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A historical review and bibliometric analysis of research on estuary pollution

Jinshui Sun [a], Ming-Huang Wang [b], Yuh-Shan Ho [b,c,*]

[a] Guangxi Water Resources Department, Nanning 530023, PR China
[b] Department of Environmental Sciences, Peking University, Beijing 100871, PR China
[c] Trend Research Centre, Asia University, Taichung 41354, Taiwan

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ABSTRACT

A bibliometric method based on Science Citation Index-Expanded published by the Thomson Reuters was used to quantitatively assess the global estuary pollution research from 1991 to 2010. The main results were as follows: there had been a notable growth trend in publication outputs. Marine Pollution Bulletin was the most active journal. Environmental sciences were top popular subject categories. USA produced the most single, internationally collaborative, first authored and corresponding authored articles. The Chinese Academy of Sciences was the most productive institute for the total articles. Sediment was the most active research topic, which ranked 1st in article title, article abstract, author keyword, and KeyWords Plus analysis, respectively. Heavy metals received stable focus on a high degree in the field of estuary pollution research. Mostly refractory organic compounds (e.g. PAHs) became more active. Biomarkers and bioaccumulation both were active issues. Eutrophication of estuarine waters receives increasing concern in estuary pollution research.

1. Introduction

Estuaries are semi-enclosed bodies of water where freshwater from rivers and a coastal stream merges with the ocean. Furthermore, this mixing of waters with such different salt concentrations and variable physical conditions characteristics forms multiple unique habitats that support highly diverse communities and provide crucial links to nearby ecosystems (McLusky and Elliott, 2004). Because of rapid population growth and uncontrolled development in many coastal areas worldwide estuaries exhibit severe pollution impacts by introduction of a wide variety of chemical contaminants. Many of the chemicals substances are known to concentrate in the water, or accumulate in estuarine sediments (McCain et al., 1988) or bioaccumulate by sediment-dwelling organisms (Meador et al., 1995). Pollutants enter estuaries through storm drains; industrial discharges; runoff from lawns, streets, and farmlands; discharges from sewage treatment plants; and atmospheric deposition.

A main emphasis of estuary research is to study the effects of pollution. Estuaries can be affected by contamination in the following major ways: oxygen depletion (e.g. hypoxia, anoxia) (SaizSalinas, 1997), toxic substances accumulation or bioaccumulation (e.g. toxic organic compounds, petroleum products, and heavy metals) (Bryan and Langston, 1992), spills (e.g. oil spills) (Colombo et al., 2005), pathogens (e.g. from sewage) (Lipp et al., 2001), and thermal pollution (e.g. heated effluent from power plants) (Keser et al., 2005). In addition, Sediment quality also has received increasing concern because sediment is known to act as both a repository for contaminants and as a pollutants source with potential impacts on the quality of estuary ecosystem (Budzinski et al., 1997; Santos et al., 2009). Researchers all over the world have studied the trends of estuary pollution research and published many papers related to those topics (Van Geen et al., 1997; Davis et al., 2000). However, a comprehensive statistical review of the global estuary pollution research has never been done.

Bibliometrics, were firstly introduced by Pritchard, which means the application of mathematical and statistical methods to books and other media of communication (Pritchard et al., 1969). Citation analysis and content analysis are commonly used bibliometric methods. Bibliometrics have wide applications in various areas to elevate research performance or assess the research trends by investigating the publication characteristics, such as authorship, sources, subjects, geographical origins, and citations (Small, 2003). Bibliometric analysis was performed for "estuaries and coasts" published since 1960 by the *Coastal and Estuarine Research Federation*, the bibliographic analysis of data was compiled by the online version of the Science Citation Index Expanded (SCI-Expanded) during the period of 1992–2005 (Fourqurean et al., 2008). In their study, variations of the journal's name, the page size, the number of papers and pages published per year, the number of papers downloaded per month since 1999, the impact factor, authorship, countries, and institutions of the published

* Corresponding author at: Trend Research Centre, Asia University, Taichung 41354, Taiwan. Tel.: +866 4 2332 3456x1797; fax: +866 4 2330 5834.
E-mail address: ysho@asia.edu.tw (Y.-S. Ho).

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articles were analyzed, additionally, the number of citations of the authors and publications were also identified, the results showed *Estuaries and Coasts* was acted as a journal on the rise that stood up in comparisons of quality and citation rate with other journals in its field after the scope of *Estuaries and Coasts* was broadened. Bibliometric analysis was also performed by Clarke et al. (2007) in the field of public health research literature for Europe, the research articles were based on the Science Citation Index Expanded (SCI-Expanded) and the Social Science Citation Index (SSCI) databases for published between 1995 and 2004; output for country by population, Gross Domestic Product (GDP), burden of disease using DALYs, and language were analyzed, the results indicated that there was obvious variation in public health publication by country in Europe, Eastern, and southern European countries showed under-invest in public health research compared with northern European countries and compared to relative health need. Zhang et al. (2010a) used the paper title, abstract, author keyword, and KeyWords Plus analysis method to quantitatively assessing current research trends on volatile organic compounds, by using the related literature in the Science Citation Index Expanded (SCI-Expanded) database from 1992 to 2007. The research trends could be evaluated by analysis on the frequency of words in title, words in abstract, author keywords, and KeyWords Plus in different periods (Zhang et al., 2010b). Moreover, a method named "word cluster analysis" was presented to find research hotspots of risk assessment research field (Mao et al., 2010). In this study, bibliometric approaches were used to quantitatively and qualitatively investigate the global research trends of estuary pollution during the period of 1991–2010. Research performances of country and institute with five indicators such as total, collaborative, independent, first authored, corresponding authored articles, were also presented (Hu et al., 2010).

