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Research trends of sludge treatment based on bibliometric analysis from 1992 to 2009

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ABSTRACT

Sludge is the production of the sewage treatment, which is characterized by higher water contents, complicated components, huge yields, and lethal impact on the environment. Therefore the sewage treatment has attracted more attention. Bibliometric analysis is used in the study for quantitative evaluation of current research trend on the sludge. The research articles indexed from the Science Citation index-Expended in Web of Science database published from 1992 to 2009 were investigated. Results indicated that the scientific papers published on the sewage treatment had significant increase over the years and America dominated the research outputs. However among the institutes, the CSIC from Spain has the largest production. In the field of the environment engineering, the journals Water Research and Bioresource Technology have published more articles in this area. The most cited papers are respectively quoted 596 times and 465 times. Key words analysis reveals that removal, degradation, heavy-Metals, bacteria, digestion have become the research hotspots during the latest 18 years.   © 2015 Trade Science Inc. - INDIA

KEYWORDS

Sewage treatment;
Science database;
Bibliometric analysis;
Research hotspots.

INTRODUCTION

Because of the rapid development of wastewater treatment, the world sludge production is also rapidly increasing, thus making the effective and harmless disposal of sludge a research hotspot[1-4]. Different properties of the wastewater can result in different characteristics of the sludge produced[5-7]. Many sludge treatment and disposal technologies have been developed for sludge with different properties, like sludge dewatering, resource utilization, incineration, landfill, etc[8-11].

In this study, by doing bibliometric analysis with articles published during the past 18 years concerned sludge treatment in SCI journals, distribution patterns of articles on the sludge treatment is described based on the statistics data and quantitative analysis[12]. The result of the study can help summarize the research worldwide process of sludge treatment and provide a scientific guide of the global universal ecological problem for the researchers.

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MATERIALS AND METHOD

ISI Web of Science is widely used scientific information source which covers the most subjects categories. Documents used in this study were based on the online database of the Science Citation Index(SCI) from the ISI Web of Science. "Sludge and ((trea* not treatment not treating not treated not treatments not treat not TREATABILITY not treats not Treaty not treatable not treatmenr not treament not treatin not treatablity) or (dispos* not disposability not DISPOSITION not disposals not disposal not disposed not disposers not disposer not dispose not DISPOSABLE not disposing not dispositions))" were used as the keywords to search titles, abstracts and keywords from 1992 to 2009 and 21722 articles were searched out. Of all the 21722 articles, 15441 were journal articles(71.085%), 5112 proceeding papers(23.534%), 835 reviews(3.844%), 104 meeting abstracts(0.479%), 83 notes(0.382%), 63 editorial materials(0.290%), 41 discussions(0.189%), 13 corrections(0.060%), 10 letters(0.046%), 8 news items(0.037%), 5 reprints(0.023%), 4 addition corrections(0.018%), 2 book reviews(0.009%) and 1 database review(0.005%). As journal articles were the most representational document type, the 15441 journal articles were chosen as the original data for the study. All the needed information including names of authors, title, year of publication, keywords, names of journals publishing the articles, subject categories, contact address and etc. was manually put into Microsoft Excel 2007. Journal articles without all the needed information for this study were excluded and only 12648 were left to be analyzed. Of all the 12648 journal articles, English articles were 12181, accounting for 96.30%, which indicated its dominant position and higher widespread rate in the future. Portuguese(0.90%), German(0.75%), Japanese(0.44%) and Spanish(0.42%) were the following top languages with highest frequency. There were only 11 Chinese articles, accounting for 0.08% of all.

Articles originating from England, Scotland, Northern Ireland and Wales were reclassified as being from the United Kingdom. Articles originating from Hong Kong were reclassified as being from China. Collaboration type was determined by the addresses of the authors. If the addresses of authors were from the same country, the article was marked "single country article". Otherwise, it was marked "internationally collaborative article". "Single institute article" and "interinstitutionally collaborative article" were classified in the similar way.

