Solid waste related research in Science Citation Index Expanded

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Abstract

A bibliometric approach was employed to quantitatively assess current research trends on solid waste by analyzing the related publications in the Science Citation Index Expanded (SCI-Expanded) database from 1991 to 2010. The general analyses were processed by characteristics of distribution covering publication outputs, journals, Web of Science categories, countries, and institutes, and research emphases and trends including author keywords, words in title, words in abstract, and KeyWords Plus analysis. Over the last 20 years, annual publication outputs showed a notable growth trend. *Waste Management* published the most articles, and the solid waste related articles were becoming centered in this journal, especially in 2009 and 2010. The G7 (the USA, Germany, the UK, Japan, France, Canada, and Italy) played active roles in publication, and the USA was the most productive country. Particularly, China experienced the greatest growth rate, and surpassed the USA in annual production in 2008. Furthermore, the searching keyword "solid waste*" was migrating from the fields of author keywords, title, and abstract to the field of KeyWords Plus. By synthetic analysis of these keywords, it was concluded that landfill, waste-to-energy, composting, and recycling were the common solution methods for solid waste problems, and would continue to be the leading research methods. Heavy metals, anaerobic digestion, sewage sludge, soil, and adsorption were also considered as hot spots. Food waste, another increasing concern, had strong potential in the near future.

Keywords: Solid Waste, Research Trends, Bibliometric, SCI-Expanded

1. Introduction

Worldwide solid waste related problems are paid much attention by large amount of scientific articles originated from many countries around the world [1]. However, the attempts to gather the systematic data to get a panoramic view on this solid waste research were quite few. The bibliometric methods have been used commonly in many disciplines of science and engineering to study the scientific production and research trends [2-6]. Quantitative analysis and statistics were used to analyze distribution patterns of publications in a given topic, field, institute or country [7]. The Science Citation Index Expanded (SCI-Expanded) database from the Web of Science, the Thomson Reuters, was the most important and frequently used database for the bibliometric research to get a review of scientific accomplishment in many studying fields [8,9]. Conventional bibliometric methods often evaluate the research trends by publication outputs of countries, research institutes, journals, research fields' analysis [10-12] as well as by citation analysis [13,14]. However, we cannot accurately indicate the developmental trends or the future orientation of the research field only depending on those methods. More information, closer to the research itself, such as words in title [15], author keywords [16], KeyWords Plus [17] and words in abstract [18] was recently introduced to obtain more specific research emphases and trends.

To map the trends of solid waste related research, the bibliometric method has ever been employed for solid waste research from 1993-2008 [1]. By comparison, this study not only extended the analyzed time span from 16 years (1993-2008) to 20 years (1991-2010) in order to get a broader field of vision, but also put emphasis on researching hot spots and trends by adding performance of searching keywords in different keywords fields, abstract's words analysis, and trends of hot issues to provide a more comprehensive and complete study. Therefore, characteristics of distribution covering countries, institutes, journals, and Web of Science categories, and research emphases and trends including author keywords, words in title, words in abstract, and KeyWords Plus during the period of 1991-2010 were analyzed.

2. Date Sources and Methodology

"Solid waste*" including "solid waste", "solid wastes", "solid wasteforms", and "solid waster" was used as the searching keyword to search topic in SCI-Expanded in the period from 1991 to 2010. The topic search can trace the related information in the title, abstract, author keywords and KeyWords Plus at one time. All the following analyses referring to document type, language, output, Web of Science category, journal, country, institution, words in title, abstract, author keywords, and KeyWords Plus were analyzed by Microsoft Excel 2007.

Introduction of pretreatment before calculation and interpretation of proper nouns in subsequent analysis was presented. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Articles from Hong Kong were included in the ones from China. Collaboration type was determined by the addresses of the authors, where the term "single country article" was assigned if the researchers' addresses were from the same country. The term "internationally collaborative article" was designated to those articles that were coauthored by researchers from multiple countries. The term "single institute article" was assigned if the researchers' addresses were from the same institute. The term "inter-institutionally collaborative article" was assigned if authors were from different institutes. The impact factor of a journal was determined as reported in the Journal Citation Reports (JCR) 2010.

3. Results and Discussions

Altogether 9,514 publications met the selection criteria mentioned above, containing 13 document types. Article was the most frequently used document type (7,819; 82.2%). Others were proceedings paper (1,011), review (394), editorial material (116), meeting abstract (86), news item (30), note (22), letter (16), correction (9), book review (4), reprint (3), correction, addition (3) and discussion (1). As journal articles which are peer-reviewed within this field were dominant in the document types, only articles were identified for the further analysis, while all others were discarded.