2. Data sources and methods

The data used in this study were based on the online version of the Science Citation Index Expanded (SCI-Expanded) which was accessed from the Thomson Reuters Web of Science. According to Journal Citation Reports (JCR), it indexes 8005 major journals with citation references across 174 scientific disciplines in 2010. The online version of SCI-Expanded was searched with keywords ("pollution", "pollutions", "polluted", "polluting", "pollutant", "pollutants", "pollute", "pollutes", "contamination", "contaminations", "contaminate", "contaminant", "contaminants", "contaminated", and "contaminating") and ("estuary", "estuaries", "estuarius", "estuaria", "estuaries", "estuarial", "estuarian", and "estuarine") to compile a bibliography of all articles related to the research on estuary pollution. Articles originating from England, Scotland, Northern Ireland, and Wales were grouped under the UK heading. Articles from Hong Kong were included in China. The impact factor (IF) of a journal was determined for each document as reported in the JCR 2010. Contributions of different institutes and countries were estimated by the affiliation of at least one author to the articles. Collaboration type was determined by the addresses of the authors, where the term "single country articles" was assigned if the researchers' addresses were from the same country. The term "internationally collaborative articles" was designated to those articles that were coauthored by researchers from multiple countries. The term "single institute article" was assigned if the researchers' addresses were from the same institute. The term "inter-institutionally collaborative articles" was assigned if authors were from different institutes (Li and Ho, 2008).

All the articles referring to estuary pollution from 1991 to 2010 were analyzed as follows. The aspects covered document type and language of publications, characteristics of publication outputs, distribution of output in subject categories and journals, publication outputs of country and institute; and word in article title, abstract, author keyword, and KeyWords Plus.

3. Results and discussion

3.1. Document type and language of publication

The total papers met the selection criteria mentioned in the Web of Science database from 1991 to 2010 are 5976. From the distribution analysis, 12 document types were found. Article (5026) was the most-frequently used document type comprising 84% of the total publications, followed by proceedings paper articles (674; 11%), reviews (204; 3.4%), editorial materials (24; 0.40%), and meeting abstracts (22; 0.37%). The others showing less significance were notes (10), letters (9), corrections (2), discussions (2), and one for news item, book chapter review, book chapter article about an individual, and biographical-item, respectively. Only 5026 original articles were considered for further analysis. Languages of all articles were grouped. Ninety-eight percent of all these journal articles were published in English (4947). Several other languages also appeared, containing Spanish (21), Portuguese (19), French (19), Malay (2), Japanese (2), Polish (2), German (1), and Russian (1). English was by far the dominant language in estuary pollution research because it was the main language in many fields (Hsieh et al., 2004). Moreover, more journals listed in Web of Science were English-language publications (Chiu and Ho, 2007). However it should be pointed out that the SCI-Expanded database has been criticized for its heavy bias in favor of English-language publications (Kurmis, 2003).

3.2. Characteristics of publication outputs

The estuary pollution research was growing during the last 100 years, from 1 article in 1902 to 33 articles in 2010 by using the searching keywords in title words only (Fig. 1). The earliest articles were published in 1902 and 1904. In 1902, Paton et al. reported the influence of pollution upon fish in Tyne estuary, using dissolved oxygen (DO) as the measure of the degree of pollution (Paton, 1902). In 1904, "The pollution of tidal estuaries" was pub-

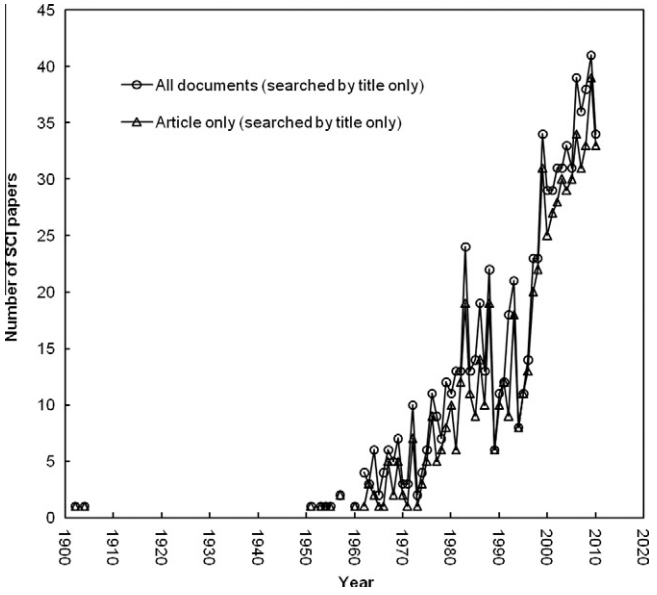

Fig. 1. Number of SCI-Expanded publications referring to searching keywords in the title only during the last 100 years.

