
Bibliometric analysis of biosorption technology in water treatment research from 1991 to 2004

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Abstract: A bibliometric analysis based on the *Science Citation Index* was carried out on biosorption technology-related publications during the time span of 1991 to 2004 in water treatment research in the ISI subject categories of environmental engineering, environmental sciences, and water resources. Results showed that yearly production has sharply grown. The US and Canada respectively produced 13% and 12% of the total output. In the five years after publication, 34% of papers were cited more than 10 times, while 5.7% were never cited in the same period. Nine papers of the top 20 most-frequently cited articles were published in *Water Research*.

Keywords: scientometrics; biosorption; SCI; citation.

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Biographical notes: Yuh-Shan Ho obtained his PhD (1995) at the University of Birmingham, United Kingdom. He became Professor in the Department of Environmental Sciences at Peking University, China, in 2006. He has published 110 papers in refereed journals (which have attracted more than 3800 citations). His research interests are adsorption process for water and wastewater treatment, and bibliometric studies.

1 Introduction

Biosorption is a process for water treatment. Early applications of the biosorption process were for sewage and waste treatment (Ullrich and Smith, 1951, 1957). It was also investigated for use in renovating wastewater in the chemical industry (Stasiak, 1969) and for uranium recovery (Chiu and Zajic, 1978). In recent years, biosorption has been recommended as an alternative treatment option for wastewaters containing dyes (Fu and Viraraghavan, 2001), heavy metals (Kapoor and Viraraghavan, 1995; Vegliò and Beolchini, 1997) and organic pollutants (Aksu, 2005). Metal biosorption process simulation tools involved in both the equilibrium and dynamic aspects of the sorption process have been summarised. Simultaneous consideration of sorption equilibria, sorbate solution chemistry, biosorption mechanisms, mass transfer and fluid-flow, all of

which determine the overall sorption performance, and the shape of the column breakthrough curve are thought to be important points of the design of biosorption column systems (Volesky, 2003). In addition, regeneration of biosorbent materials and testing of immobilised raw biomasses with real industrial effluents were suggested for further investigations in the direction of modelling the development of biosorption processes (Vegliò and Beolchini, 1997).

Bibliometrics is a research method used in library and information sciences. It utilises quantitative analysis and statistics to describe distribution patterns of publications within a given topic, field, institute or country. One common way of conducting bibliometric research is to use the *Science Citation Index (SCI)* that traces publications of the Institute for Scientific Information (ISI). The *SCI* has been used for the bibliometric analysis of medical topics (Ugolini and Mela, 2003; Hsieh et al., 2004; Chiu and Ho, 2005). Topics in the field of science and engineering have also been studied using bibliometric methods, for instance, the profile of the *Chemical Engineering Journal* and *Biochemical Engineering Journal* was investigated as reflected by its publications, references and citations (Schubert, 1998), the growth and trends of fullerene research as reflected in its journal literature (Braun et al., 2000), the scientific productivity in environmental psychology in Mexico (Lena, 1997) and the impact of *Solid State Communications* in view of its ISI citation data (Marx and Cardona, 2003). Evaluating the performance of each research topic is necessary in order to indicate the impact and contribution of authors in their respective fields.

The purpose of this study was to gain insights into the structure of biosorption performance in water treatment research. These documents were analysed and evaluated according to publication and citation distributions and were used to determine the quantitative characteristics of biosorption research.

2 Materials and methods

The 2003 edition of the *Journal Citation Reports (JCR)*, published by *ISI*, lists 170 subject categories including 5907 journals in the *SCI*. Documents used in this study were based on the database of the *SCI* obtained by subscription from the *ISI*, Web of Science, Philadelphia, PA, USA.

One hundred and 83 journals listed in the three *ISI* subject categories of environmental engineering ($n = 35$), environmental sciences ($n = 131$) and water resources ($n = 55$) were considered in this study. 'Biosorption' was used as a keyword to search titles, abstracts or keywords. Papers, editorial materials, notes, reprints and reviews were obtained from the results of the search for document types. Papers originating from England, Scotland, Northern Ireland and Wales were grouped under the UK heading. The impact factor (IF) of a journal was determined for each document as reported in the year 2003 *JCR*. Collaboration type was determined by the address of each author, where 'independent' was assigned if no collaboration between countries was determined. 'International collaboration' was assigned if the paper was cosigned by authors from more than one country.