3.1. Distribution of Publication Outputs

Distribution of Languages

For languages analysis, English was the predominant language of articles on solid waste related study from 1991 to 2010. Among 7,819 articles, 7,562 articles were published in English, accounting for 96%. This maybe partly due to the fact that USA was the country that published the most SCI publications [1,13,17], and SCI is an American-based database. There were 16 languages except for English, which were Portuguese (52), Japanese (49), Spanish (47), German (32), Polish (22), French (19), Chinese (18), Czech (4), Russian (4), Turkish (3), Malay (2), Slovene (1; 0.013%), Rumanian (1), Italian (1), Finnish (1), and Korean (1).

Distribution of Published Year

The number of publications in a given field is an important indicator to evaluate the research activities [19]. During the study period, the annual number of articles increased nearly 11-fold from 88 in 1991 to 965 in 2010. Table 1 shows annual numbers of articles saw an upward trend during the 20 years. The average number of authors per article rose from 2.5 in 1991 to 3.9 in 2010, with an overall average number of 3.3 authors. The number of references cited per article increased 2.6-fold from 13 in 1991 to 34 in 2010. The annual average article length almost remained the same, with the overall average length of 9.9 pages.

Distribution of Journals and Categories

The total articles (7,819) were published in 1,052 journals in 135 categories, based on the classification of Web of Science categories, the Thomson Reuters. Table 2 lists the top 10 journals with the greatest numbers of articles (TP > 100). Thirty-six percent of the articles resided in these top 10 most productive journals. *Waste Management*, *Waste Management & Research* and *Journal of Hazardous Materials* were the top 3. *Bioresource Technology* and *Environmental Science & Technology* which had the impact factor greater than 4, ranked 4th and 7th respectively.

Table 1. Characteristics of articles for every year from 1991-2010.

Year	TP	AU/TP	NR/TP	PG/TP
1991	88	2.5	13	10
1992	132	2.8	13	11
1993	152	2.8	14	11
1994	154	2.8	16	10
1995	198	3.0	14	9.0
1996	195	2.8	21	11
1997	243	2.9	23	12
1998	277	3.2	22	10
1999	250	3.4	22	10
2000	277	3.3	22	10
2001	300	3.3	23	10
2002	340	3.4	23	10
2003	393	3.5	25	10
2004	414	3.6	25	10
2005	460	3.6	27	10
2006	536	3.6	29	10
2007	691	3.8	29	10
2008	833	3.8	29	9.1
2009	921	3.9	31	8.7
2010	965	3.9	34	9.2
Total	7,819			
Average		3.3	23	10

TP: number of articles; AU/TP, NR/TP, and PG/TP: average number of authors, cited references, and pages per articles.

The trends of the 7 top journals in production are illustrated in Fig. 1. The most productive journal, *Waste Management*, was the only journal whose annual production kept increasing, and had been growing expeditiously since 2005. It was noteworthy that the total number of articles in 1991-2010 was 634, while 240 articles were published in 2009 and 2010, accounting for 45% of the total articles in *Waste Management*. In 2010, the annual number of articles in *Waste Management* was twice more than that in *Bioresource Technology*, the 2nd journal. The increases of number of articles in other journals were not as significant as that in *Waste Management* in recent years. The proportion of the articles in the top 7 journals had continued to rise from 35% in 2001 to 39% in 2010. In particular, the total number of articles in *Waste Management* accounted for only 2.7% of the total articles in 2001, but 13% in 2010. Numbers of articles in *Bioresource Technology* and *Journal of Hazardous Materials* also significantly increased after 2005, but fell in 2009 and 2010, respectively.

Distribution of Countries and Institutions

There were 1,023 articles without author address information in Web of Science. The remaining 7,717 articles were from 118 countries. Among these articles, 6,424 (83%) articles were single country articles, while 1,291 (17%) were international collaborative articles. Table 3 presents the top 20 productive countries/territories.

Table 2. Top 10 most productive journals with the number of articles, impact factor and Web of Science category.

Journal	TP (%)	IF	Web of Science category
Waste Manage.	634 (8.1)	2.358	environmental engineering; environmental sciences
Waste Manage. Res.	460 (5.9)	1.222	environmental engineering; environmental sciences
J. Hazard. Mater.	379 (4.8)	3.723	environmental engineering; civil engineering; environmental sciences
Bioresour. Technol.	323 (4.1)	4.365	agricultural engineering; biotechnology & applied microbiology; energy & fuels
Resour. Conserv. Recycl.	269 (3.4)	1.969	environmental engineering; environmental sciences
Chemosphere	233 (3.0)	3.155	environmental sciences
Environ. Sci. Technol.	204 (2.6)	4.825	environmental engineering; environmental sciences
J. Air Waste Manage. Assoc.	122 (1.6)	1.567	environmental engineering; environmental sciences; meteorology & atmospheric sciences
Environ. Technol.	108 (1.4)	1.007	environmental sciences
Compost Sci. Util.	105 (1.3)	0.484	ecology; soil science

TP (%): total number of publications and percentage of total publication for a certain journal; IF: impact factor in 2010.