lished in *Lancet* (Anonymous, 1904). From 1904 to 1950, the world academic article related estuary pollution in SCI-Expanded database never appeared again. After the 1950s, some developed countries, for example, UK and Germany suffered from serious water pollution because of rapid industrialization and population growth (Johnstone and Horan, 1996; Seeger, 1999). Furthermore, the rapid economic development and increasing urbanization in developing countries, such as China and India, resulted in even more severe water pollution problems from the 1980s (Bowonder, 1986; Wu et al., 1999). Therefore, estuary pollution had received increasing concern since then, and the world academic publication in SCI-Expanded database had a notable growth after the 1990s. In addition, several rules and regulations were adopted to prevent water pollution and reduction efforts had decreased contaminant levels in the estuary environment from the 1990s (Bryan and Langston, 1992; Harino et al., 2003; Reay, 2009). As a result, estuary pollution research has became one of the most important and dynamic field of environmental research (Carpenter et al., 1998; Santos et al., 2009). Several publication output characteristics of current estuary pollution research during the study period of 1991–2010 were summarized in Table 1. The annual number of articles, the average number of authors, and the annual number of cited references increased significantly. Only 95 articles were published in 1991, while the number of articles increased to 451 in 2010. The annual number of journal articles published and the number of articles cited to estuary pollution research increased more than fourfold and sevenfold, respectively. There was an average of 3.1 authors per estuary pollution related to article in the year 1991, while the number steadily increased to 4.7 in 2010. The gradual increases in the number of journal articles outputs and the references revealed stable growth and communication in estuary pollution research during the study period.

3.3. Output in subject categories and journals

The JCR Science 2010 Edition contained 8005 major journals with 174 subject categories in SCI. The top five popular subject categories were environmental sciences (3138; 63%), marine and freshwater biology (1386; 28%), toxicology (734; 15%), oceanography (520; 10%), and water resources (453; 9.0%). From 48 articles in 1991 to 289 articles in 2010, environmental sciences were holding primacy all through the study period, and were not exceeded by other study fields (Fig. 2). Marine and freshwater biology and toxicology was as follows. Publication of these subject categories increases moderately. The growth of articles in categories of oceanography and water resources was relatively slower. As the use of statistics in any scientific discipline can be considered a key element in evaluating its degree of maturity (Palmer et al., 2005), the statistical analysis result could provide a current view of the international estuary pollution research emphases of this topic. Table 2 listed the top 20 most active journals producing articles on estuarine pollution including the impact factor (IF), the SCI-Expanded category of the journal, the position of the journal in its category, the number of articles, and the percentage of total articles. The IF of a journal was determined for each document as reported in the year 2010 JCR. *Marine Pollution Bulletin*, a quarterly journal published by Elsevier Science, ranked first with 424 (8.4%) published articles; *Science of the Total Environment* ranked second with 218 (4.3%) articles; *Environmental Toxicology and Chemistry*, *Environmental Monitoring and Assessment*, and *Environmental Pollution* ranked 3rd, 4th, and 5th, respectively.

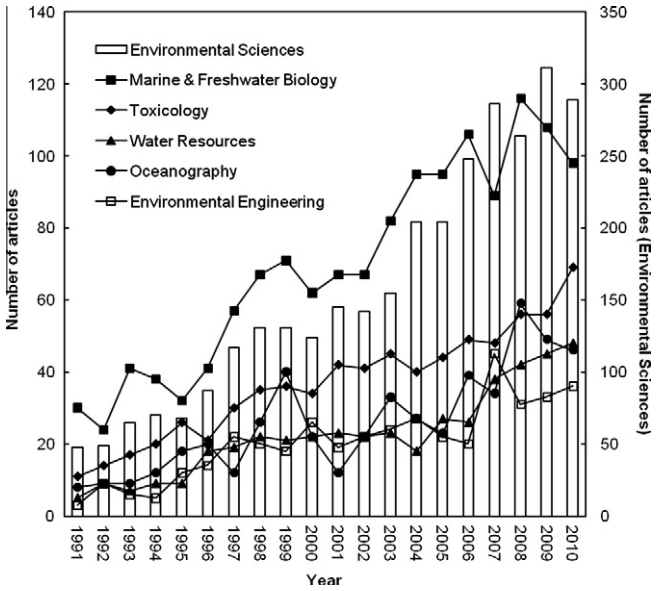

Fig. 2. Comparison of the growth trends of the top six subject categories during 1991–2010.

Table 1
Characteristics by year of publication outputs including total publications, number of authors, page counts, and number of cited references.

PY	TP	AU	AU/TP	NR	NR/TP	PG	PG/TP
1991	95	294	3.1	2851	30	1141	12
1992	76	237	3.1	2253	30	898	12
1993	108	325	3.0	3470	32	1215	11
1994	116	376	3.2	3526	30	1290	11
1995	107	355	3.3	3908	37	1218	11
1996	144	481	3.3	4963	34	1703	12
1997	180	635	3.5	6213	35	1996	11
1998	211	755	3.6	7335	35	2363	11
1999	231	839	3.6	8274	36	2745	12
2000	207	750	3.6	7606	37	2436	12
2001	215	834	3.9	8134	38	2429	11
2002	232	902	3.9	9034	39	2747	12
2003	259	986	3.8	10,329	40	3153	12
2004	332	1297	3.9	13,482	41	3984	12
2005	325	1316	4.0	13,086	40	3843	12
2006	398	1649	4.1	15,833	40	4447	11
2007	407	1838	4.5	16,319	40	4392	11
2008	452	2036	4.5	18,875	42	4624	10
2009	480	2168	4.5	21,099	44	4891	10
2010	451	2127	4.7	20,409	45	4713	10
Total	5026	20,200		196,999		56,228	
Average			4.0		39		11

TP, number of articles; AU, number of authors; PG, page count; NR, cited reference count; AU/TP, PG/TP, and NR/TP, average of authors, pages, and references in a article.