The bibliometric impact of a publication is assessed in terms of the number of citations that it has received relative to other outputs in the journal. Let total number of papers be P , and let C be the number of total citations for the first five years (including the publication year and the following four years) since the papers were published.

The average number of citations per publication (CPP) is defined as the total citations over total publications to produce a value for the average number of citations per paper produced. In some cases, we only discuss the papers published in the period from 1991 to 2000 because there were no data for CPPs after 2000.

Documents were analysed according to their type, language of publication, publication output, publication pattern, authorship, country of publication, citation analysis, papers and cited reference analysis.

3 Results and discussion

The distribution of document types identified by ISI was analysed. From this analysis, five document types were found. The paper was the most frequently used document type comprising 96% of the total production, followed distantly by reviews (10, 2.0%). Editorial materials (5, 1.0%), notes (3, 0.6%) and reprints (1, 0.2%) showed lesser significance than papers and reviews. The languages in which documents were published were dominated by English, with only one paper being published in French. As the dominant type of document, 477 papers were analysed in the following study.

3.1 Publication output

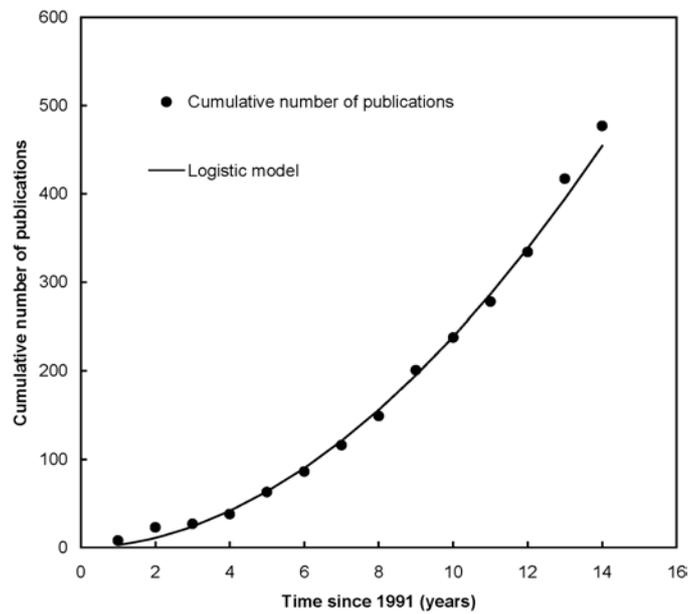
The results of publication output are shown in Table 1. For the period from 1991 to 2004, the cumulative number of papers consistently increased. In 1991, eight papers were published, while in 2004 the cumulative number of papers was 477. The relationship between the cumulative number of publications and year was determined as a quantitative trend of patent ductus arteriosus (PDA) surgery treatment research (Hsieh et al. 2004) and homeopathy research (Chiu and Ho, 2005). Figure 1 shows a significant correlation with a logarithmic model. A double logarithmic plot of the data showed that there was a linear relation with a high coefficient of determination ($r^2 = 0.996$) in the period 1993–2004. The logistic curve fitting denoted that a constant growth rate was sustained for yearly publications.

