EA research field over the past 20 years. Hot spots such as "biodiversity" and "climate change" have been emphasized in current EA research, a trend that will likely continue in the future. The h-index has been used to evaluate the research quality among countries all over the world, while the improvement of developing countries' EA systems is becoming a popular research topic. Our study reveals patterns in scientific outputs and academic collaborations and serves as an alternative and innovative way of revealing global research trends in the EA research field.

Introduction

Over the last two decades, more and more human environments face challenges due to rapid global urbanization and population growth, especially in certain developing countries (e.g., China and some Southeast Asian countries). Environmental assessment (EA) has been emerging in this context, which is the process of estimating and evaluating the significant short-term and long-term effects of a program or project on the quality of its location's environment, is of increasing public concern, particularly since this process involves identifying ways to minimize, mitigate, or eliminate these effects and/or compensate for their impact. Other processes, such as environmental impact assessment (EIA) and strategic environmental assessment (SEA), are prepared on the basis of an EA. EIA is widely known to be the assessment of the possible impact (positive or negative) of a proposed project on the environment, considering natural, social, and economic aspects (Mondal and Rashmi, 2010). An EIA regime was first determined in legal form in the USA in1969 and was then introduced to legislations of many other countries and organizations. SEA is considered to be increasingly important in current EA research and represents a programmatic EIA process that is applied to policies, plans, or programs (Al-Abdulghani et al., 2013). Thus, the targets of SEA are different from traditional EIA objectives (e.g., specific projects), while they have been widely applied by both developed and developing countries to confront increasing complexity behind and around current environmental development and decision-making processes derived from the new forms of proactive intervention in more strategic contexts. Comparing to traditional EIA for projects, new impact assessment tools, inherently adaptable to more strategic, and often incremental, levels of decision-making are therefore needed in building policy and planning, which outcome could largely influence project planning and design. Different EA methods have long been recognized as important tools that can help to develop policy reviews, ecosystems protections, and sustainable development aids in the contemporary world. Thus, it is of urgent importance to understand the global trends of EA research fields that are concerned with sustaining human life.

Bibliometrics refers to the research methodology employed in library and information sciences, which utilizes quantitative analysis and statistics to describe the distribution patterns of articles within a given topic, field, institution, or country. Many investigators have recently used these methods in global trends studies of specific fields (Vergidis et al., 2005; Falagas et al., 2006; Kumari, 2006). Bibliometric methods have been applied to assess the scientific outputs or research patterns of authors, journals, countries, and institutes and to identify and quantify international cooperation (Abramo et al., 2011; Chiu and

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Ho, 2007; Ho et al., 2010). For example, in order to analyze the global trends of research productivity in tropical medicine, Falagas et al. (2006) studied the contributions of different world regions to the published research of leading tropical medicine journals during the period of 1995 to 2003. Similarly, Rajendram et al. (2006) used statistic methods to describe the worldwide alcohol-related research from 1992 to 2003. An assumption is made in these studies that the number of research publications of a country in a certain scientific subfield reflects its commitment to the state of science and is a reasonable indicator of the country's Research and Development efforts in that field. However, traditional bibliometric analysis in scientific research fields has two universal deficiencies. First, the original data are usually insufficient, as many studies only select a limited number of journals or categories to represent global research trends related to a given topic (Klein and Hage, 2006; Mela and Cimmino, 1998). Second, changes in the number of citations or publication counts within certain countries and organizations cannot completely represent the development trends or future orientations of that research field (Arrue and Lopez, 1991). Thus, additional quantitative information related to topics and geophysical distributions of the research itself should be introduced into any bibliometric study of research trends (Chuang et al., 2007; Li et al., 2009; Liu et al., 2011; Wang et al., 2013). It has been shown that some newly developed bibliometric analysis provides a spatial distribution of authors and the country/institution collaboration network (Liu et al., 2011). Recently, a new index, the geographic impact factor (GIF), was constructed to evaluate the academic geographic influence of authors in a specific scientific field during a certain period (Zhuang et al., 2012).

In this study, we attempt to use bibliometric methods to quantitatively and qualitatively study the global research trends of EA-related research. Common research tools utilized by bibliometric practitioners include the Science Citation Index (SCI) and Social Science Citation Index (SSCI), which are searchable databases of publications that are maintained by the Institute for Scientific Information (ISI). Keywords may be input into the SCI and SSCI, and the output can be used to determine the impact of authors, institutes, countries, etc. in a particular discipline. The data presented in this work represent the contributions of the major regions of the world to research productivity, published during a 20-year period in all the SCI and SSCI journals within the field of EA-related research. The aims of this study were to reveal underlying patterns in scientific outputs, characteristics of international collaboration, and author distribution of EA-research; to establish the medium- and long-term strategies of these fields; and to develop priority strategies for the future.

Data source and methodology

The methodology used in this research was similar to recent bibliometric studies from our collaborators (Chuang et al., 2007; Wang et al., 2013). Data were obtained from the online version of the ISI Web of Science: SCI (Science Citation Index). "Environment* assess*" (including "environmental impact assessment", "plan environmental impact assessment", "strategic environmental impact assessment", "strategic environmental assessment", et al.) were used as keywords to search all articles from 1993 to 2012 that contained these words in the title, abstract, or keywords list. We elected to drop any 2013 articles from our search because some of the latest publications from 2013 may not have been uploaded to the online database by the time of our data collection. In total, 135,426 publications met the selection criteria. Upon further examination, only 113,468 of these publications (83.8%) were categorized as "articles" and used for further analysis as relevant citable items in this study.

Downloaded information from each article included the following: names of authors, contact address, title, year of publication, keywords, subject categories, names of publishing journals, and times cited for each year. The records were downloaded into spreadsheet software, and additional programming was manually performed regarding the number of authors, country of origin of the collaborators, and impact factors of the publishing journals (Zhuang et al., 2012). Impact factors were taken from the *Journal Citation Report* (JCR) published in 2012. The h-indexes related to total citations were calculated for all countries with more than 50 articles during the selected period. The h-index is defined by the h of total N papers with *at least* h citations each while the other (N-h) papers have h citations each (Bar-Ilan, 2008; Hirsch, 2005). To be specific, the h-index for an author or a country is the number h of papers among an author or a country's number of publications (Np) that have at least h citations each. The collaboration type was identified through the address of each author, as "independent" was assigned to this field if no collaboration was present while "international collaboration" was assigned if the paper was cosigned by researchers from more than one country.