CHARACTERISTICS OF PUBLICATION OUTPUTS DURING 1992–2009

The total number of journal articles related to sludge treatment during the past 18 years was dis-
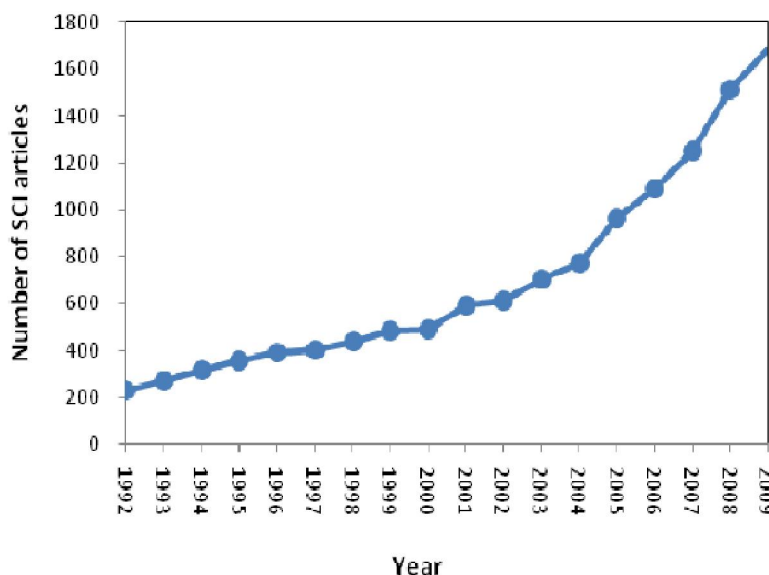

Figure 1 : Number of SCI articles on sludge treatment or disposition during 1992 to 2009

TABLE 1 : Statistical information of the publication about sludge treatment from 1992 to 2009

Year	TP	AU	AU/TP	NR	NR/TP	PG	PG/TP
1992	236	731	3.1	4610	20	2115	9.0
1993	276	868	3.1	5899	21	2468	8.9
1994	319	1015	3.2	6516	20	2942	9.2
1995	363	1110	3.1	7477	21	3127	8.6
1996	394	1222	3.1	8848	22	3473	8.8
1997	409	1330	3.3	10045	25	3745	9.2
1998	444	1512	3.4	11013	25	3987	9.0
1999	486	1596	3.3	11314	23	4339	8.9
2000	495	1765	3.6	11711	24	4216	8.5
2001	598	2120	3.5	15306	26	5335	8.9
2002	615	2261	3.7	16050	26	5622	9.1
2003	708	2614	3.7	19261	27	6711	9.5
2004	778	2886	3.7	21072	27	7030	9.0
2005	969	3713	3.8	27032	28	8652	8.9
2006	1093	4210	3.9	32728	30	9914	9.1
2007	1256	4970	4.0	37077	30	10835	8.6
2008	1518	5976	3.9	44962	30	12780	8.4
2009	1691	6948	4.1	52678	31	14132	8.4
Total	12648	46847		343599		111423	
Average			3.5		25.3		8.9

played in Figure 1 where the research trend in this field can be indicated. The amount of researches on sludge treatment, according to this figure, was continuously increasing for the past 18 years, with slow rate before 2000 and significantly fast rate after 2002, which was affected by. More detailed statistical information of these publications about sludge treatment was summarized in TABLE 1. From the table, the number of the articles published in 2009 (1691) was over 7 times more compared with that of 1992(236). The average number of authors per article increased from 3.1 in 1992 to 4.1 in 2009, with an overall average of 3.5. The cited reference count during the 18 years also had a very fierce increase, changing from 20 to 31 in average, which reflected the important reference of these published articles. Moreover, the average length of the journal articles had an unsteady trend with an overall average of 8.9 pages. The overall statistical data showed that researchers from all over the world paid more and more attention to the field of sludge treatment since the serious environmental pollution raised by the fast economic development alarmed us to seek for ef-

fective ways of solving water pollution problems as soon as possible.

Distribution of countrywide and institute publications

The contribution of different countries was evaluated by the location of the affiliation of at least one author of each published articles. The top 10 countries ranked by the number of their publications during the past 18 years was displayed in TABLE 2 which also included the percent and rank of single country articles, internationally collaborative articles, first author articles and corresponding author articles. USA, with 2142 articles in total(accounting for 17%), had almost twice more articles than China, the second rank country with 1068 articles (accounting for 8.5%). Furthermore, USA also had the highest number of single country publications, which made it the most independent research country worldwide. Spain, Canada, UK, Japan, Germany, France and India published over 500 articles, with respectively 6.7%, 6.2%, 5%, 5.5%, 3.6%, 3.3% and 4.1% single country publications. The amount

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TABLE 2 : Top 10 most productive countries of articles on sludge treatment in research period