Articles from the top 20 countries/territories accounted for 95% of the total articles. The seven major industrialized countries (G7), the USA, Germany, the UK, Japan, France, Canada, and Italy ranked in the top 13 countries, accounting for around 46% of the 7,717 articles. Similarly, the excellent performance of G7 was common in other researches [20-22]. The average C (percentage of international collaborative publication in the country's total publication) of the 20 countries/territories was 30%. The countries/territories whose C was greater than 40% were Belgium (49%, CPR: 17th), Germany (48%, CPR: 6th), Netherlands (45%, CPR: 14th), Canada (42%, CPR: 3rd), and Denmark (41%, CPR: 13th). The USA was ranked 1st in all indicators, TP, SP, CP, FA, and RP, with C of 24%. China was ranked 2nd in TP, SP, CP, FA and RP, with C of 36%. India was ranked 4th in TP, SP, CP, FA, and RP, but its C was just 16%.

Figure 1. The growth trends of the top 7 journals in production.

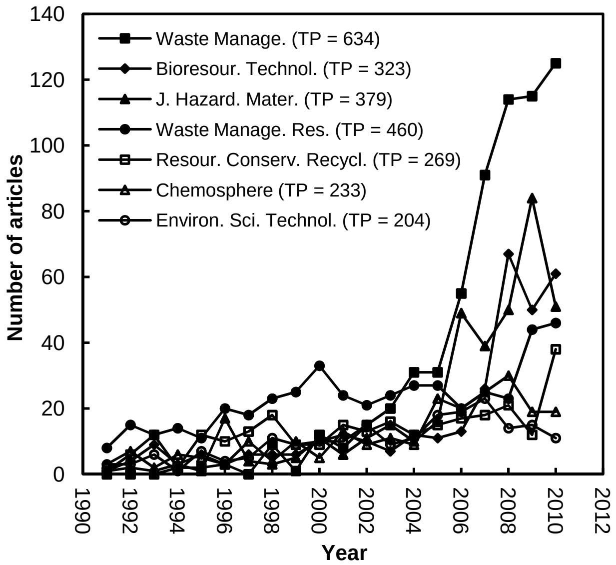


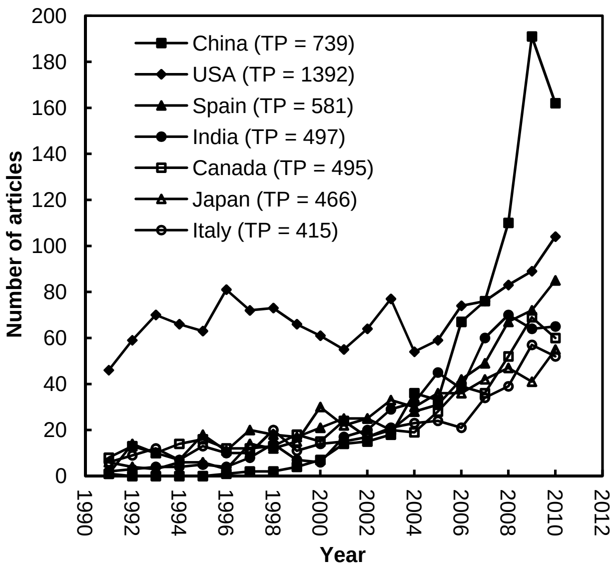
Table 3. Top 20 most productive countries of articles during 1991-2010.

Country	TP	TP R (%)	SP R (%)	CP R (%)	FA R (%)	RP R (%)	C%
USA	1,392	1 (18)	1 (16)	1 (26)	1 (16)	1 (15)	24
China	739	2 (10)	2 (7.3)	2 (21)	2 (7.9)	2 (8.1)	36
Spain	581	3 (7.5)	3 (6.7)	4 (12)	3 (6.8)	3 (6.7)	26
India	497	4 (6.4)	4 (6.5)	10 (6.0)	4 (5.9)	4 (6.0)	16
Canada	495	5 (6.4)	8 (4.5)	3 (16)	6 (5.1)	6 (5.1)	42
Japan	466	6 (6.0)	5 (5.6)	8 (8.4)	5 (5.2)	5 (5.3)	23
Italy	415	7 (5.4)	6 (5.0)	9 (7.4)	7 (4.7)	7 (4.7)	23
UK	366	8 (4.7)	9 (3.9)	6 (8.9)	9 (3.8)	9 (3.8)	31
Taiwan	333	9 (4.3)	7 (4.5)	16 (3.4)	8 (3.9)	8 (4.0)	13
France	324	10 (4.2)	11 (3.1)	5 (10)	11 (3.2)	11 (3.2)	39
Turkey	282	11 (3.7)	10 (3.9)	21 (2.6)	10 (3.5)	10 (3.6)	12
Germany	242	12 (3.1)	15 (2.0)	6 (8.9)	14 (2.2)	14 (2.2)	48
Sweden	216	13 (2.8)	13 (2.2)	11 (5.6)	13 (2.4)	12 (2.5)	33
Brazil	207	14 (2.7)	12 (2.5)	15 (3.6)	12 (2.4)	12 (2.5)	23
South Korea	175	15 (2.3)	16 (1.8)	12 (4.6)	15 (2.0)	16 (2.0)	34
Greece	162	16 (2.1)	14 (2.2)	26 (1.7)	16 (2.0)	15 (2.0)	14
Denmark	138	17 (1.8)	17 (1.3)	13 (4.3)	17 (1.5)	17 (1.5)	41
Netherlands	112	18 (1.5)	21 (1.0)	14 (3.9)	19 (1.1)	20 (1.0)	45
Australia	111	19 (1.4)	19 (1.1)	19 (3.0)	18 (1.2)	18 (1.2)	35
Belgium	88	20 (1.1)	28 (0.70)	17 (3.3)	27 (0.78)	24 (0.80)	49