For the purposes of the study, we classified the various countries into eight world regions: Europe, the United States of America (USA), Asia (excluding China), North America (excluding the USA), Oceania, South America, China, and Africa. This classification is based on a combination of geographic, economic, and scientific criteria (United Nations Statistical Yearbook, 2004). The number of published articles was used as indexes of research productivity. The emphasis of this work was to determine the characteristics of scientific articles based on research activity trends (e.g., categories, journals, and country distributions) and trends in the research subjects (e.g., author keywords).

Results and discussion

Article characteristics

Several publication output characteristics of current EA research during the time span of 1993 to 2012 are summarized in Table 1. As the table shows, the annual number of articles, the average number of authors, and the annual number of countries and journals publishing EA-related literature increased significantly. Only 1607 articles were published in 1993 but rose to 13,072 in 2011 and 14,557 in 2012. In addition, while the average number of authors per EA article was 3.0 for 1993, this number steadily increased to 4.7 by 2012. The article with the most authors (125), published in *Atmospheric Chemistry and Physics*, 2011, provided the results of the European Aerosol Cloud Climate and Air Quality Interactions project (EUCAARI), which can be used in both European and global environmental assessments of the impact of aerosol as well as corresponding abatement strategies (Kulmala et al., 2011). The annual number of countries that participated in EA research increased rapidly during the selected period, beginning with a minimum of 81 countries in 1993 and rising to a maximum of 163 in 2012. Along with the development of ISI, an increasing number of journals published research papers related to environmental assessment. The average article lengths fluctuated slightly, with an overall average of 11.1 pages. Twenty-seven references were cited per article in 1993, compared to 45 references per article in 2012, an obvious increase over the course of this 20-year period.

The cumulative progression in the number of articles from 1993 to 2012 is further illustrated by Fig. 1. By utilizing a logistic regression model, we simulated the growth pattern based on the cumulative publications in each year from the 1993 as the first year, which can be expressed as follows (Reed and Pearl, 1927):

$$P = 1610.8 \times e^{0.1106t}, \tag{1}$$

where P is the annual number of articles and t is the number of years after 1993 (for $t = 0, 1, 2, \ldots, 19$). Due to the high coefficients of determination ($r^2 = 0.979$) of Eq. (1), the world publications related to EA research could be estimated using this statistical model. The fit of the logistic model showed that yearly publications experienced distinct growth, marked by an increased rate, and the inflexion of the logistic model would probably occur in 2023 (29.8 years after 1993), which indicates that the current growth rate could be sustained, at least in the next 10 years. Based on the model of our study period, it can be calculated that, in 2019, the annual number of scientific papers on the topic of

Table 1
Major characteristics of the publication of environment assessment research.

Year	A	PG	NR	AU	C	TC	TC/A	AU/A	PG/A	NR/A	J	A/J
1993	1627	18,498	44,147	4917	81	44,231	27.2	3.0	11.4	27.1	920	1.8
1994	1888	26,885	52,802	5991	76	52,529	27.8	3.2	14.2	28.0	1044	1.8
1995	2138	24,268	65,732	6751	75	64,345	30.1	3.2	11.4	30.7	1184	1.8
1996	2452	27,465	81,374	7921	88	72,233	29.5	3.2	11.2	33.2	1277	1.9
1997	2643	29,614	88,284	8960	93	79,442	30.1	3.4	11.2	33.4	1357	1.9
1998	2918	33,368	97,558	10,026	103	85,919	29.4	3.4	11.4	33.4	1437	2.0
1999	3116	35,349	107,301	11,078	105	91,760	29.4	3.6	11.3	34.4	1573	2.0
2000	3339	37,334	113,943	12,168	100	101,028	30.3	3.6	11.2	34.1	1573	2.1
2001	3528	39,052	122,171	12,891	102	95,219	27.0	3.7	11.1	34.6	1662	2.1
2002	4093	45,569	145,389	15,467	116	108,745	26.6	3.8	11.1	35.5	1768	2.3
2003	4580	52,389	166,123	17,509	129	113,778	24.8	3.8	11.4	36.3	1871	2.4
2004	4810	53,832	177,090	19,228	121	111,137	23.1	4.0	11.2	36.8	1991	2.4
2005	5374	60,796	198,906	21,812	129	113,187	21.1	4.1	11.3	37.0	2108	2.5
2006	6261	69,540	235,710	26,088	139	113,023	18.1	4.2	11.1	37.6	2281	2.7
2007	7460	81,299	286,492	31,256	137	112,423	15.1	4.2	10.9	38.4	2705	2.8
2008	8765	95,023	344,690	37,183	138	106,665	12.2	4.2	10.8	39.3	3010	2.9
2009	9444	99,685	376,875	41,242	149	86,673	9.2	4.4	10.6	39.9	3270	2.9
2010	11,403	123,799	487,790	50,932	152	72,839	6.4	4.5	10.9	42.8	3617	3.2
2011	13,072	142,345	579,072	60,392	151	44,782	3.4	4.6	10.9	44.3	3814	3.4
2012	14,557	158,131	654,180	68,245	163	14,315	1.0	4.7	10.9	44.9	4027	3.6
Total	113,468	125,4241	4,425,629	470,057	199	168,4273	14.8	4.1	11.1	39.0	8956	12.7

A, AU, C, J: the annual number of total articles, authors, countries, and journals, respectively; PG, NR: the number of pages and references in total articles, respectively; TC: total number of citations; TC/A: total citation per publication; AU/A, PG/A, NR/A: the average number of authors, pages, and reference per article, respectively; A/J: the average number of articles in an individual journal.

EA will be twice that of 2012, with the growth pace not decreasing before the year 2023.