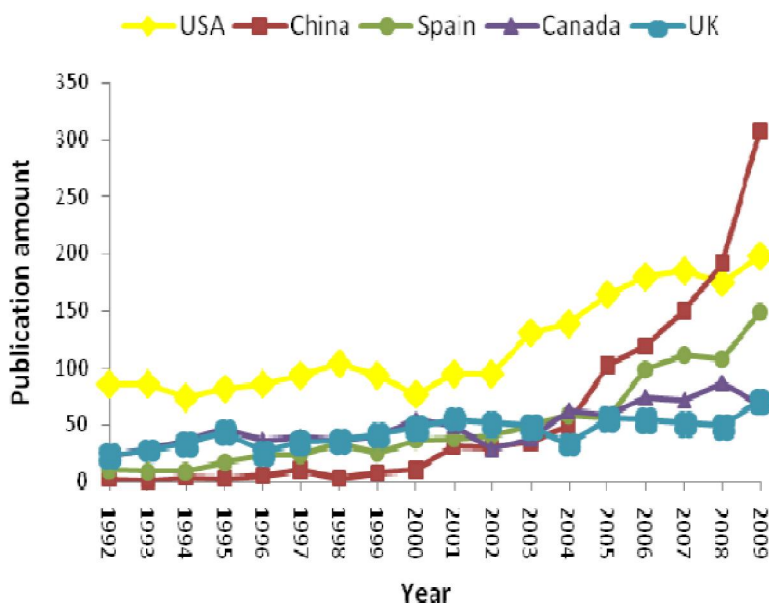| Country	TP	TP R (%)	SP R (%)	CP R (%)	FP R (%)	RP R (%)
USA	2142	1 (17)	1 (15)	1 (27)	1 (14)	1 (14)
China	1068	2 (8.5)	2 (6.9)	2 (16)	2 (7.2)	2 (7.3)
Spain	897	3 (7.1)	3 (6.7)	6 (9.2)	3 (6.3)	3 (6.6)
Canada	880	4 (7)	4 (6.2)	4 (11)	4 (6)	4 (5.8)
UK	788	5 (6.3)	6 (5)	3 (12)	6 (5)	6 (4.7)
Japan	759	6 (6)	5 (5.5)	8 (8.5)	5 (5.3)	5 (5.3)
Germany	614	7 (4.9)	9 (3.6)	4 (11)	8 (3.6)	9 (3.6)
France	538	8 (4.3)	10 (3.3)	7 (8.8)	10 (3.3)	10 (3.4)
India	514	9 (4.1)	7 (4.1)	19 (3.8)	7 (3.7)	7 (3.7)
Turkey	462	10 (3.7)	8 (3.8)	22 (3)	9 (3.4)	8 (3.6)

Figure 2 : Publication output of the top 5 countries during 1992 to 2009

TABLE 3 : Top 10 most productive institutions of articles on sludge treatment in research period

Institution	TP	TP R (%)	SP R (%)	CP R (%)	FP R (%)	RP R (%)
CSIC,Spain	184	1 (4.9)	2 (1.6)	2 (1.5)	1 (1)	1 (1.3)
Chinese Acad Sci,China	144	2 (3.9)	8 (0.68)	1 (1.5)	3 (0.59)	2 (0.94)
Indian Inst Technol,India	124	3 (3.3)	4 (1)	4 (1.1)	7 (0.54)	3 (0.88)
Dokuz Eylul Univ,Turkey	105	4 (2.8)	1 (1.7)	57 (0.37)	2 (0.69)	4 (0.84)
Natl Taiwan Univ,Taiwan	104	5 (2.8)	8 (0.68)	5 (1)	3 (0.59)	5 (0.74)
Nanyang Technol Univ,Singapore	100	6 (2.7)	4 (1)	11 (0.74)	5 (0.56)	6 (0.72)
Univ Queensland,Australia	98	7 (2.6)	10 (0.63)	6 (0.94)	11 (0.46)	10 (0.6)
Univ British Columbia,Canada	96	8 (2.6)	4 (1)	15 (0.69)	6 (0.55)	8 (0.63)
Univ Quebec,Canada	94	9 (2.5)	14 (0.55)	6 (0.94)	9 (0.5)	7 (0.7)
Harbin Inst Technol,China	91	10 (2.4)	240 (0.085)	3 (1.2)	31 (0.25)	9 (0.63)

trend of publications of the first eight countries on time span was indicated from Figure 2. According to the figure, China had relatively less publications before 2001. However, after that the amount of articles published by China started to increase sig-nificantly. Till 2008, China became the most productive country in the field of sludge treatment. This demonstrated that sludge treatment had become a very important issue in China.