3.4. Country/territory publications

There were eight articles (0.16%) without author address information. Thus 5018 articles with author address information, published from 1991 to 2010 were analysis. This covered 112 countries/territories, of which 4008 (80%) were single country articles covering 72 countries/territories and 1010 (20%) were internationally collaborative articles covering 103 countries/territories. Table 3 lists the countries/territories published over 100 articles on estuarine pollution during the study period. Number of total, single country, internationally collaborative, first authored, and corresponding authored articles, together with their percentage are exhibited in Table 3. The number of countries involved in estuary pollution research increased rapidly. Seventeen European countries, seven Asian countries/territories, four American countries, two African countries, and one Oceania country were ranked in the top 30 productive countries of articles. The

Table 2
The top 20 most active journals producing articles on estuarine pollution with the number, impact factor, Web of Science subject category of journals, and the position of the journal in its category during the period of 1991–2010.

Journal title	TP (%)	IF 2010	Subject category	Position
Marine Pollution Bulletin	424 (8.4)	2.359	Environmental sciences	51/193
			Marine and freshwater biology	16/93
Science of the Total Environment	218 (4.3)	3.190	Environmental sciences	26/193
Environmental Toxicology and Chemistry	186 (3.7)	3.026	Environmental sciences	34/193
			Toxicology	25/83
Environmental Monitoring and Assessment	185 (3.7)	1.436	Environmental sciences	106/193
Environmental Pollution	175 (3.5)	3.395	Environmental sciences	22/193
Estuarine Coastal and Shelf Science	171 (3.4)	1.887	Marine and freshwater biology	31/93
			Oceanography	19/59
Environmental Science & Technology	167 (3.3)	4.825	Environmental engineering	2/45
			Environmental sciences	9/193
Chemosphere	158 (3.1)	3.155	Environmental sciences	28/193
Marine Environmental Research	121 (2.4)	1.953	Environmental sciences	70/193
			Marine and freshwater biology	27/93
			Toxicology	52/83
Archives of Environmental Contamination and Toxicology	112 (2.2)	1.930	Environmental sciences	73/193
			Toxicology	54/83
Water Air and Soil Pollution	88 (1.8)	1.765	Environmental sciences	83/193
			Meteorology and atmospheric sciences	31/68
			Water resources	19/76
Water Research	84 (1.7)	4.546	Environmental engineering	4/45
			Environmental sciences	11/193
			Water resources	1/76
Estuaries	81 (1.6)	2.133 (2007 JCR)	N/A	N/A
Aquatic Toxicology	78 (1.6)	3.333	Marine and freshwater biology	6/93
			Toxicology	19/83
Marine Ecology-Progress Series	77 (1.5)	2.483	Ecology	48/130
			Marine and freshwater biology	13/93
			Oceanography	9/59
Environment International	74 (1.5)	4.691	Environmental sciences	10/193
Hydrobiologia	69 (1.4)	1.964	Marine and freshwater biology	26/93
Environmental Geology	69 (1.4)	1.070	Environmental sciences	136/193
			Multidisciplinary geosciences	98/167
			Water resources	38/76
Marine Chemistry	67 (1.3)	2.751	Multidisciplinary chemistry	38/147
			Oceanography	6/59
Journal of Coastal Research	60 (1.2)	0.679	Environmental sciences	169/193
			Physical geography	32/42
			Multidisciplinary geosciences	132/167

IF, impact factor; TP, total publications; N/A, not applicable.

Table 3
Top 15 most productive countries/territories of articles on estuarine pollution during 1991–2010.

Country/territory	TP	TP R (%)	SP R (%)	CP R (%)	FP R (%)	RP R (%)	C%
USA	1354	1 (27)	1 (26)	1 (31)	1 (23)	1 (23)	23
UK	621	2 (12)	2 (9.8)	2 (23)	2 (10)	2 (9.5)	37
Spain	439	3 (8.7)	3 (7.7)	4 (13)	3 (7.5)	4 (7.6)	30
China	430	4 (8.6)	4 (7.6)	5 (12)	3 (7.5)	3 (7.7)	29
France	357	5 (7.1)	5 (5.2)	3 (15)	5 (5.5)	5 (5.5)	42
Australia	250	6 (5.0)	6 (4.7)	10 (6.1)	6 (4.4)	6 (4.4)	25
Portugal	240	7 (4.8)	8 (3.8)	8 (8.6)	7 (4.1)	7 (4.2)	36
Brazil	234	8 (4.7)	7 (4.2)	9 (6.5)	8 (4.0)	8 (4.1)	28
Canada	231	9 (4.6)	10 (2.8)	6 (12)	10 (3.2)	10 (3.2)	52
India	185	10 (3.7)	9 (3.7)	17 (3.8)	9 (3.4)	9 (3.2)	21
Germany	167	11 (3.3)	13 (1.8)	7 (9.2)	13 (2.1)	13 (2.2)	56
Italy	158	12 (3.1)	11 (2.5)	12 (5.6)	11 (2.4)	11 (2.5)	36
Belgium	133	13 (2.7)	12 (1.9)	12 (5.6)	12 (2.1)	12 (2.2)	43
The Netherlands	125	14 (2.5)	14 (1.6)	11 (6.0)	14 (1.6)	14 (1.5)	49
Japan	100	15 (2.0)	17 (1.1)	14 (5.3)	15 (1.5)	15 (1.5)	54

TP, total articles; SP, single country articles; CP, internationally collaborative articles; FP, articles with first author; RP, articles with corresponding author; %, share in articles; R, Rank; %C, the percentage of internationally collaborative articles in total articles for each country.

USA published the most articles (1354) and completed the most single and collaborative articles. Moreover, the first authored and corresponding authored articles of the USA were also ranked top one. UK followed distantly behind the United States, and ranked the 2nd position in terms of all indicators. The seven major industrial countries (G7: Canada, France, Germany, Italy, Japan, the UK, and the USA), were all ranked in the top 15 of total articles. The result indicated that the developed countries hold a dominant position in estuary pollution research as this pattern has occurred in most scientific fields (Mela et al., 1999). Moreover, some developing countries, such as BRIC (China, India, Brazil, and Russia) were also listed as productive countries.