Journals and categories distribution

Based on the classification of subject categories in the *Journal Citation Report* (JCR) from the ISI database, the publication output data of EA research has been distributed across 280 subject categories during the last 20 years. Subject categories containing 1000 or more EA-related articles were statistically analyzed in Fig. 2. The number of scientific articles per category exhibited sustained growth during the time period covered, which indicates that EA research has been steadily emerging in various categories. In addition, since the use of statistics in any scientific discipline constitutes a key element in evaluating its degree of maturity, our results provided a current view of the environmental assessment research emphases of this topic (Palmer et al., 2005). The three most common categories were "Environmental Sciences and Ecology", "Engineering", and "Public, Environmental and Occupational Health". As the three categories holding primacy throughout the last 20 years, these exceeded other study fields that mainly focused on the methods used in policy, planning, and programming case studies as applied in environmental assessments, such as environmental impact assessment and strategic environmental assessment (Mortberg et al., 2007; Stewart-Oaten and Bence, 2001; Wang et al., 2006). The three aforementioned categories also represent those with the highest growth rates in recent years, as numerous treatment and protection technologies that fall within these categories have been employed to solve environmental issues.

In total, 113,468 articles were published in 8956 journals (SCI and SSCI), including specialty journals as well as journals of other disciplines. Out of the 8956 journals, 6752 (75.4%) contributed less than 10 articles during the entire 20-year period and cannot be identified as

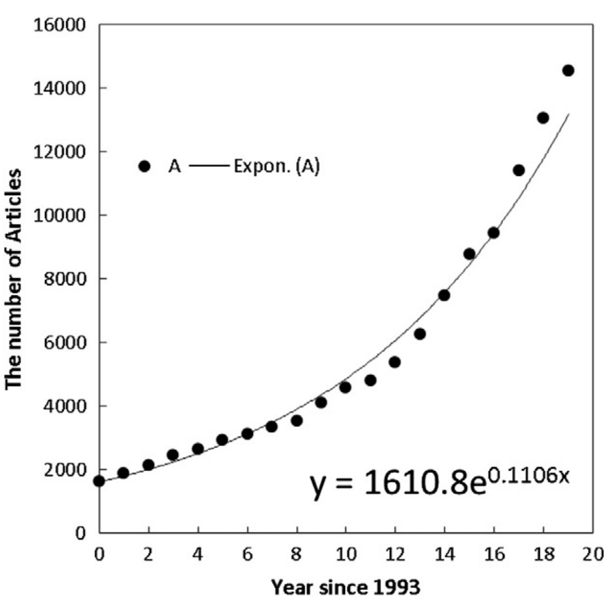

Fig. 1. Annual number of publications during the period of 1993 ~ 2012 (The filled black circle represents the annual cumulative publications from 1993 to the specific year; the curve simulated the growth pattern of global publications based on logistic regression model.

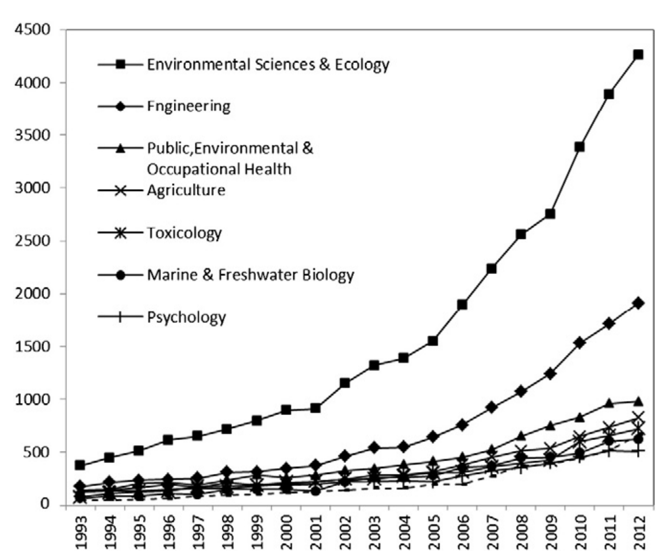

Fig. 2. Comparisons of the growth trends of Subject categories containing 1,000 above Environmental Assessment related articles during the last 20 years.

Table 2
The 15 most active journals with the number of articles, impact factor, ISI subject category of journals, and the position of the journal in its category during the period of 1993 to 2012.

Journal	IF	R (TC)	TC/A	Country	A	Rank (A)			
						93–97	98–02	03–07	08–12
Environmental Science & Technology	5.257	2 (38,033)	29.1	USA	1307	4 (70)	2 (183)	1 (375)	1 (679)
Environmental Toxicology and Chemistry	2.618	5 (19,043)	17.4	USA	1093	1 (101)	1 (197)	2 (279)	4 (516)
Science of the Total Environment	3.258	7 (15,898)	15.9	Netherlands	1003	3 (80)	4 (139)	5 (232)	3 (552)
Chemosphere	3.137	6 (18,100)	19.5	UK	930	2 (93)	5 (120)	4 (260)	5 (457)
Environmental Monitoring and Assessment	1.592	43 (5096)	6.6	Netherlands	767	11 (48)	8 (91)	6 (210)	6 (418)
Environmental Health Perspectives	7.26	3 (27,007)	36.7	USA	735	7 (63)	3 (145)	3 (261)	11 (266)
PLoS One	3.73	68 (3545)	5.2	USA	684	3011 (0)	3769 (0)	385 (14)	2 (670)
Journal of Environmental Management	3.057	24 (7153)	12.7	USA	565	5 (68)	10 (78)	12 (134)	9 (285)
International Journal Of Life Cycle Assessment	2.773	35 (5453)	10.6	USA	513	3011 (0)	23 (51)	8 (156)	8 (306)
Applied and Environmental Microbiology	3.678	4 (21,711)	42.9	USA	506	8 (60)	9 (88)	7 (158)	20 (200)
Journal of Cleaner Production	3.398	44 (4995)	9.9	UK	503	3011 (0)	183 (15)	11 (136)	7 (352)
Marine Pollution Bulletin	2.531	17 (8287)	17.4	USA	475	10 (50)	11 (75)	9 (137)	16 (213)
Environmental Management	1.647	40 (5170)	11.4	USA	454	9 (56)	7 (112)	15 (122)	27 (164)
Environmental Pollution	3.73	21 (7687)	18.2	UK	422	18 (35)	18 (56)	17 (108)	13 (223)
Aquatic Toxicology	3.73	12 (8908)	21.7	Netherlands	411	81 (17)	22 (53)	16 (120)	14 (221)

IF: the journal impact factor; R (TC): the rank and the number of the total number of citations of the individual journal; TC/A: the average number of total number of citations per article of the journal; Country: the journal country; A: the number of total articles; Rank (A): the rank of the total number of articles.