TP: total publications; SP: independent publication; CP: international collaborative publication; FA: publication of the country of the first author; RP: publication of the country of corresponding author; R (%): rank (share in publications); C%: percentage of international collaborative publications in total publications in each country.

Figure 2 describes the trends of the 7 most productive countries. The USA had the most articles during 1991-2007, maintaining superiority over the other countries. However, China, which experienced the highest growth rate in recent years, equaled the USA in the number of articles in 2007, and then surpassed USA. The number of articles from China was 2.1 times greater than that from the USA in 2009, and 1.6 times in 2010. In the 20 years studied, the standard deviation (SD) of numbers of articles from the USA was 13, which was the lowest among the top 7 countries, indicating a steady trend. China, whose SD of the annual number of articles was 57 and the number of articles in 2010 was 4.4 times than its overall average figure, showed the highest growth energy. The outstanding energy of China was not surprising, as it was reported that it experienced a sustained and remarkable increase in scientific production [23], and has been the world's second largest producer of scientific publications since 2006 [24].

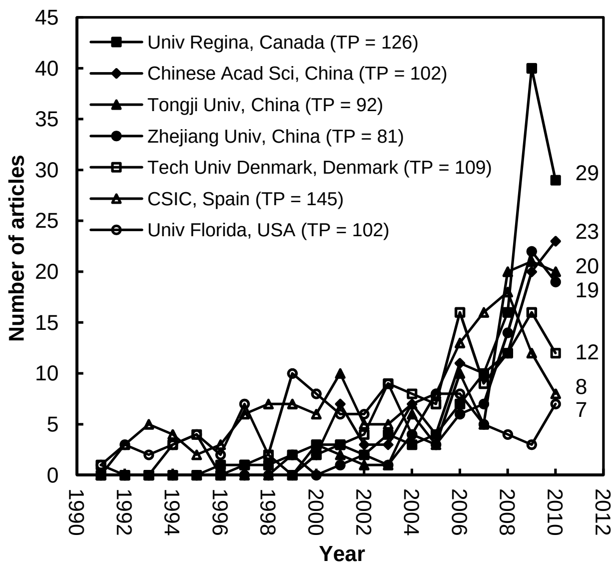
Figure 2. The growth trends of the 7 most productive countries.



There were total 3,860 institutes contributing to the solid waste related research. Among the 7,717 articles, 4,161 (54%) were single institute publications, and the percentage of inter-institute articles (46%) was obviously greater than that of international collaborative articles (17%). Table 4 presents the top 20 most productive institutes from 1991-2010. The percentage of total articles from the 20 institutes to the total articles was 19%. The Spanish National Research Council, Chinese Academy of Science, and the Indian Institute of Technology were ranked 1st, 4th, and 8th, respectively. However, they were integrated research centers which made up of many relatively independent institutes throughout their country. Among the 20 institutes, 4 are in the USA and 5 are in China. Taiwan, Spain and Japan each have two institutes. Canada, Denmark, India, UK and Singapore each have one institute. By excluding these integrated institutes, the most productive institutes were University of Regina in Canada (126) which ranked 2nd with C 93%, CPR 1st, and SPR 75th, followed by Technical University of Denmark in Denmark (109), and University of Florida in USA (102). Peking University and North China Electric Power University were not shown in the top 20 institutes in the study targeting at 1993-2008 [1], but they ranked 12th and 11th during 1991-2010, indicating that the two universities had a good outlook in solid waste research. The percentage of inter-institute publications to the total publications of Peking University and North China Electric Power University were all larger than 80%, with their CPR ranking 8th and 5th, SPR 96th, and 202nd respectively.