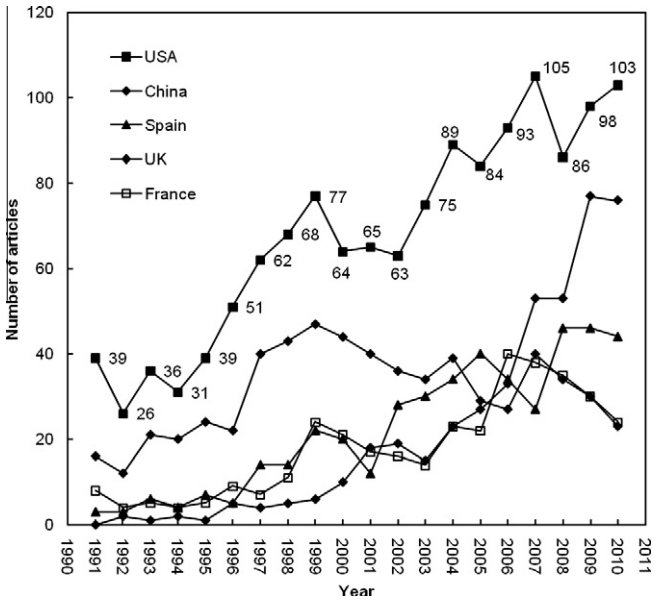

Fig. 3. Comparison of the growth trends of the top 5 productive countries in publications on estuarine pollution during 1991–2010.

The time-trend analysis among the top five productive countries of peer-reviewed scientific publications on estuarine pollution is displayed in Fig. 3. The USA has exhibited its dominant position in estuary pollution research since 1991. An apparent turning point was appeared at 1999 in UK, which may be due to a series of positive pollution regulations was established and the status of UK estuaries pollution gained some improvement (Richards et al., 2000; Galante-Oliveira et al., 2009). China had a high growth pace in recent 10 years, and finally ranked 2nd in 2010. Estuary pollution-related studies grow more attention due to serious environmental pollution problems, which mainly resulted from the rapid economic and industrial development (Wong et al., 2002).

3.5. Institute publications

A total of 5018 articles with author address information published from 1991 to 2010 were analyzed. There were 3160 institutes devoted to the estuary pollution related research. The top 20 most productive institutions with their respective outputs are displayed in Table 4. There were seven USA, two UK, two Portugal, two Spain, two France, two Canada, one China, one Brazil, and one Australia research institutions ranked in the top 20 research institutions. The Chinese Academy of Sciences was the most productive institute for the total articles (145), as well as single institute articles (45), first authored articles (106), and corresponding authored articles (104), while the inter-institutionally collaborative articles (100) ranked 1st. There is a bias for the Chinese Academy of Sciences, as it has many branches in many cities. In this study, the articles of these institutes were pooled under one heading, dividing the articles among the branches would have given different rankings (Li et al., 2009b).

3.6. Distribution of words in article title, abstract, author keywords, and KeyWords Plus analysis

Article title, which always contained the information of the whole paper, is important to help readers find the information they are looking for. An abstract is a brief summary of a research paper or any in-depth analysis of a particular subject or discipline, and is often used to help the reader quickly ascertain the paper's purpose. Article title and abstract analysis both were effective word statistical analysis, which could be used to make inferences of the scientific literature or to identify the subjective focus and emphasis specified by authors. Author keywords are the words that are used to reveal the internal structure of an author's reasoning. Author keywords analysis could offer the information of research trend that is concerned by researchers (Li et al., 2009a). KeyWords Plus is a kind of automatic indexing used in the citation databases produced by Web of Science, which provided additional search terms extracted from the titles of articles cited by authors in their bibliographies and footnotes (Garfield, 1990). The KeyWords Plus analysis as an independent supplement, reveals the articles contents with more details. Using the keywords to analyze the trend of research by bibliometric method could be found recently (Zhang et al., 2009). In this paper, the research tendency of this field was analyzed by using word statistical analysis technique. The title and abstract were firstly divided into single words then statistical method was used to analyze them. Some prepositions apparently were used frequently during our study period but were useless

Table 4
Twenty most productive institutions publishing articles on estuarine pollution from 1991 to 2010.