popular journals in this field. Table 2 shows quantitative and citation attributes for the 15 most productive journals, including a ranking of paper quantities within four distinct sub-periods: 1993–1997, 1998–2002, 2003–2007, and 2008–2012. As the flagship journal of this particular research field, the USA journal *Environmental Science & Technology* published the most EA research papers (1307; 1.2%), followed by *Environmental Toxicology and Chemistry* (USA; 1093; 1.0%) and *Science of the Total Environment* (Netherlands; 1003; 0.9%). During the entire period, a decrease of ranking in annual publications occurred for the following journals: *Marine Pollution Bulletin*, *Environmental Management*, and *Environment International*. On the contrary, the publication quantities of *Energy Policy*, *Agriculture Ecosystems & Environment*, and the *Journal of Applied Ecology* experienced such significant growth that they ranked 13th, 14th, and 36th, respectively, during the period of 2008–2012. Throughout the field of EA research, the journal with the highest impact factor (IF) was *CA:A Cancer Journal for Clinicians* (63.342; USA), followed by the *New England Journal of Medicine* (51.296; USA) and *Nature Reviews Cancer* (31.583; England). The most frequently cited journal remained *Environmental Science & Technology*, with 38,033 total citations during the study period, although *Applied and Environmental Microbiology* (USA) had the highest average TC score (42.9) among the top 15 core journals. However, while *Applied and Environmental Microbiology* had a higher average TC of individual articles, the journal's IF was slightly lower than that of *Environmental Science & Technology*. The IF is typically used to evaluate a journal's relative importance, especially when compared to others in the same field (Benavent et al., 2004). However, it has been suggested that there is no definite correlation between a journal's impact factor and the citation frequency of the article in question (Walter et al., 2003). Actually, when used to indicate the quality of an article, a journal's impact factor will upgrade bad articles and downgrade good ones (Gisvold, 1999). In the area of EA research, a higher journal impact factor can hardly determine the power of an article. Hence, other factors, such as the h-index, are widely used to qualify the quality of papers or journals in a specific field (Bar-Ilan, 2008). In the next section, we have used the h-index to evaluate the research quality among global countries within the EA field.

Global correlative (divided by eight regions)

There were 605 (0.53%) articles published from 1993 to 2012 without author address information on the ISI Web of Science. Among the remaining 112,863 papers with author address information for that period, 25,330 (22.3%) were international collaborative papers while 87,533 (77.14%) were single-country publications. However, these single-country publications were diverse, covering 149 different countries or territories, with most articles originating from the USA (29,574; 33.8%) and the UK (7351; 8.4%). For further study, we geocoded the affiliations of authors using CiteSpace (Chen, 2004) and plotted the worldwide geographic distribution of authors (Fig. 3). The major spatial clusters of authors in North America, Europe, and East Asia could be clearly distinguished, and we could also discriminate several minor clusters in other parts of the world based on Fig. 3. There were two clusters of authors on the east and west coasts of the United States and another two clusters near London, UK, and Paris, France. These clusters of authors were consistent with the fact that these regions house a large number of universities and research institutes that have made substantial contributions to EA publications. In Fig. 3, very few authors in the environment assessment field are found from Africa and South America. Although more and more attentions have been recently paid on the environmental issues among developing countries in these areas, they are still under the situations that require more latest environmental technologies and managements from developed countries with more experiences during the their long history of environmental assessment and managements.

Data concerning the absolute and relative production of articles in each world region during the selected period are presented in Table 3. With the exception of the earliest five-year period (1993–1998), Europe exceeds all other world regions in publications of EA research during the investigation period. Oceania, South America, and Africa were the areas with the lowest research productivity in the field of environmental assessments. European countries and the USA were the first two regions presenting a constant total product throughout the study period. However, European countries appear to produce more publications and, more importantly, participate in more research collaborations with other regions in the field of EA than the USA. This may be explained by the fact that Europe has a longer tradition in researching environmental protection than the USA. In addition, European countries held many colonies in the developing areas of the world during the 19th and first part of the 20th century (Mulligan, 1981), which could largely facilitate international collaboration among these countries.

For further study, the top 15 countries/territories were ranked by the number of publications produced in each, including the number, h-index, and TC of independent articles and internationally collaborated articles (Table 4). Two North American countries, eight European countries, three Asian countries, one South American country, and one Oceania country were ranked in the top 15 in publications. There were still no African nations within the top 25 most productive countries, although South African ranked 27th in EA research participation. The impact of EA articles among all of the countries can be assessed based