Table 1 Annual production of biosorption in the subject categories of environmental engineering, environmental sciences and water resources

<i>Year</i>	<i>No. of publications</i>	<i>Cumulative no.</i>
1991	8	8
1992	15	23
1993	4	27
1994	11	38
1995	25	63
1996	23	86
1997	30	116
1998	33	149
1999	52	201

Table 1 Annual production of biosorption in the subject categories of environmental engineering, environmental sciences and water resources (continued)

Year	No. of publications	Cumulative no.
2000	37	238
2001	40	278
2002	56	334
2003	83	417
2004	60	477

Figure 1 Cumulative number of publications by year

3.2 Publication patterns

In total, 477 papers were published in 47 journals including specialty journals in the ISI subject categories of environmental engineering, environmental sciences and water resources. Of the 47 journals, 14 (30%) journals contained only one paper, five (11%) journals contained two and three (6.4%) journals contained four, five, six and eight papers each. Table 2 shows the ten journals with the most published papers including the impact factor (IF), the *ISI* category of the journal, the position of the journal in its category, the number of papers and the percentage of total papers. *Water Research* published the most papers (91, 19%), followed by *Water Science and Technology* (52, 11%), *Environmental Science and Technology* (47, 10%), *Environmental Technology* (39, 8.2%) and *Chemosphere* (31, 6.5%). The impact factor (IF) of a journal is defined by the *JCR*, and is derived by dividing the number of current citations to papers published in the previous two years by the total number of papers published in the previous two years. It is a measure of the frequency with which the average paper in a journal has been cited in a particular year. The impact factor is used to evaluate a

journal's relative importance, especially when compared to others in the same field. The distribution of papers by reference to their IF was as follows: 10% of total papers had an IF of less than three, 5.7% had an IF of 2~3, 34% had an IF of 1~2, 41% had an IF of 0.5~1 and 9.4% had an IF of <0.5. Eight four percent of papers were published in journals with an IF of less than two. The mean impact factor for all of the papers in journals was 1.37. The journal with the highest impact factor (3.592) was *Environmental Science and Technology*.

Table 2 Ten journals with the most publications including impact factor, the *ISI* category of the journal, the position of the journal in its category and number of papers

<i>Journal</i>	<i>IF</i>	<i>P (%)</i>	<i>ISI category and position</i>
Water research	1.812	91(19)	Environmental engineering (4/35) Environmental sciences (23/131) Water resources (1/55)
Water science and technology	0.71	52(11)	Environmental engineering (16/35) Environmental sciences (84/131)
Environmental science and technology	3.592	47(10)	Environmental engineering (1/35) Environmental sciences (2/131)
Environmental technology	0.563	39(8.2)	Environmental sciences (107/131)
Chemosphere	1.904	31(6.5)	Environmental sciences (19/131)
Journal of Hazardous materials	1.099	19(4.0)	Environmental engineering (7/35) Environmental sciences (60/131)
International biodeterioration and biodegradation	0.621	18(3.8)	Environmental sciences (90/131)
Journal of environmental science and health part A-Toxic/Hazardous substances and environmental engineering	0.481	18(3.8)	Environmental engineering (25/35) Environmental sciences (114/131)
Water air and soil pollution	0.883	14(2.9)	Environmental sciences (68/131) Water resources (17/55)
Environmental pollution	2.002	13(2.7)	Environmental sciences (17/131)
Fresenius environmental bulletin	0.325	13(2.7)	Environmental sciences (123/131)

3.3 Authorship

The average number of authors per paper, from 1991 to 2004, was 3.2. Of the 477 papers, 21 (4.4%) were written by a single author, 155 (32%) by two authors, 143 (30%) by three authors, 85 (18%) by four authors, 39 (8.2%) by five authors, 19 (4.0%) by six authors, seven (1.5%) by seven authors, four (0.84%) by eight authors and one (0.21%) by nine authors. However, there were three (0.63%) instances with no author information in the *ISI*, Web of Science. The most-frequent numbers of authors were two or three, which was seen in 298 (62%) papers.

In the 477 papers published, there were 1058 authors. However, there were three papers for which no author information was available. These three papers were therefore omitted from the remainder of the author analysis. Of the 474 papers with author

information, 842 authors (80%) contributed to one paper, 123 (12%) to two papers, 49 (4.6%) to three papers, 14 (1.3%) to four papers, 13 (1.2%) to five papers, seven (0.66%) to six papers, four (0.38%) to seven papers, one (0.095%) to eight papers, two (0.19%) to nine papers and one each contributed to ten, 15 and 22 (0.095%) papers. Volesky at the University of McGill in Canada contributed to 22 papers, the highest number of paper published by an individual, followed by Le Cloirec at the Ecole des Mines de Nantes of France with 15 papers and Chua at Hong Kong Polytechnic University with ten papers. Table 3 shows the top ten contributors on an authored paper and total paper basis.