The top 10 institutes ranked by the number of

their publications during the past 18 years was displayed in TABLE 3, which also included the percent and rank of single institute articles, interinstitianally collaborative articles, first author articles and corresponding author articles. Of the top 10 institutes, 6 were from China(including Hong Kong), 2 from Canada, 2 from Turkey, and respectively 1 from Spain, India, Taiwan, Singapore, Australia, Netherlands, Belgium, UK, France and USA. Though CSIC from Spain was the most productive institution in this field, Dokuz Eylul University from Turkey had more independent research ability. During 1992 to 2009, the 6 most productive institutions in China were Chinese Acad SCI, Harbin Inst Techol, Tongji University, Tsinghua University, Zhejiang University and Hong Kong University, respectively ranking 2, 10, 13, 14, 15 and 20 of all the institutions.

Distribution of output in subject categories and journals

In 2007, Journal Citation Report(JCR) of the ISI contained 6426 major journals across 172 scientific disciplines in the Science Citation Index(SCI). Based on the classification of subject categories in JCR, the 12648 publications about sludge treatment during the past 18 years were distributed into 145 SCI subject categories. According to the statistical data, the most common subject categories were Environ-

mental Sciences, Environmental Engineering, Water Resources, Biotechnology & Applied Microbiology, Chemical Engineering. This indicated that sludge treatment was an important issue in the environmental field and the technology of sludge treatment was a key to disposing the waste generated after water treatment. The output trend of the most common subject categories was statistically analyzed in Figure 3. From this figure, the number of articles about sludge treatment in the 5 most common subject categories was steadily increasing during the past 18 years, especially in the field of Environmental Sciences, which showed the great concern on sludge treatment and disposition. There was a vast increase in the number of articles in Environmental Sciences and Environmental Engineering which could be caused by the more and more intense lack of energy and water resources in the recent years.

The 12648 articles were published in 1135 journals. The top 10 journals which published the most articles on sludge treatment from1992 to 2009 were separately analyzed in TABLE 4 where the core journals with their impact factors, the number of publication, the percentage of total articles and subject categories were listed. Water Research with 1111 articles(accounting for 8.8%) ranked first and it also had a relatively high impact factor, which makes the journal a very impactive publication in the field of sludge treatment. Next to Water Research were
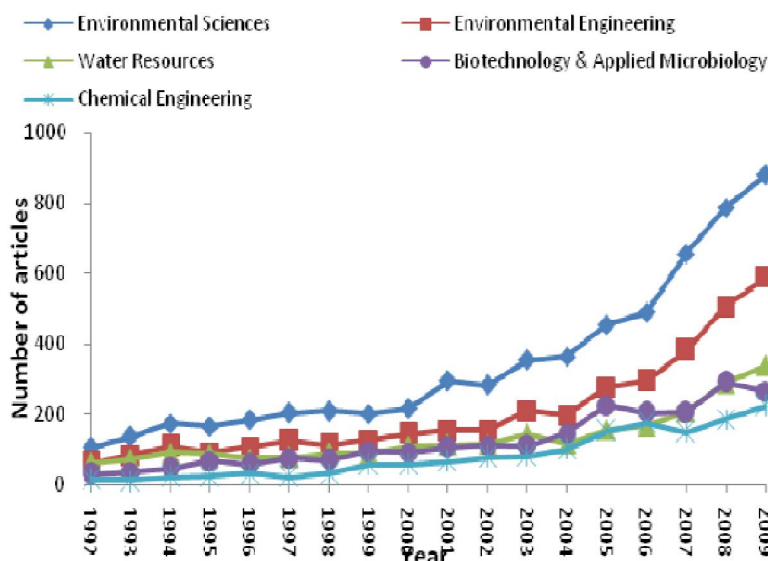

Figure 3 : Comparison between the growth trends of subject categories on the top 5 sludge treatment relate articles during the past 18 years