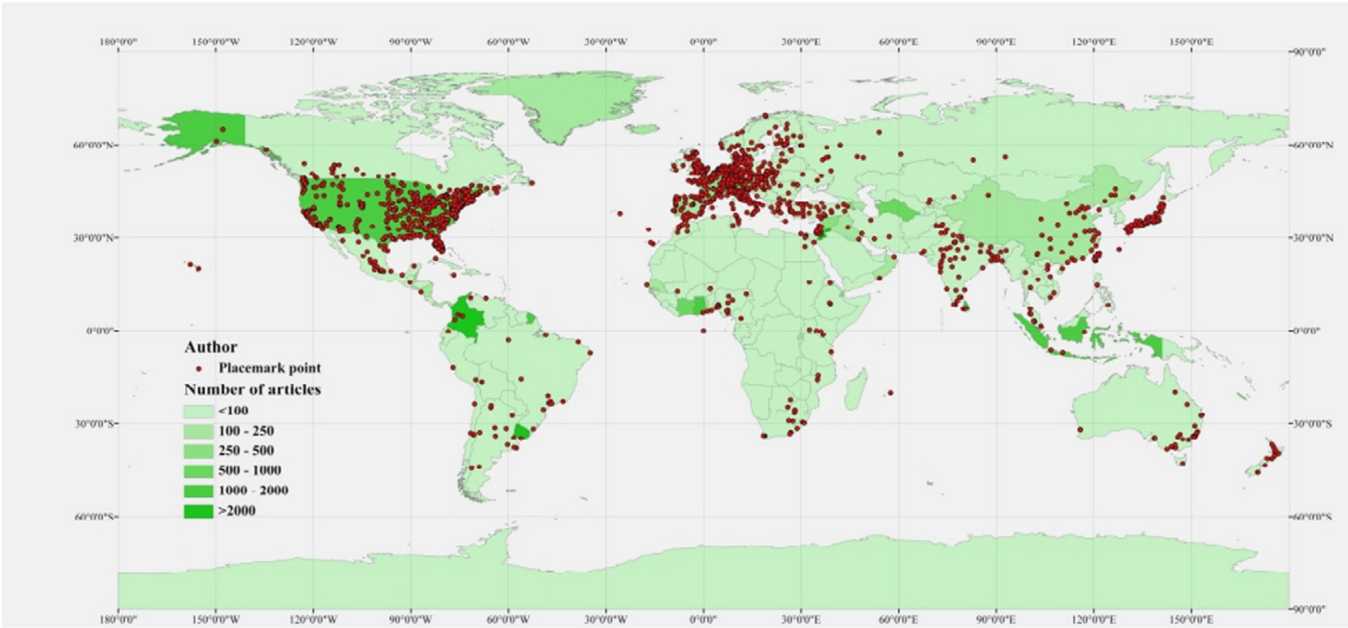

Fig. 3. Global geographic distribution of authors according to the total number of articles by country/territory during the study period from 1993–2012.

on their h-indexes, which have been widely used in the bibliometric field to characterize the scientific output and impact of researchers, institutions, and countries (Garcia-Pachon and Padilla-Navas, 2014; Martinez et al., 2014; Zhai et al., 2014). The USA and UK have the highest h-index among countries all over the world in terms of EA research, indicating a higher quality of publications than other countries. Traditionally developed countries (e.g., Canada, Germany, France, the Netherlands, etc.) from Europe and North America showed higher h-indexes than those of developing countries in Asia and South America (China, Brazil, and India), even as the number of publications in countries like China has risen to a near-equal level though rapid national development in recent years. Previous study has shown that the h-index is correlated with the total number of citations and publications (van Raan, 2006). The relationship between the h-index and the total number of publications can be seen in Fig. 4. An exponential model has been used to simulate the increase of the h-index with the increase in the total number of publications for the world's countries during this 20-year period. A high correlation ($r^2 = 0.92$) can be seen between the fitting line based on the numerical equation and those data points statistically summarized from the dataset in this study. However, there are still countries, such as the Netherlands, Sweden, and Switzerland, that show higher h-indexes with a relatively small number of publications compared to other productive countries, indicating a higher average quality of these nations' publications.

The top 15 productive countries occupied 77.9% of internationally collaborated articles, which signifies these countries' great research abilities in the environment assessment research field. The 7 major industrial countries (G7: Canada, France, Germany, Italy, Japan, the UK, and the USA) were ranked in the top 10 in EA publications. Moreover, the G7 also displayed highly independent productivity within the EA topic, which included 53,536 (61.1% of 87,553 papers) independent publications. The USA produced the most internationally collaborated papers (10,189) followed by the UK (5676), Canada (3398), and Germany (3553). Among 149 different countries or territories, 51 countries had not published any independent publications while only 1 country had not published any collaborative publications. Most of these were developing countries in East Europe, Latin America and the Caribbean, and Africa. The country with the highest average TC scores for both independent and internationally collaborated papers was the USA while India had the lowest average TC per independent article among the top 15 most productive countries. Table 4 also shows that the average TC indicators of all 15 countries' internationally collaborated articles are markedly higher than their national independent articles. Many studies demonstrate that more international collaboration would lead to more powerful publications due to shared ideas and workloads (McKelvey et al., 2003; Yapa et al., 2004). Large differences in the average TC can easily be seen between the internationally collaborated articles and independent articles of some developing countries, such as China, Brazil, and India. It can be concluded that these developing countries significantly benefit from international cooperation with developed countries, particularly in terms of the drinking water research field. By applying a threshold to the network centralities in the

Table 3
The number of scientific publications in the environmental assessment research field of different world regions for the period 1993–2012.

World area	Total	1993–1997	1998–2002	2003–2007	2008–2012
Europe	63,731	4414	8694	16,139	34,484
USA	39,762	4887	6963	10,385	17,527
Asia (excluding China)	12,234	592	1342	2966	7334
North America (excluding USA)	9666	970	1460	2467	4769
Oceania	7595	594	1123	1850	4028
South America	5344	187	484	1167	3506
China	4288	53	168	800	3267
Africa	3954	264	417	980	2293

Table 4
Most productive countries or regions (total, single and cooperation) in drinking water research from 1993 to 2012.

Country/Region	A	h index	Independent			International collaborative			CP/A (%)
			IP	TC	TC/IP	CP	TC	TC/CP	
USA	39,763	214	29,574	567,257	19.2	10,189	205,741	20.2	25.6
UK	13,027	151	7351	132,578	18.0	5676	113,005	19.9	43.6
Canada	8374	114	4976	72,891	14.6	3398	66,100	19.5	40.6
Germany	6957	116	3404	48,178	14.2	3553	67,702	19.1	51.1
Australia	6193	103	3819	56,180	14.7	2374	39,257	16.5	38.3
France	5966	100	3141	45,087	14.4	2825	48,516	17.2	47.4
Italy	5443	86	3321	37,706	11.4	2122	33,364	15.7	39.0
Spain	5050	78	2915	31,486	10.8	2135	31,659	14.8	42.3
China	4288	61	2379	14,455	6.1	1909	21,401	11.2	44.5
Netherlands	4112	100	1808	33,514	18.5	2304	43,287	18.8	56.0
Sweden	3001	92	1350	21,871	16.2	1651	37,050	22.4	55.0
Japan	2781	73	1769	18,512	10.5	1012	15,402	15.2	36.4
Switzerland	2647	94	1060	20,652	19.5	1587	32,390	20.4	60.0
Brazil	2626	52	1773	9841	5.6	853	10,090	11.8	32.5
India	2174	49	1669	11,035	6.6	505	5628	11.1	23.2

IP: the number of independent articles; CP: the number of international collaborative articles; A, total articles; TC: total number of citations; TC/A: average number of TC per article; CP/A, the percentage of international collaborative publications in total publications; h index: defined by the number h of papers among a country's number of publication (Np) that have at least h citations each.

collaborative network of countries/territories, we visualized a core group of countries in the collaborative network using NetDraw (Borgatti, 2002). Network centrality measures the relative importance of nodes within networks and, in our study, could be viewed as an indicator of the countries' positions within the collaborative network. In Fig. 5, the thickness of links represents the strength of collaborations, and the size of red nodes represents the amount of single-institution publications from each country. The USA took the central position in the collaborative network, as it was the principal collaborator among majorly productive countries, including the UK, Canada, and Germany (Fig. 5). It is interesting to see that most European countries are located very close to the network center, which indicates their high productivity in publications and frequent international cooperation with not only developed countries but also developing countries in Asia, Africa, and South America. Although developing countries such as China, India, and Brazil published large amounts of studies related to the environmental assessment field in recent years, they are still located in the edge of the collaborative network (Fig. 5). Most of their collaborations are highly determined by exports of environmental technologies or management methods from developed countries in Western Europe and North America.