Table 3 Ten authors with the greatest number of papers in biosorption research

<i>Ranking</i>	<i>Author</i>	<i>Institute</i>	<i>Country</i>	<i>Total no. of papers</i>
1	Volesky, B.	McGill Univ	Canada	22
2	Le Cloirec, P.	Ecole Mines Nantes	France	15
3	Chua, H.	Hong Kong Polytech Univ	Hong Kong	10
4	Andres, Y.	Ecole Mines Nantes	France	9
5	Vegliò, F.	Univ Aquila	Italy	9
6	Aksu, Z.	Hacettepe Univ	Turkey	8
7	Kaewsarn, P.	Griffith Univ	Australia	7
8	Pagnanelli, F.	Univ Rome La Sapienza	Italy	7
9	Viraraghavan, T.	Univ Regina	Canada	7
10	Yu, Q.M.	Griffith Univ	Australia	7

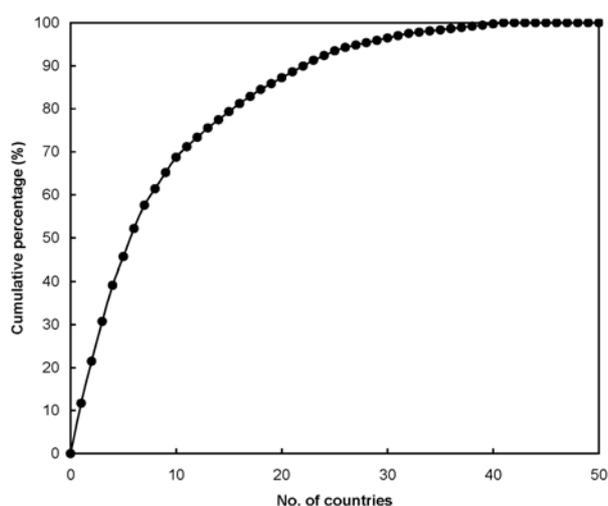
3.4 Country of publication

There were 51 papers without author address information in the *ISI*, Web of Science. For this reason, not all of the papers were included in this analysis. Table 4 shows the top ten most-productive countries between 1991 and 2004. Among the 426 papers with author address information published from 1991 to 2004, 58 (13.6%) papers were international collaborations and 368 (86.4%) were independent papers, but they were diverse, representing 50 different countries, with most papers originating from USA (54, 13%) and Canada (51, 12%). This result is not unusual, as USA is ranked top in most research fields in publications. Nine countries had no independent paper and 12 countries had no collaborative paper. Fifteen countries contributed only one or two independent papers, and 20 countries contributed only one or two collaborative papers. Figure 2 shows the relationship of the cumulative percentage of independent papers against the number of countries, and it indicates that seven countries accounted for 50% of the papers on biosorption. USA had the greatest number of independent papers, contributing 12% of all independent papers, followed by Canada with 9.8%, India with 9.2% and Turkey with 8.4%. However, Canada had the most-frequent partners accounting for 26% of the international collaborative papers followed by the UK with 21%, and USA with 19%.

Table 4 Top ten most-productive countries between 1991 and 2004

Country	IP	IP (%)	CP	CP (%)	P	P (%)
USA	43	2	11	19	54	13
Canada	36	9.8	15	26	51	12
India	34	9.2	3	5.2	37	8.7
UK	24	6.5	12	21	36	8.5
Turkey	31	8.4	2	3.5	33	7.8
France	24	6.5	5	8.6	29	6.8
Hong Kong	20	5.4	3	5.2	23	5.4
Peoples R China	13	3.5	7	12	20	4.7
Australia	9	2.5	5	8.6	14	3.3
Italy	14	3.8	0	0	14	3.3
Spain	14	3.8	0	0	14	3.3

P: total publications; IP: single-country publications;
 CP: international collaborative publications.