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TABLE 4 : Top 10 core journals

| SO	IF	TP(%)	SC
Water Research	4.355	1111(8.8)	Engineering, Environmental ; Environmental Sciences Water Resources
Bioresource Technology	4.253	572(4.5)	Agricultural Engineering Biotechnology & Applied Microbiology Energy & Fuels
Environmental Technology	0.762	450(3.6)	Environmental Sciences
Journal of Hazardous Materials	4.144	421(3.3)	Engineering,Environmental Engineering,Civil Environmental Sciences
Chemosphere	3.253	385(3)	Environmental Sciences
Water Environment Research	0.965	371(2.9)	Engineering,Environmental Environmental Sciences Limnology;Water Resources
Water Science and Technology	1.094	291(2.3)	Engineering,Environmental Environmental Sciences Water Resources
Environmental Science & Technology	4.63	271(2.1)	Engineering,Environmental Environmental Sciences
Journal of Environmental Engineering-ASCE	1.048	220(1.7)	Engineering,Environmental Engineering,Civil Environmental Sciences
Process Biochemistry	2.444	197(1.6)	Biochemistry & Molecular Biology Biotechnology & Applied Microbiology Engineering,Chemical
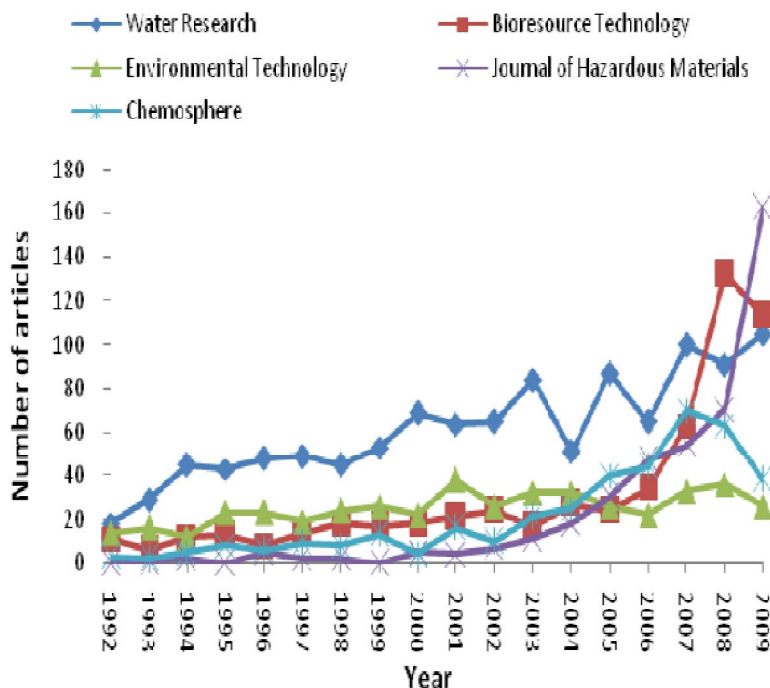
Figure 4 : Comparison between the growth trends of journals on the top 4 sludge treatment related articles during the past 18 years

Bioresource Technology, Environmental Technology, Journal of Hazardous Materials and Chemosphere with respective publication amount of 572,450,421 and 385. Figure 4 showed the growth trend of publi-

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cation output of each journal. Journal of Hazardous Materials published the least articles about sludge treatment in 1992, but became the most productive one in 2009, with a sharp growth rate during the 18 years.

Distribution of word in title analysis

The trend in sludge treatment research field could be reflected by analyzing the words in the title of articles. Words like sludge, treatment, wastewater, sewage and anaerobic appeared a lot in the title of journal articles in this field. The high frequency of word "anaerobic" could tell that anaerobic technology was the most economic and effective way to dispose sludge during the research period. Moreover, biological method was a major research direction in this field.

Distribution of author keyword analysis

Author keyword analysis offered the information of research trend which interested the researchers most. However, it is not very popular to use bibliometric method concerning author keyword to analyze the trend of research. In this study, almost 19000 author keywords were found out in the articles about sludge treatment during the past 18 years. Among them, over 17000 author keywords appeared less than 3 times, which was a hint of uncontinuous research and diverse focuses in the sludge treatment field. Author keywords appeared in the articles on sludge treatment from 1992 to 2009 were counted and ranked by total for the past 18 years in the time intervals of 4 years. The specific statistical information of the top 10 author keywords was collected

and shown in TABLE 6. Based on the data given in the table, removal of heavy metals was a focus item in sludge treatment and anaerobic nitrification was a mainstream method.

Distribution of keyword plus analysis

Analysis of keywords plus can help compare the difference between author keywords and reveal the detailed information in the articles. The distribution of the keywords plus with its rank and percentage during the research period was displayed in TABLE 7. Among the top 10 keywords plus, only the words "degration" or "bacteria"did not appear in the top 10 of author keywords, which could be regarded as additional indication that bacteria, as a kind of microorganism, was a very useful "tool" to degrade organic substance in the process of sludge treatment.