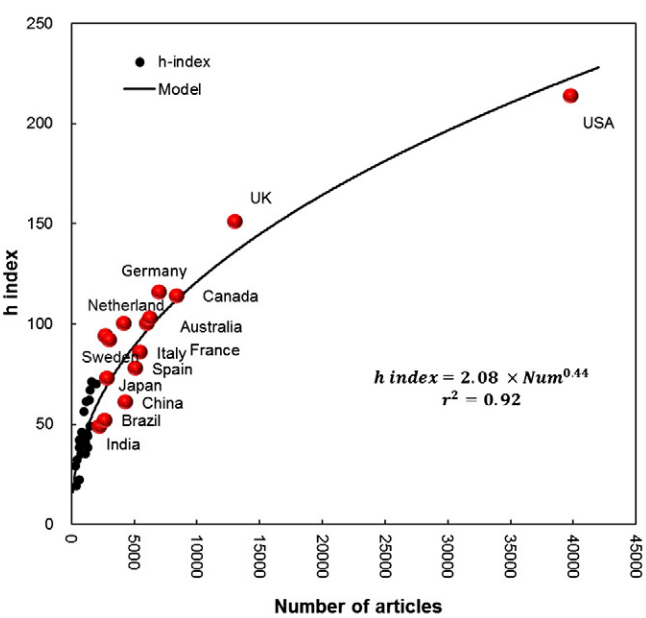

Fig. 4. Quantitative relationships between h-index and total number of articles for countries in the research field of Environmental Assessment Studies during the past 20 years (1993–2012). 15 most productive countries in publications have been labeled as red filled circles.

Author keywords distribution analysis

A keywords analysis was performed to demonstrate EA research trends and frontiers (Arrue and Lopez, 1991; Xie et al., 2008). The keywords analysis in our study utilized author keywords, which were provided by article authors as part of the articles and termed as keywords for simplicity. The 113,468 articles had 158,901 unique keywords, which appeared 439,598 times. However, 114,834 (72.27%) keywords appeared in one paper, and 153,585 (96.65%) keywords appeared in less than 10 papers. The 20 most frequently used keywords representing the research hot spots are shown within each of the 4-year intervals of the study period (1993–2012) in Table 5. During this period, the top 20 keywords appeared 15,377 times (3.5% of total keyword occurrences), which can be used to provide an overview of research trends during the period from 1993 to 2012. The frequency of keywords and their ranks follow the power–law distribution: there was a small group of keywords that were widely used, whereas most keywords were not employed frequently. This power–law distribution has also been discovered by bibliometric studies in other fields (Li et al., 2008; Wang et al., 2011, 2013).

Table 5 also shows that "risk assessment" was ranked among the 20 most frequently used keywords and that approximately 2.33% of articles published during the last 20 years in the EA field used this keyword as a subject. Further, "indicators" was the keyword with the highest rank, apart from our search terms, which demonstrates this term's significance as a tool in various EA research fields. Different environmental, biological, and ecological indicators are widely used to quantitatively assess the environmental quality (Donnelly et al., 2007; Hermann et al., 2007). The temporal evolution of the ranks of the keywords further revealed interesting terminology preferences: "indicators" was the most frequently used author keyword in the period spanning 2008–2012 although it ranked 5th in 1993–1997. This change suggested that the "indicators" selections gained popularity during our studied period. Similarly, there were only 18 articles that used "strategic environmental assessment" as their publication subject from 1993 to 1997, while this number increased to 184 (43rd and 0.41%) in the period of 2008–2012. The steady increase in this field indicates that SEA has become an increasingly important aspect of EA research. Many countries and territories have considered health, safety, and social aspects in SEA (Fischer et al., 2010). In addition, the research scope of EA is more