The growth trends of the top 7 institutes in Fig. 3 were similar with the trends of the top countries, increasing with time, especially in recent years, but most of them declined in last two years. The number of articles of University of Regina significantly increased since 2005. Among the top 7 most productive institutes, 4 are in China. Although the Spanish National Research Council ranked 1st in total publications, its publications declined since 2008, and was only ranked 6th in 2010.

Figure 3. The growth trends of the 7 most productive institutes.



3.2. Research Emphases and Trends

Appearance of Searching Keywords

All publications were searched out by searching keywords in topic including four fields: words in title; author keywords; words in abstract; and KeyWords Plus. These four kinds of keywords provide reference for readers to understand the purport of one article from different perspectives. The title of one article is the most impressive for readers, and it always contains the information that author would most like to express to the readers. Statistical analysis of keywords and title-words can be used to identify directions in science [25]. Words in abstract, as one important kind of keywords, were also analyzed for research trends recently [17,26]. The KeyWords Plus in the SCI database provide more search terms extracted from the titles of articles cited by authors in their bibliographies and footnotes [27].

Table 4. The 20 most productive institutes between 1991 and 2010.

Institute	TP	TP R (%)	SP R (%)	CP R (%)	FA R (%)	RP R (%)	C%
CSIC, Spain	145	1 (1.9)	1 (1.7)	2 (2.1)	1 (1.4)	1 (1.3)	52
Univ Regina, Canada	126	2 (1.6)	75 (0.22)	1 (3.3)	5 (1.0)	4 (1.0)	93
Tech Univ Denmark, Denmark	109	3 (1.4)	4 (1.1)	3 (1.8)	2 (1.1)	2 (1.1)	60
Chinese Acad Sci, China	102	4 (1.3)	5 (1.0)	4 (1.7)	5 (1.0)	5 (1.0)	61
Univ Florida, USA	102	4 (1.3)	2 (1.3)	9 (1.4)	3 (1.0)	6 (1.0)	48
Tongji Univ, China	92	6 (1.2)	3 (1.2)	11 (1.2)	4 (1.0)	3 (1.0)	45
Zhejiang Univ, China	81	7 (1.0)	9 (0.72)	7 (1.4)	7 (0.82)	7 (0.84)	63
Indian Inst Technol, India	79	8 (1.0)	8 (0.84)	10 (1.2)	8 (0.79)	8 (0.79)	56
Natl Taiwan Univ, Taiwan	69	9 (0.89)	24 (0.41)	6 (1.5)	17 (0.41)	19 (0.4)	75
Natl Cheng Kung Univ, Taiwan	68	10 (0.88)	6 (0.89)	17 (0.87)	9 (0.67)	9 (0.68)	46
N China Elect Power Univ, China	59	11 (0.76)	202 (0.10)	5 (1.5)	62 (0.23)	62 (0.23)	93
Peking Univ, China	57	12 (0.74)	96 (0.17)	8 (1.4)	15 (0.43)	15 (0.43)	88
Natl Inst Environm Studies, Japan	55	13 (0.71)	24 (0.41)	12 (1.1)	17 (0.41)	15 (0.43)	69
Univ Sheffield, UK	53	14 (0.69)	7 (0.87)	51 (0.48)	11 (0.57)	10 (0.63)	32
N Carolina State Univ, USA	49	15 (0.63)	28 (0.38)	15 (0.93)	15 (0.43)	17 (0.42)	67
Univ Rovira & Virgili, Spain	49	15 (0.63)	14 (0.53)	24 (0.76)	10 (0.58)	11 (0.56)	55
Kyoto Univ, Japan	47	17 (0.61)	53 (0.26)	13 (1.0)	12 (0.52)	13 (0.48)	77
US EPA, USA	46	18 (0.6)	53 (0.26)	14 (1.0)	25 (0.36)	24 (0.38)	76
Nanyang Technol Univ, Singapore	45	19 (0.58)	18 (0.48)	27 (0.70)	28 (0.32)	29 (0.32)	56
Univ Illinois, USA	44	20 (0.57)	28 (0.38)	21 (0.79)	23 (0.39)	33 (0.30)	64

TP: total publications; SP: single institute publications; CP: inter-institutionally collaborative publications; FA: publication of the institute of the first author; RP: publication of the institute of corresponding author; R (%): rank (share in publications); C%: percentage of inter-institutionally collaborative publications in total publications in each institute.