Institute	TP	TP R (%)	SP R (%)	CP R (%)	FP R (%)	RP R (%)	C%
Chinese Academy of Sciences, China	145	1 (2.9)	1 (2.1)	1 (3.5)	1 (2.1)	1 (2.2)	69
United States Environmental Protection Agency (US EPA), USA	121	2 (2.4)	4 (1.5)	2 (3.1)	2 (1.5)	2 (1.5)	73
CSIC, Spain	96	3 (1.9)	8 (1.1)	3 (2.5)	7 (1.0)	8 (1.0)	75
University of Plymouth, UK	82	4 (1.6)	2 (1.8)	9 (1.5)	5 (1.1)	6 (1.1)	54
Rutgers State University, USA	82	4 (1.6)	7 (1.2)	5 (2.0)	3 (1.2)	4 (1.1)	70
University of Aveiro, Portugal	80	6 (1.6)	27 (0.56)	4 (2.4)	4 (1.1)	3 (1.2)	85
Plymouth Marine Laboratory, UK	78	7 (1.6)	10 (1.0)	5 (2.0)	10 (0.84)	11 (0.71)	73
National Oceanic and Atmospheric Administration (NOAA), USA	77	8 (1.5)	4 (1.5)	9 (1.5)	8 (1.0)	7 (1.1)	57
IFREMER, France	68	9 (1.4)	22 (0.60)	7 (1.9)	12 (0.72)	12 (0.67)	81
U.S. Geological Survey, USA	66	10 (1.3)	22 (0.60)	8 (1.8)	23 (0.52)	14 (0.62)	80
University of Huelva, Spain	65	11 (1.3)	3 (1.7)	24 (1.0)	6 (1.1)	5 (1.1)	43
University of Bordeaux 1, France	62	12 (1.2)	11 (0.88)	12 (1.5)	17 (0.6)	17 (0.56)	69
University of Sao Paulo, Brazil	57	13 (1.1)	22 (0.60)	9 (1.5)	16 (0.62)	16 (0.58)	77
University of Sydney, Australia	49	14 (1.0)	6 (1.3)	35 (0.77)	9 (0.88)	9 (0.79)	45
Texas A&M University, USA	49	14 (1.0)	27 (0.56)	13 (1.3)	25 (0.50)	26 (0.42)	76
Fisheries & Oceans Canada, Canada	49	14 (1.0)	22 (0.6)	15 (1.3)	21 (0.56)	17 (0.56)	73
University of Porto, Portugal	47	17 (0.94)	20 (0.65)	18 (1.2)	20 (0.58)	17 (0.56)	70
University of Quebec, Canada	47	17 (0.94)	35 (0.46)	13 (1.3)	30 (0.42)	26 (0.42)	79
University of North Carolina, USA	46	19 (0.92)	13 (0.84)	24 (1.0)	11 (0.74)	10 (0.77)	61
University of South Carolina, USA	46	19 (0.92)	15 (0.74)	22 (1.0)	13 (0.64)	21 (0.52)	65

TP, total articles; SP, single institute articles; CP, inter-institutionally collaborative articles; FP, articles with first author; RP, articles with corresponding author; %, share in articles; R, Rank; %C, the percentage of inter-institutionally collaborative articles in total articles for each institute.