Figure 2 Cumulative percentage of biosorption papers by country

3.5 Citation analysis

The citation analysis is the citation count for a journal, an paper, a field or a country's publications. This is the frequency with which papers published in a journal are cited in other papers. The total citation count was obtained from *SCI*, Web of Science, and this shows the total number of times that a particular paper has been cited by all journals listed in the database. The number of citations does not actually indicate the quality of a paper, but is a measure of its impact or visibility. Among biosorption papers in this study, the most-frequently cited paper was 'Contribution of sulfonate groups and alginate to heavy metal biosorption by the dry biomass of *Sargassum fluitans*'. This paper published by Fourest and Volesky (1996) in *Environmental Science and Technology* (with an IF of 3.592) was cited 107 times since it was published in 2004.

Volesky published not only the most-frequently cited paper but also published the most number of papers on this topic.

The time dependence of a single paper is called its history and may be viewed as the 'sales figure' of the paper (Marx and Cardona, 2003). Similarly, the time dependence of a topic, biosorption research in this study, can also be called its history and can similarly be viewed as a sales figure of the research topic (Hsieh et al., 2004; Chiu and Ho, 2005). Figure 3 shows the relationship between paper life and percentage of cited papers in a year. In the beginning year (zero year here), this was lower because all papers appeared in that published year. The percentage of cited papers suddenly rose in the next four years and reached their maximum after five years, after which a slight decline was visible. The citation history of the cited papers is shown in Figure 4. There was a peak five years after publication for all papers taken together. After that, a decline was also observable. The peak position depends on the research discipline and was about two years in the case of homeopathy (Chiu and Ho, 2005). The average number of citations per publications (CPP) was defined as the total citations for the first five years (including the publication year and the following four years) divided by the total publications; this produced a value for the average citation per paper produced. A list of the 20 most-frequently cited papers (citations in five years after publication) between 1991 and 2000 is shown in Table 5. These top 20 papers were written by 77 authors from 12 different countries. Canada dominated the citation frequency with outstanding production of five papers, followed by USA with four papers and Australia and UK, each with three of the top 20 most-frequently cited papers. The top 20 papers were published in seven journals among which *Water Research* published nine papers, *Environmental Science and Technology* published seven and *Environmental Technology*, *Geomicrobiology Journal*, *Journal of Hazardous Materials*, *Science of the Total Environment* and *Water Environment Research* each published one paper. Four papers were international collaborations. Volesky with colleagues published five of the 20 most-frequently cited papers in biosorption research. Among all authors, Volesky had the highest contribution to citations. Seventy-four authors contributed to only one of the 20 most-frequently cited papers.

Figure 3 Percentage of biosorption papers cited by paper life

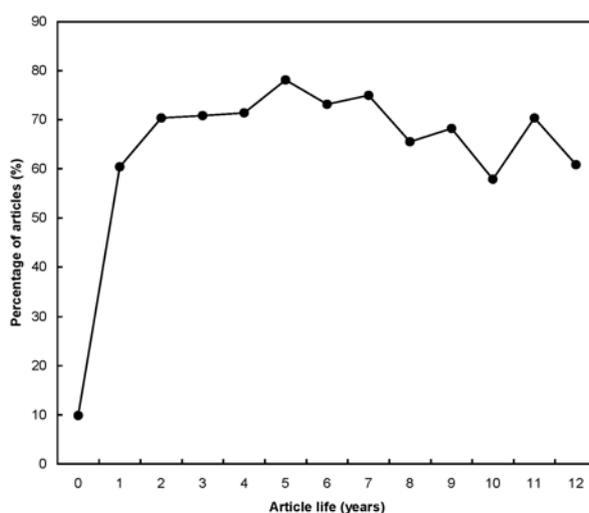
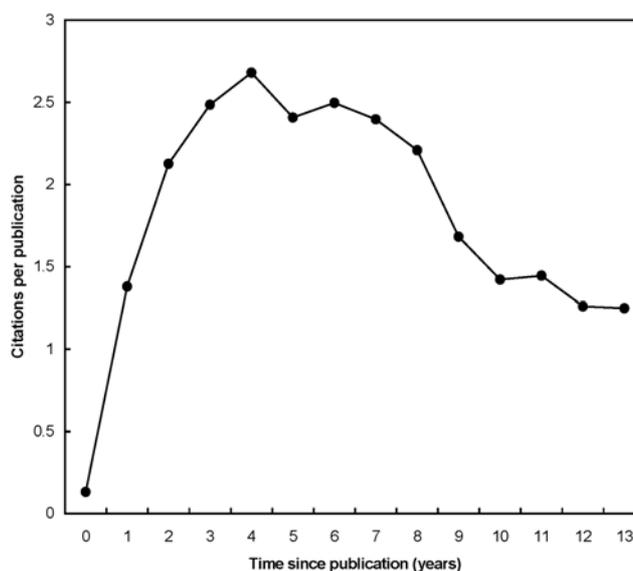