The appearance of the searching keywords “solid waste*” are shown by the proportion of articles searched out by searching words in four fields (PP_{TI}, PP_{AB}, PP_{AU}, and PP_{KW}) in 1991-2010 (Fig. 4). The calculation process was shown as following. P_{TI} is the proportion of the articles (*TI*) searched out by searching words in title to total articles with title recorded information; P_{AB} is the proportion of the articles (*AB*) searched out by searching words in abstract to total articles with abstract recorded information; P_{AU} is the proportion of the articles (*AU*) searched out by searching words in author keywords to total articles with author keyword recorded information; and P_{KW} is the proportion of the articles (*KW*) searched out by searching words in KeyWords Plus to total articles with KeyWords Plus recorded information. PP_{TI}, PP_{AB}, PP_{AU}, and PP_{KW} were calculated as following four equations:

$$PP_{TI} = \frac{P_{TI}}{P_{TI} + P_{AB} + P_{AU} + P_{KW}} \times 100\%$$

$$PP_{AB} = \frac{P_{AB}}{P_{TI} + P_{AB} + P_{AU} + P_{KW}} \times 100\%$$

$$PP_{AU} = \frac{P_{AU}}{P_{TI} + P_{AB} + P_{AU} + P_{KW}} \times 100\%$$

$$PP_{KW} = \frac{P_{KW}}{P_{TI} + P_{AB} + P_{AU} + P_{KW}} \times 100\%$$

AB had the highest proportion in the whole study period, which may be partly due to its large quantity of words. The numbers of articles (*TI*, *AB*, *AU*, and *KW*) from four searching fields all had increasing trends, with the increasing number of total articles. However, the proportion presented in Fig. 4 describes different trends. In 1991, the descending order of proportion was PP_{AB} (87%), PP_{AU} (61%), PP_{TI} (44%), and PP_{KW} (7%). After 1991, only the trend of *KW* showed an increasing trend, while the other types of articles by different keywords fields *AB*, *AU*, and *TI* decreased gradually. In 2010, the descending order of proportion had been changed to PP_{AB} (65%), PP_{KW} (41%), PP_{TI} (30%), and PP_{AU} (29%). PP_{AU} fell by 32% from the 2nd in 1991 to the last one in 2010, while PP_{KW} climbed by 34% from the bottom in 1991 to the 2nd in 2010. More and more articles searched out by "solid waste*" came from the articles searched out by searching words in KeyWords Plus instead of title, abstract and author keywords. It indicated that the indirectly solid waste related articles, which utilized solid waste related articles to conduct their researches, were getting popular.

Distribution of Keywords

As for the analysis of four kinds of keywords, author keywords were the most useful and significant words to provide the view of research trends and emphases, because of its semantic integrity and significance, single title words' and abstract words' uncompleted meaning, and KeyWords Plus's indirectly correlation. Recently, words in the paper title, abstract, author keywords, and KeyWords Plus in different periods have been analyzed to provide information of research emphases and trends in many researches [20,26,28-30]. In the following analysis, the meaningful and important analysis of author keywords were displayed, and words in title, words in abstract, and KeyWords Plus were also analyzed to support and supplement for research trends and emphases. All single words in the titles and abstracts of solid waste related articles were analyzed statistically. Some prepositions and common words such as "of", "the", "and", and "during" were discarded because they were meaningless for the analysis.

Figure 4. The growth trends of proportion of articles by different searching fields.