for the analysis of research trend. Therefore, all these empty words, together with the searching words were discarded in our analysis. Based on the distribution of word in article title, article abstract, author keyword, and KeyWords Plus analysis, popular estuary pollution research issues could be roughly found by the statistically analysis. These keywords were calculated and ranked by total 20-year study and 4 year-time periods. "Sediments" and "sediment" was the most frequently used word, which ranked 1st in article title, article abstract, author keyword, and KeyWords Plus analysis, respectively. Estuary sediments provide abundant benthic community habitats. They also act as a sink and reservoir for a variety of environmental contaminants (Grant and Middleton, 1993). In addition, contaminants binding of sediments can spread to the surroundings. They can transport from the sediment to water, resuspend when sediments are disturbed, or be absorbed by sediment-swelling organisms (bioaccumulation). As a consequence contaminated sediments can have severed effects on living organisms and ecosystems (Budzinski et al., 1997; Santos et al., 2009). Sediments are an important medium between chemical and biological processes (Turner and Millward, 2002). Therefore, "sediments" was the most important issue in estuary pollution research field from 1992 to 2009 (Bryan and Langston, 1992; Chapman and Wang, 2001; Couceiro et al., 2009). Heavy metal cycling is a serious problem faced in estuary environments due to the anthropogenic activities (Milenkovic et al., 2005). Estuary pollution by heavy metals has become an issue of increasing environmental concern (Du Laing et al., 2009). The keyword "heavy metals" (or "heavy metal") ranked 2nd and 5th in the author keyword and KeyWords Plus analysis, respectively, while "metals" (or "metal") ranked 3rd in the article title and abstract analysis, respectively. Mercury (Hg) is one of the most hazardous pollutants that present in aquatic environments (Pereira et al., 2009). The existence of mercury in estuary systems has led to much concern over their influence on plants and animals life in these environments (Lawson and Mason, 1998; Sunderland et al., 2004). Many countries have finalized strict restrictions on anthropogenic sources of mercury (Meybeck et al., 2007). However, historically contaminated sediments may still act as a source of mercury to the aquatic environment when the areas requiring maintenance dredging or where sediments may be disturbed and resuspended into the water column (Alonso et al., 2000; De Marco et al., 2006). Therefore, the research focused on mercury pollution has still been a hotspot in estuary during 1991–2010. The author keyword "mercury" ranked 47th (1.0%) in 1991–1995, and top 8th (3.2%) in 2006–2010. Other main heavy metals, such as cadmium (Cd), copper (Cu), and lead (Pb), were addressed more concern in estuary pollution. The keyword "copper" ranked 13rd and 19th; the keyword "cadmium" ranked 20th and 16th; and the keyword "lead" ranked 27th and 42nd in the author keyword and KeyWords Plus analysis, respectively. Thus, heavy metals received stable focus on a high degree in the field of estuary pollution research during the study period, and the reason might lie to mine exploitation and advance in industrialization; more importantly, heavy metals' persistence and toxicity could cause hazardous impacts on the environment, especially heavy metals may be bioconcentrated, bioaccumulated and biomagnified within food chains (Costa et al., 2009). Salinity is the controlling factor for the distribution of contaminants in sediment and in overlying or interstitial waters (Chapman and Wang, 2001); salinity variations may be an important factor governing the bioavailability of heavy metals towards sediment-dwelling organisms (Du et al., 2002). Therefore, salinity also has received more attention in recent years, which can be obviously reflected from the author keywords analysis, the author keyword "salinity" ranked 112th (0.49%) in 1991–1995, ranked 42nd (1.1%) in 1996–2000, ranked 33rd (1.3%) in 2001–2005, and top 35th (1.1%) in 2006–2010. Polycyclic aromatic hydrocarbons (PAHs) are one of the most important classes of anthropogenic organic contaminants in estuary environment. PAHs has been paid more attention because it has mutagenic and genotoxic potential and its potential effects on estuarine Organism by the long-term toxicity and persistence of PAHs (Budzinski et al., 1997; Vane et al., 2007). The research focused on PAHs developed considerably during 1991–2010, and was raised more concern in recent years. The author keyword "PAHs" and "polycyclic aromatic hydrocarbons" ranked 47nd (1.0%) and 112th (0.49%) in 1991–1995, while they ranked 15th (2.2%) and 36th (1.2%) in 1996–2000, ranked 8th (3.9%) and 17th (2.0%) in 2001–2005, and top 6th (3.6%) and 14th (2.3%) in 2006–2010. KeyWords Plus "PAHs" never appeared in 1991–1995, while it ranked 473nd (0.22%) in 1996–2000, shiftily ranked 87th (1.3%) in 2001–2005, and 39th (2.4%) in 2006–2010. KeyWords Plus "polycyclic aromatic hydrocarbons" ranked 16th (4.1%) in 1991–1995, while it ranked 15th (4.9%) in 1996–2000, it ranked 12th (5.9%) in 2001–2005, and top 8th (8.6%) in 2006–2010. Moreover, the percentage of articles with keywords "PAHs" in article title and abstract analysis went up from 0% to 4.1% in 1991–1995 to 2.4% and 10% in 2006–2010. These results were highly accorded with increasing attention given to PAHs research in recent years (Luo et al., 2004; Beg et al., 2009). Polychlorinated biphenyls (PCBs), a group of persistent organic pollutants (POPs) derived entirely from anthropogenic sources, are widespread in the estuarine environment as organic pollutants (Durell and Lizotte, 1998). PCBs are of great environmental concern because they are potentially harmful to aquatic organisms, and pose a health threat to the seafood-consuming public (Binelli and Provini, 2003). Although, PCBs production were banned by the United States Congress in 1979 and by the Stockholm Convention on Persistent Organic Pollutants in 2001, and reduction efforts had lowered their levels in the environment from the 1970s. However, because of its persistence, PCBs concentrations almost exceeded the threshold of concern for human health in the environment, and continued to pollute the water column from various sources (Santschi et al., 2001; Davis et al., 2007). The author keywords and KeyWords Plus analysis also indicated that PCBs (or polychlorinated biphenyls) continue to be a problem in estuary environment. The author keyword "PCBs" ranked 15th (2.0%) in 1991–1995, while it ranked 55th (0.92%) in 1996–2000, it ranked 10th (3.3%) in 2001–2005, and 21th (1.6%) in 2006–2010. Moreover, KeyWords Plus "PCBs" ranked 99th (1.0%) in 1991–1995, while it ranked 129th (0.78%) in 1996–2000, it ranked 143th (0.83%) in 2001–2005, and 76th (1.4%) in 2006–2010. Tributyltin (TBT), a component of antifouling paints which has been widely employed on boat hulls in marine water, is extremely toxic and causes damages to reproduction in aquatic organisms (Langston and Pope, 1995). TBT's high toxicity to non-target organisms led to its regulation in several European countries, the United States and other countries (Alzieu, 1998; Harino et al., 2003; Smith et al., 2008). Especially, when more countries were generally in favor of this Convention and ratified the Convention, TBT's concentrations in estuaries had been gradually reduced (Evans, 1999; Ruiz et al., 2008; Choi et al., 2009), which also indicated that regulations forbidding the use of TBT-based antifoulants on vessels <25 m in length have been an effective way in reducing environmental levels of these compounds (Evans et al., 2001). Its change can be obviously noticed from the author keywords, KeyWords Plus, article title, and abstract analysis. The author keyword "TBT" and "tributyltin" ranked 47th (1.0%) and 21st (1.5%) in 1991–1995, while they ranked 307th (0.22%) and 63rd (0.70%) in 2006–2010. KeyWords Plus "TBT" and "tributyltin" ranked 148th (0.73%) and 31st (2.9%) in 1991–1995, while they ranked 318th (0.43%) and 188th (0.71%) in 2006–2010. The percentage of articles with keywords "TBT" in article title and abstract analysis shiftily descended from 1.0% and 4.3% in 1991–1995 to 0.37% and 2.0% in 2006–2010. The percentage of articles with keywords "tributyltin" in article title and abstract analysis dropped

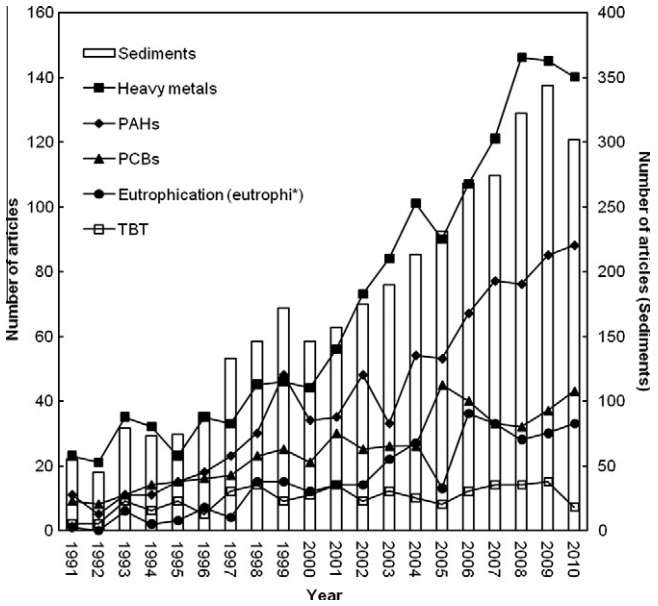

Fig. 4. Distribution of hot topic keywords in estuary research during 1991–2010.