Distribution of cited times of publications analysis

The articles cited for the most times were critical guide in this field. Of all the 12648 articles, "Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data" was cited for 596 times since published.

SUMMARY

In this bibliometric research, some significant characteristics of the research performance on sludge treatment from 1992 to 2009 can be summarized. Of all the 12648 articles chosen from the database of SCI, English were the mainstream language. The

TABLE 5 : Top 30 frequency of words in title of the articles on sludge treatment from 1992 to 2009

Words in title	92-09 TP	92-09 R (%)	92-97 R (%)	98-03 R (%)	04-09 R (%)
Sludge	4285	1(34)	1(25)	1(37)	1(35)
Treatment	2947	2(23)	2(20)	2(22)	2(25)
Wastewater	2386	3(19)	9(6)	3(19)	3(22)
Sewage	1470	4(12)	7(7.1)	4(13)	4(12)
Anaerobic	1367	5(11)	3(11)	6(10)	6(11)
Activated	1357	6(11)	14(5.4)	5(12)	5(11)
Removal	1061	7(8.4)	11(5.7)	8(7.3)	7(10)
Soil	949	8(7.5)	5(7.9)	7(8.7)	11(6.9)
Process	823	9(6.5)	8(6.3)	10(5.8)	10(6.9)
Reactor	796	10(6.3)	15(5.4)	12(5.4)	9(6.9)

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TABLE 6 : Top 10 frequency of author keywords used

Author Keyword	92-09 TP	92-09 R (%)	92-97 R (%)	98-03 R (%)	04-09 R (%)
Activated sludge	1062	1 (11)	1 (18)	1 (13)	1(8.6)
Sewage sludge	752	2 (7.6)	2 (8.3)	2 (9.2)	2(6.8)
Wastewater treatment	580	3 (5.9)	10 (3.2)	3 (6.5)	3(6.1)
Sludge	483	4 (4.9)	3 (5.6)	4 (5.7)	5(4.4)
Wastewater	416	5 (4.2)	45 (1)	5 (4.6)	4(4.7)
Heavy metals	385	6 (3.9)	6 (4.6)	6 (4.5)	8(3.5)
Nitrification	374	7 (3.8)	4 (4.9)	7 (3.8)	7(3.5)
Anaerobic digestion	361	8 (3.6)	8 (4.3)	8 (3.5)	6(3.6)
Biodegradation	336	9 (3.4)	5 (4.8)	9 (2.9)	9(3.3)
Denitrification	282	10 (2.8)	6 (4.6)	10 (2.7)	11(2.6)

TABLE 7 : Top 10 frequency of keywords plus used

Keyword plus	92-09 TP	92-09 R (%)	92-97 R (%)	98-03 R (%)	04-09 R (%)
Activated-sludge	1464	1 (13)	5 (5.9)	2 (10)	1 (16)
Waste-water	1158	2 (10)	10 (4.9)	5 (8.4)	2 (12)
Sewage-sludge	1094	3 (10)	1 (9.5)	4 (8.6)	4 (11)
Sludge	1083	4 (10)	3 (8.6)	3 (8.9)	5 (10)
Removal	977	5 (8.8)	7 (5.3)	7 (5.7)	3 (11)
Waste-water treatment	861	6 (7.8)	32 (1.9)	10 (5)	6 (10)
Degradation	782	7 (7.1)	6 (5.4)	8 (5.7)	7 (8)
Water	747	8 (6.8)	2 (8.8)	1 (11)	12 (4.8)
Heavy-metals	638	9 (5.8)	4 (6.6)	6 (6.7)	9 (5.2)
Bacteria	550	10 (5)	7 (5.3)	9 (5.2)	10 (4.8)

amount of published articles on sludge treatment per year tended to increase continuously with a more and more fast rate. USA was the most productive country in this field and also published the most independent articles. China, as the second most productive country, had a significant increase in the amount of publications on sludge treatment during the past 18 years and had surpassed USA since 2008. CSIC from Spain was the most productive institution in this field. Subject categories like Environmental Sciences, Environmental Engineering, Water Resources, Biotechnology & Applied Microbiology, Chemical Engineering were the most common fields that these articles belonged to. Water Research included 1111 articles, ranking the first of all the journals concerned.

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