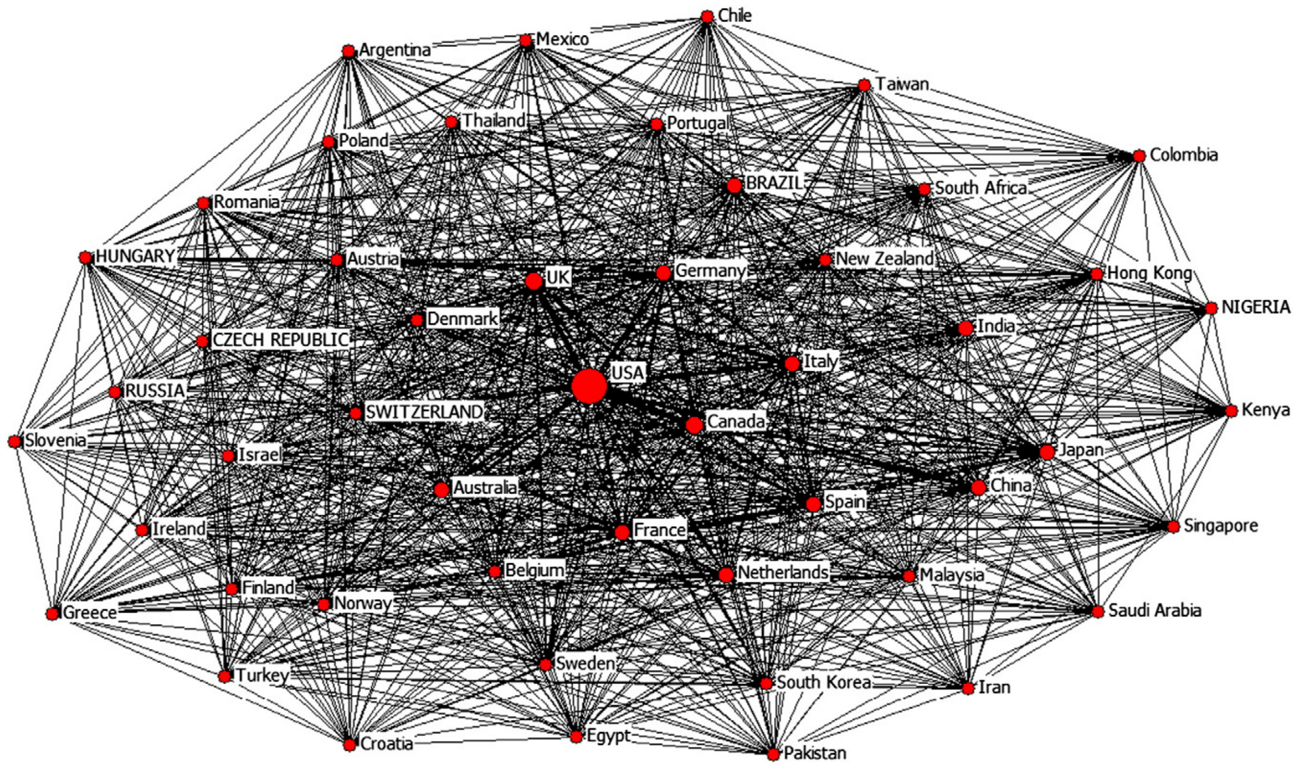

Fig. 5. Core inter-institutional collaboration network (The thickness of links represents the strength of collaborations, and the size of nodes represents the amount of single-institution publications).

extensive, from environmental contamination to ecological damage and social impact, including "climate change", "biodiversity", "water quality", "soil", "social impact", and also public health, as "epidemiology", "asthma", and "toxicity" are progressively becoming important content in EA research. Keywords including "pollution", "water quality", "air pollution", and "waste management" were formerly the focus of EA in the earlier period; however, "biodiversity" and "climate change" have attracted worldwide attention in recent years and were largely taken into the process of EA (Larsen et al., 2013; Safont et al., 2012; Turner et al., 2013). "Climate change" and "biodiversity" increased from last to 3rd and then to 13th during the 2008–2012 time period, and the increasing frequency of their occurrence showed the continued emphasis of these terms in EA publications. Besides the indicators system mentioned above, several other popular decision-theoretic approaches (i.e., "risk assessment", "life cycle assessment", "image analysis", and "dynamics analysis") can also be seen in the statistical results of author

Table 5
Top 20 most frequently used author keywords during the selected period.

Author keyword	1993–2012		1993–1997		1998–2002		2003–2007		2008–2012	
	A	R (%)	A	R (%)	A	R (%)	A	R (%)	A	R (%)
Risk assessment	1925	1 (2.33)	136	1 (2.62)	327	1 (2.99)	587	1 (2.8)	875	2 (1.92)
Indicators↑	1559	2 (1.89)	48	5 (2.25)	208	3 (1.90)	401	2 (1.91)	902	1 (1.98)
Environment	1391	3 (1.68)	117	2 (2.25)	211	2 (1.93)	373	3 (1.78)	690	4 (1.52)
Climate change↑	944	4 (1.14)	24	36 (0.46)	57	31 (0.52)	159	8 (0.76)	704	3 (1.55)
Life cycle assessment↑	887	5 (1.07)	16	73 (0.31)	77	13 (0.71)	206	6 (0.98)	588	5 (1.29)
Children	767	6 (0.93)	38	13 (0.73)	109	5 (1)	224	4 (1.07)	396	7 (0.87)
Heavy metals	704	7 (0.85)	28	28 (0.54)	88	10 (0.81)	208	5 (0.99)	380	9 (0.84)
Epidemiology	665	8 (0.8)	66	4 (1.27)	134	4 (1.23)	157	10 (0.75)	308	13 (0.68)
Sustainability	657	9 (0.8)	23	38 (0.44)	74	17 (0.68)	124	23 (0.59)	436	6 (0.96)
Assessment	656	10 (0.79)	44	9 (0.85)	76	15 (0.7)	148	14 (0.7)	388	8 (0.85)
GIS	630	11 (0.76)	26	30 (0.5)	70	21 (0.64)	174	7 (0.83)	360	10 (0.79)
Water quality	608	12 (0.74)	38	14 (0.73)	72	19 (0.66)	158	9 (0.75)	340	11 (0.75)
Biodiversity↑	563	13 (0.68)	17	66 (0.33)	72	20 (0.66)	154	12 (0.73)	320	12 (0.7)
Stress	557	14 (0.67)	75	3 (1.44)	76	14 (0.7)	131	20 (0.62)	275	18 (0.6)
Asthma	539	15 (0.65)	42	10 (0.81)	90	8 (0.82)	156	11 (0.74)	251	22 (0.55)
Toxicity	537	16 (0.65)	33	21 (0.64)	77	12 (0.71)	151	13 (0.72)	276	17 (0.61)
Environmental impact	511	17 (0.62)	35	19 (0.67)	60	28 (0.55)	137	18 (0.65)	279	14 (0.61)
Fish	488	18 (0.59)	23	39 (0.44)	93	6 (0.85)	130	21 (0.62)	242	27 (0.53)
Monitoring	480	19 (0.58)	26	31 (0.5)	68	22 (0.62)	146	15 (0.7)	240	28 (0.53)
Soil	480	20 (0.58)	37	16 (0.71)	61	26 (0.56)	142	17 (0.68)	240	29 (0.53)
Strategic↑	309	51 (0.37)	18	61 (0.35)	25	138 (0.23)	82	50 (0.39)	184	43 (0.41)

A: the number of articles used the author keyword; R (%): the rank and percentage of the frequency of author keywords used.

keywords. “Life cycle assessment” (LCA) ranked 5th in 2008–2012, showing obvious growth. During the last century, LCA was mainly used in industrial fields, but currently, most researchers have widely used it to assess the impact of products, processes, and activities on the environment (Nie et al., 2010; Ucherek, 2003). Additionally, EA research has focused on applying and improving new techniques and methods, such as “GIS (geographic information system)” and “modeling”. The evaluated objects of EIA or SEA included complexity and flexibility, modeling, monitoring, and other tools or systems and were required to improve the accuracy and reliability of the EA process and its conclusions. In recent years, the need to enhance public participation in the EA field and the efficacy of alternative mechanisms in achieving this goal have been central themes in EA literature (O'Faircheallaigh, 2010). Currently, there is a gap between the EA research of developing countries and that of developed countries, although developing countries are garnering more attention in their EA research pursuits. Accordingly, “developing countries” ranked 678th in 1993–1997, and its rank soared to 25th by 2012. Nevertheless, the EA process in developing countries (i.e., China, Brazil, and India) is primarily project-based with greater emphasis on EIA in these countries' environmental policies, while more strategic environmental assessments are conducted in developed countries (e.g., the USA, Germany, the UK, and Japan). As one of the largest developing countries, the rank of “China” increased from 291st to 13th in the last two decades. Due to China's massive economic growth over this time period, environmental pollution has gradually become one of the nation's major challenges. The field of environmental assessment in China has developed rapidly, while significant improvements in the laws, guidelines, and standards (based on the existing experiences of developed countries) make the Chinese environment assessment process more standardized (Meng et al., 2012).