Figure 4 Citation history of biosorption research**Table 5** The 20 most-frequently cited biosorption-related research papers (no. of citations in the five years after publication) between 1991 and 2000

Rank	C	Authors	Year	Title	Journal
1	52	Fourest and Volesky	1996	Contribution of sulfonate groups and alginate to heavy metal biosorption by the dry biomass of <i>Sargassum fluitans</i>	Environmental science and technology
2	38	Figueira et al.	2000	Biosorption of metals in brown seaweed biomass	Water research
3	37	Pagnanelli et al.	2000	Biosorption of metal ions on <i>Arthrobacter</i> sp.: Biomass characterisation and biosorption modeling	Environmental science and technology
4	36	Chang et al.	1997	Biosorption of lead, copper and cadmium by biomass of <i>Pseudomonas aeruginosa</i> PU21	Water research
5	32	Urrutia et al.	1998	Microbial and surface chemistry controls on reduction of synthetic Fe(III) oxide minerals by the dissimilatory iron-reducing bacterium <i>Shewanella alga</i>	Geomicrobiology journal
6	31	Sarret et al.	1998	Structural determination of Zn and Pb binding sites in <i>Penicillium chrysogenum</i> cell walls by EXAFS spectroscopy	Environmental science and technology
6	31	Matheickal et al.	1999	Biosorption of Cadmium(II) from aqueous solutions by pre-treated biomass of marine alga <i>Durvillaea potatorum</i>	Water research

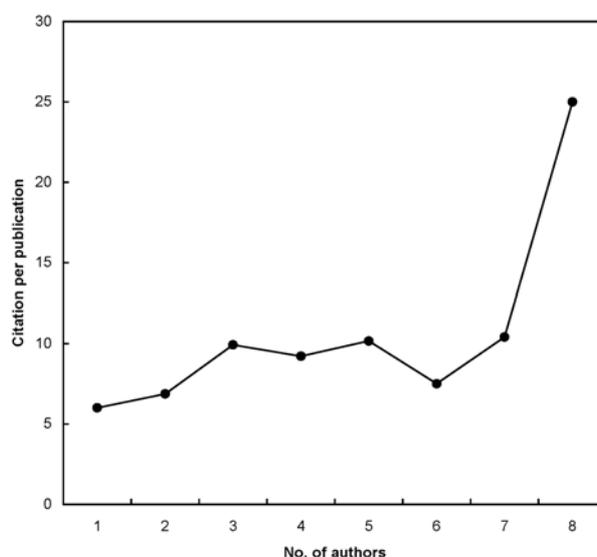
Table 5 The 20 most-frequently cited biosorption-related research papers (no. of citations in the five years after publication) between 1991 and 2000 (continued)