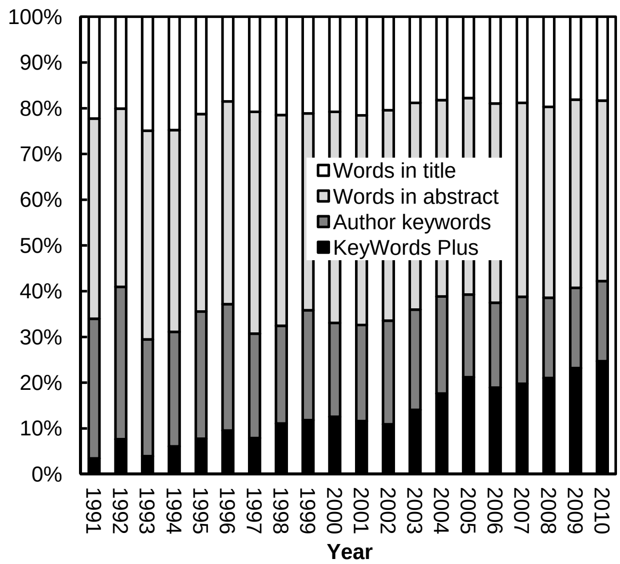


Table 5 presents the 20 most frequently used author keywords in 1991-2010 by 5-year study. The study revealed that 12,467 author keywords were used from 1991-2010. The most frequently used word was "municipal solid waste", indicating that municipal solid waste (MSW) has been a major challenge in urban areas in recent years [31]. Except for searching words "solid waste", the following most frequently used author keyword was "heavy metal", whose ranking order rose from the 13th in 1991-1995 to 3rd in 2001-2005, and stayed the 4th in the period 2006-2010. This indicated that heavy metal was paid more and more attention in this period, which was also found to be a significant focus in wastewater pollution [21]. "Landfill" was in the 4th place, and the related word "leachate" was the 9th, which also appeared in the most frequently title words. Another hot issue was related to composting. "Compost" and "composting" were ranked the 7th and the 8th, respectively. Also, "fly ash" and "incineration" ranked the 10th and the 13th respectively. Similarly, "ash", "incinerator", "fly", and "incineration" were listed in the top 25 title words. The rank of "fly" grew significantly in title words list, which was ranked the 715th in 1991-1995, but the 17th in 2006-2010. Fly ash is the by-product produced during the combustion of municipal solid waste [32]. "Recycling" was ranked the 7th in the list, showing a bright outlook. "Waste management" and "solid waste management" were listed in the top words of author keywords. Waste management was found to be an important tool to reduce waste more efficiently in many countries, such as New Zealand [33], Mexico [34], Portugal [35], and Kolkata India [36]. In addition, "anaerobic digestion", "adsorption", "kinetics", "biogas" and "sewage sludge" were also in the top 20 words of author keywords. In particular, "food waste" was ranked the 44th in author keywords which was not in this Table, but it had a notable increasing trend in the past 20 years with no article during 1991-1995, the 230th in 1996-2000, the 42nd in 2001-2005 and the 39th in 2006-2010. Recently, the impacts of food waste with increasing quantity were paid much attention, such as its impact on MSW angle of internal friction [37], impact of food waste disposers in the generation rate and characteristics of MSW [38], and impact in MSW on sorption of heavy metals [39].

For the analyzed results of words in titles, words in abstracts, most top-words were repeated to the most frequently used author keywords in Table 5. The top words of these two keywords fields were also centered on landfill, composting, waste-to-energy, and recycling. For the analysis results of KeyWords Plus, "soil" had a higher ranking in KeyWords Plus list than that in the author keywords list. Besides, "water", "behavior", "degradation", "emissions", "model", and "temperature", only appeared in the ranking of the KeyWords Plus top list, describing the wide vision of solid waste research.

Table 5. Top 20 most frequent author keywords during 1991-2010 and 5 four-year periods.

Author keywords	TP	91-10 Rank (%)	91-95 Rank (%)	96-00 Rank (%)	01-05 Rank (%)	06-10 Rank (%)
municipal solid waste	540	1 (9.9)	1 (15)	1 (10)	1 (10)	1 (9.2)
solid waste	364	2 (6.7)	2 (11)	2 (8.2)	2 (6.8)	2 (5.8)
heavy metals	268	3 (4.9)	13 (3.4)	5 (5.2)	3 (6.6)	4 (4.2)
landfill	256	4 (4.7)	8 (5.0)	3 (6.3)	4 (5.9)	5 (3.7)
anaerobic digestion	252	5 (4.6)	7 (5.6)	11 (3.8)	11 (2.8)	3 (5.5)
recycling	214	6 (3.9)	5 (6.3)	4 (5.7)	5 (4.0)	9 (3.2)
compost	200	7 (3.7)	6 (6)	9 (4.4)	8 (3.4)	7 (3.4)
composting	187	8 (3.4)	10 (4.7)	7 (4.5)	15 (2.6)	6 (3.4)
leachate	179	9 (3.3)	4 (6.9)	6 (4.9)	10 (3.2)	12 (2.5)
fly ash	172	10 (3.2)	17 (2.8)	12 (2.6)	6 (3.8)	11 (3.0)
waste management	160	11 (2.9)	11 (4.4)	20 (1.8)	14 (2.7)	10 (3.1)
adsorption	159	12 (2.9)	18 (2.2)	22 (1.7)	11 (2.8)	8 (3.3)
incineration	154	13 (2.8)	12 (3.8)	10 (4.1)	7 (3.7)	18 (2.0)
solid waste management	132	14 (2.4)	15 (3.1)	7 (4.5)	16 (2.2)	19 (1.9)
solid wastes	125	15 (2.3)	3 (7.5)	13 (2.2)	11 (2.8)	21 (1.5)
leaching	120	16 (2.2)	38 (1.3)	17 (2.0)	8 (3.4)	20 (1.8)
biogas	120	16 (2.2)	8 (5.0)	22 (1.7)	20 (1.7)	15 (2.3)
kinetics	98	18 (1.8)	38 (1.3)	71 (0.66)	21 (1.5)	15 (2.3)
environment	97	19 (1.8)	N/A	24 (1.6)	36 (1.1)	13 (2.3)
sewage sludge	89	20 (1.6)	29 (1.6)	15 (2.1)	19 (1.7)	23 (1.5)

TP: publications in the study period; %: percentage of publications containing this author keyword; N/A: not available.