from 1.0% to 3.5% in 1991–1995 to 0.55% and 1.7% in 2006–2010. Briefly, the main pollutants in estuaries were heavy metal and refractory organic contaminants, and the distribution of the pollutants can be showed in Fig. 4. Pollution is probably the most important threat to water quality in estuaries. Water quality in estuaries is often compromised by the entrenchment of nutrients and organic matter, the influx of pathogens, and the accumulation of heavy metals and chemical contaminants (Kennish, 2002). The author keywords "water quality" ranked 7th (3.9%) in 1991–1995, while it ranked 11th (2.8%) in 2006–2010. KeyWords Plus "water quality" ranked 148th (0.73%) in 1991–1995, while it ranked 27th (3.2%) in 2006–2010. The keywords analysis "water quality" indicated that water quality was an active issue in estuary pollution research field from 1991 to 2010 (Valiela et al., 1997; Bainbridge et al., 2009). Biomarker was defined as the physiological, biochemical, and histological changes used as indicators of exposure to chemical contaminants and/or of its effects at the suborganismal or organismal level (Hugget et al., 1992). Compared with conventional chemical residue analysis, biomarkers offered a valuable way for monitoring environmental quality, which generally correspond more specifically and rapidly to environmental change compared to responses seen at the population and community level. The author keywords "biomarkers" ranked 112nd (0.49%) in 1991–1995, while it ranked 13th (2.5%) in 2006–2010. Moreover, the percentage of articles with keywords "biomarkers" in KeyWords Plus analysis went up from 0.24% in 1991–1995 to 1.4% in 2006–2010. Thus, it apparently indicated that increasing interest has been raised to develop the biomarkers for monitoring environmental quality in estuary aquatic ecosystems (Allen et al., 1999; Vieira et al., 2009). Bioaccumulation referred to the process by which toxic substances (e.g. pesticides, organic chemicals, and heavy metals) accumulate and keep on accumulating in living organisms. Several studies have revealed that toxic substances have the ability to bioaccumulate in the food chain, causing higher trophic organisms to become contaminated with higher concentrations of toxic substances than their prey (Vallack et al., 1998; Lawrence and Mason, 2001). The author keywords "bioaccumulation" ranked 21st (1.5%) in 1991–1995, while it ranked 7th (3.2%) in 1996–2000, 16th (2.1%) in 2001–2005, and 9th (3.1%) in 2006–2010. Moreover, the percentage of articles with keywords "bioaccumulation" in KeyWords Plus analysis increased from 0.49% in 1991–1995 to 2.3% in 2006–2010. As a result of the degree of toxic substances contamination, researchers have made great efforts in study the bioaccumulation of toxic substances (Wang et al., 2009). The keywords "eutrophication" and "nutrients" have relatively high ranks. Eutrophication is the enrichment of water as a result of nutrient enrichment (Nixon, 1995). Potential consequences of nutrient enrichment include ecological changes, socioeconomic impairments such as fisheries, aquaculture, and tourism, and serious human health threats (Carpenter et al., 1998; Anderson et al., 2002; Whitall et al., 2007). In the past decades, it is well known that many of estuaries are heavily or moderately eutrophied worldwide (Bricker et al., 1999; Cloern, 2001). Author keywords "eutrophication" and "nutrients" ranked 42nd and 112nd in 1991–1995, while ranked 17th and 15th in 2006–2010. The results were highly in accordance with great attention given to eutrophication research in recent decade. The reason for increasing concern on eutrophication research was due to a wide range of human activities, which had substantially increased the rate of delivery of plant nutrients to many estuarine areas (Anderson et al., 2002; Kemp et al., 2009).

4. Conclusions

In this study, dealing with estuary pollution SCI-Expanded journals' papers, some significant points on the worldwide research trends were obtained throughout the period from 1991 to 2010. In total, 12 document types were found in the total 5976 publications. English was the dominant language of estuary pollution research. Along with the development of SCI-Expanded, estuary pollution research continually grew and started to go up significantly in 1960s. It could be predicted that the number of scientific publications related to estuary pollution research would still grow rapidly in the future. The results indicated that *Marine Pollution Bulletin* was the most active journal. The results also revealed environmental sciences, marine and freshwater biology, and toxicology were top three popular subject categories. USA produced the most single, collaborative, first authored and corresponding authored articles. Meanwhile, China showed a swift grow pace, and finally ranked 2nd in 2010. The Chinese Academy of Sciences was the most productive for the total articles while US Environmental Protection Agency produced the second inter-institutionally collaborative articles. Keywords analysis obviously indicated that sediment (or sediments) was the most active research issues in the studied period. Additionally, heavy metals obtained stable focus on a high degree in estuary pollution research during the study period. Furthermore, mostly refractory organic compounds (e.g. PAHs, PCPs) became more active in estuary pollution research; however, TBT was gradually under control after the more effective legislation banning the use of TBT came into force. In addition, biomarkers and bioaccumulation both were active issues in estuary pollution research during the study period. Finally, the rate of delivery of nutrients substantially increased in estuarine areas due to a wide range of human activities; as a consequence, Eutrophication of estuarine waters was becoming a global phenomenon with widespread effects and would receive increasing concern in estuary pollution research in the future.

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