<i>Rank</i>	<i>C</i>	<i>Authors</i>	<i>Year</i>	<i>Title</i>	<i>Journal</i>
8	30	Layton et al.	2000	Mineralisation of steroidal hormones by biosolids in wastewater treatment systems in Tennessee USA	Environmental science and technology
9	29	Williams et al.	1998	Comparison between biosorbents for the removal of metal ions from aqueous solutions	Environmental science and technology
9	29	Yu et al.	1999	Heavy metal uptake capacities of common marine macro algal biomass	Water research
9	29	Davis et al.	2000	<i>Sargassum</i> seaweed as biosorbent for heavy metals	Water research
12	28	Cimino et al.	2000	Removal of toxic cations and Cr(VI) from aqueous solution by hazelnut shell	Water research
13	24	Jansson-Charrier et al.	1996	Vanadium (IV) sorption by chitosan: Kinetics and equilibrium	Water research
14	22	Brower et al.	1997	Comparison of ion-exchange resins and biosorbents for the removal of heavy metals from plating factory wastewater	Environmental science and technology
14	22	Butter et al.	1998	The removal and recovery of cadmium from dilute aqueous solutions by biosorption and electrolysis at laboratory scale	Water research
14	22	Gardea-Torresdey et al.	2000	Characterisation of Cr (VI) binding and reduction to Cr (III) by the agricultural byproducts of <i>Avena monida</i> (Oat) biomass	Journal of Hazardous materials
17	21	Brady et al.	1994	Biosorption of heavy-metal cations by nonviable yeast biomass	Environmental technology
17	21	Schiewer and Volesky	1995	Modelling of the proton-metal ion exchange in biosorption	Environmental science and technology
17	21	Kratochvil et al.	1998	Removal of trivalent and hexavalent chromium by seaweed biosorbent	Environmental science and technology
17	21	Delgado et al.	1998	Heavy metal biosorption by dried powdered mycelium of <i>Fusarium flocciferum</i>	Water environment research
17	21	Chick et al.	2001	Microbial interactions with tributyltin compounds: Detoxification, accumulation, and environmental fate	Science of the total environment

C: No. of times cited in the first five years since publication.

In total, 236 papers with author information were published from 1991 to 2000. Of these 236 papers, 13 (5.5%) papers were not cited in the first five years after the papers were published, and 27 (11%) papers were cited four times that was the most common number of citations in the same period. Figure 5 shows that the citations per publication increased with number of author.

Figure 5 Relationships between citation per publication in the five years after publication and the number of authors



3.6 Cited reference analysis

In total, 7628 documents were cited by the 477 papers for a total number of citations of 12,574 and a mean number of 26 references per paper. Only 0.68% of documents were cited more than ten times, while 48% were cited only once. Totally, 4,958 authors were cited in the references for biosorption research. A list of the 20 most-frequently cited authors with their publications and citations (citations in five years after publication) for biosorption-related research papers is shown in Table 6.

Table 6 Top 20 most-cited authors of biosorption-related research papers

<i>Author</i>	<i>No. of papers</i>	<i>No. of times cited</i>
Volesky, B.	39	276
Tsezos, M.	43	235
Fourest, E.	11	145
Gadd, G.M.	44	145
Aksu, Z.	32	122
Kuyucak, N.	20	109
Schiewer, S.	19	104
Crist, R.H.	12	102

Table 6 Top 20 most-cited authors of biosorption-related research papers (continued)

<i>Author</i>	<i>No. of papers</i>	<i>No. of times cited</i>
Tobin, J.M.	12	97
Beveridge, T.J.	26	90
Holan, Z.R.	4	79
Kratochvil, D.	13	75
Matheickal, J.T.	12	73
Vegliò, F.	9	61
Kapoor, A.	11	61
Guibal, E.	15	60
Ho, Y.S.	18	59
Sag, Y.	24	58
Zhou, J.L.	12	52
Chang, J.S.	9	49

4 Conclusions

Linear relation between annual cumulative number of publications and year were obtained. In comparison, lesser document types and languages have appeared in biosorption research compared with other research fields. Small-group collaboration was a popular method of coauthorship. The top three ranking countries of publication were USA, Canada and India. The most-frequently cited paper was published in the *Environmental Science and Technology* that is the second highest impact factor journal in the category of environmental sciences and the highest impact factor journal in the category of environmental engineering. Top 20 cited papers were written by 77 authors from 12 different countries, and were all published in English.

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