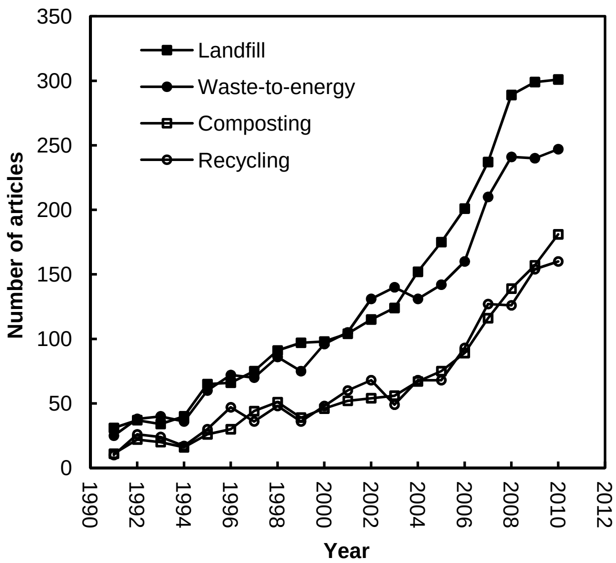
Trends of Hot Issues

To overcome the shortcomings of the analysis of only one type of keywords, words in title, words in abstract, author keywords, and KeyWords Plus are combined, and hot spots are searched in the combination to find research trends. This is a new method which can only be found in recent researches [20,26]. Each hotspot was supported by a single word or word cluster.

Generally speaking, each word cluster was composed of several supporting words, including their plural forms, abbreviation, other transformations, and near synonyms. The above results stated that landfill, waste-to-energy, composting, and recycling were the most popular solid waste disposal methods. As for the keywords analysis results and the related previous study [1], these four hotspots were clustered as following. Landfill was clustered by “landfill”, “leachate”, “leaching”, and other words and phrases containing “landfill”, “leachate”, and “leaching”. Composting was clustered by “compost”, “composting” and other words and phrases containing these words. Waste-to-energy related researches were supported by “waste-to-energy”, “incinerate”, “incineration”, “incinerator”, “combustion”, “energy recovery”, “fly ash”, “bottom ash”, “waste to energy”, and other related words and phrases containing these words. Recycling related researches were supported by “recycle”, “recyclable”, “recycling”, “reuse”, “resource recovery”, “waste recovery”, “material recovery”, “metal recovery”, and other related words and phrases containing these words. Then, the clustered words were searched in the combination of words in title, words in abstract, author keywords, and KeyWords Plus to obtain the trends of hot issues.

The trends of these four methods during 1991-2010 are illustrated in Fig. 5. As the total articles increased, number of articles on each method had climbed at a high growth rate especially in the beginning of 20th century. Landfill, the oldest technology of solid waste disposal, was still once upon than waste-to-energy and had 301 articles in 2010. It continued to be the most attractive disposal route for solid waste [40-42]. Most of researches were dedicated to landfill gas and leachate, such as their formation mechanism [43,44], adverse environmental impacts [45,46], and control methods [47,48]. The closely following method, waste-to-energy had 247 articles in 2010. It can recover energy from discarded MSW, which was recognized as a renewable source of energy, and is playing an increasingly important role [49,50]. PCDD/F and related compounds [51], incinerator ashes [52], emissions [53] and combustion thermal energy recovery [54] related to waste-to-energy were paid much attention. Another common disposal method, composting, was becoming increasingly recognized as a viable and economical method in 1990s, and was widely used in many facilities [55], particularly as the point of its economic viability, capability for nutrients recycling and waste minimization [56,57]. Large amounts of MSW compost production were frequently used in agriculture to provide nutrients [58]. Recycling with 160 articles in 2010 was set nationally in many countries for source reduction and reuse. Developed countries, like USA, had the recycling rate from less than 10 percent of MSW generated in 1980 to over 33 percent in 2008 [59]. However, the cost of MSW recycling deserved much deliberation before widely adoption [60,61].

Figure 5. The growth trends of landfill, waste-to-energy, composting, and recycling.



4. Conclusions

The systematical performance on characteristics of publication outputs, journals, countries and institutes, and keywords proportion, trends of hot issues of solid waste related research throughout the period from 1991 to 2010 were obtained. The number of annual publication had a significant increasing trend. The total 7,819 articles were published in 1,052 journals, distributed in 135 Web of Science categories. *Waste Management* published the most articles, and the submissions of solid waste related articles were becoming concentrated in this journal. The articles from the top 20 most productive countries took the overwhelming majority of the total articles, in which the G7 accounted for a half of total world production. Especially, the USA had the most publications. China had the greatest growth rate, and its annual number of articles surpassed America, in 2008. Words in title, author keywords, abstracts, and KeyWords Plus were analyzed to obtain hot issues and their trends. Articles searched out by searching words in abstract were the most, and the proportions of articles searched out by searching words in KeyWords Plus was increasing, while the proportions of articles in author keywords, title, and abstract were decreasing. The focuses of solid waste study nowadays were landfill, waste-to-energy, composting, and recycling, and they will continue be the focuses in a foreseeable future. Food waste, heavy metals, anaerobic digestion, sewage sludge, soil, and adsorption were also considered as hot spots.

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