During further study, we assessed the preferred author keywords for several of the most productive countries in this research field (Table 6). Based on the results of the statistical analysis, different focuses can be clearly observed among various countries over the world. Although “indicators” evaluations have served as an important and popular method for global EA research, they seem to be more acceptable and preferred in European countries (e.g., the UK and Germany) than in North American countries (e.g., the USA and Canada). In addition to its widespread use of new techniques like “GIS” and “remote sensing” in its EA research, the USA has also recently placed more emphasis on public health during the recent decades. Meanwhile, Canada focused more on “fish” experiments than other productive countries in this field. The UK and Germany showed similar patterns of author keywords ranking, while they both emphasized the applications of modeling and monitoring EA studies. Our results clearly show that “risk assessment”- and “climate change”-related research are hot spots among all productive countries in this field during our selected study period.

Conclusions

Our analysis indicated that an author keywords analysis was an effective approach for mapping global EA research published during the period from 1993 to 2012. Many significant points have been found. A logistic regression was applied to model the correlation between the annual number of articles and the year. It can be predicted that the number of scientific papers on the topic of EA will continue to grow at a high rate in the future and might double by the year 2019. More studies have been conducted regarding the categories of “Environmental Sciences and Ecology”, “Engineering”, and “Public, Environmental and Occupational Health” to seek solutions for environmental issues. This indicates that there is no definite correlation between the journal impact factor and the citation frequency of the article in EA-research fields. Internationally collaborated articles were more prevalent in recent years than earlier years, and increasing international collaboration would lead to more powerful articles due to the sharing of ideas and workloads. Some developing countries, such as China, India, and

Table 6
Frequency of author keywords used in publications of the 4 most productive countries from 1993 to 2012.

World		USA		UK		Canada		Germany	
Keywords	A (%)	Keywords	A (%)	Keywords	A (%)	Keywords	A (%)	Keywords	A (%)
Risk assessment	1925 (2.33)	Risk assessment	761 (3)	Risk assessment	241 (2.6)	Risk assessment	152 (2.6)	Risk assessment	147 (2.9)
Environment	1391 (1.68)	Environment	437 (1.7)	Environment	228 (2.4)	Environment	127 (2.1)	Indicators	127 (2.5)
Climate change	944 (1.14)	Children	328 (1.3)	Climate change	178 (1.9)	Climate change	111 (1.9)	Climate change	69 (1.4)
Life cycle assessment	887 (1.07)	Climate change	304 (1.2)	Indicators	136 (1.4)	Canada	106 (1.8)	Life cycle assessment	67 (1.3)
Children	767 (0.93)	Epidemiology	296 (1.2)	Sustainability	113 (1.2)	Indicators	91 (1.5)	Environment	64 (1.3)
Heavy metals	704 (0.85)	Genetics	279 (1.1)	Biodiversity	105 (1.1)	Sustainability	77 (1.3)	Biodiversity	61 (1.2)
Epidemiology	665 (0.8)	Exposure assessment	259 (1)	Genetics	101 (1.1)	Fish	71 (1.2)	Children	60 (1.2)
Sustainability	657 (0.8)	Stress	236 (0.9)	Life cycle assessment	87 (0.9)	Life cycle assessment	53 (0.9)	Asthma	49 (1)
Assessment	656 (0.79)	Assessment	233 (0.9)	Temperature	83 (0.9)	Children	52 (0.9)	ICF	47 (0.9)
GIS	630 (0.76)	Asthma	230 (0.9)	Assessment	81 (0.9)	Toxicity	52 (0.9)	Epidemiology	44 (0.9)
Water quality	608 (0.74)	Water quality	225 (0.9)	Conservation	79 (0.8)	Mercury	49 (0.8)	Heavy metals	43 (0.8)
Biodiversity	563 (0.68)	Physical activity	202 (0.8)	Epidemiology	78 (0.8)	Metals	46 (0.8)	Monitoring	43 (0.8)
Stress	557 (0.67)	Depression	185 (0.7)	Monitoring	78 (0.8)	Physical activity	46 (0.8)	Environmental risk assessment	41 (0.8)
Asthma	539 (0.65)	GIS	168 (0.7)	Modeling	76 (0.8)	Air pollution	44 (0.7)	Germany	40 (0.8)
Toxicity	537 (0.65)	Remote sensing	162 (0.6)	Children	74 (0.8)	Arctic	44 (0.7)	Biomonitoring	39 (0.8)

A (%): the number and percentage of articles that used the author keyword.

Brazil, benefit greatly from international cooperation. During our study period, the G7 displayed high productivity in both independent and internationally collaborated articles for the drinking water research field. Most developing countries in East Europe, Latin America and the Caribbean, and Africa need the help of developed countries in their publications.

The temporal evolution of ranks of the keywords revealed interesting terminology preferences, with "indicators" becoming the most frequently used author keyword in the last 5 years. This change suggested that the applications of indicators to quantitatively make environment assessments with various techniques were growing more and more popular during our study period. Similarly, a steady increase in focus on SEA can be found in this field, which indicates that strategic environmental assessment has become a more important component of EA research. To summarize, the research scope of EA has grown increasingly extensive. It can be widely seen that current environment assessment in developed countries is usually combined with issues of 'climate changes' and 'biodiversity', while developing countries still put particular emphasis on 'public health' and 'social impact'. The popularity of these areas of focus is expected to continue in future EA research endeavors.

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