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Characteristics and trends in global lead removal research: a Science Citation Index Expanded-based analysis

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ABSTRACT

A bibliometric analysis was performed to reveal the trends in lead removal research in 1991–2015. The data used in this study were derived from the Science Citation Expanded Index of Web of Science. A total of 1,532 articles were found from the search results. An exponential growth of articles was observed for the period of 1991–2015 and *Journal of Hazardous Materials* was the most productive journal. USA was most active country in the lead removal research. The researchers were keen on investigating the new economical method for the removal of lead from wastewater and this work would be useful to the researchers to know the trends in lead removal research.

Keywords: Lead removal; Research; Productive authors; Productive institutes; Productive countries

1. Introduction

Heavy metals are hazardous pollutants that, in spite of occurring naturally, are released in major amounts to the environment due to anthropogenic activities, which is increasingly becoming serious issue [1]. The excessive levels of heavy metals can be introduced into the environment, for example, by industrial waste or fertilizers [2]. Metals are considered as significant toxic pollutants [3]. Lead is malleable, blue-gray, heavy metal that occurs naturally in the earth's crust and a common environmental contaminant [4] and it is accounting for 13 mg kg^{-1} of earth's crust [5]. Several stable isotopes of lead exist in nature, including, in order of abundance, ^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb [5]. Lead is a ubiquitous toxic heavy metal with an exceptional physical and chemical property that makes it appropriate for a great range of applications [6]. Lead can be used as pure metal or alloyed with other metals, or as chemical compounds. It is commonly used along with other metals in the production of storage battery, wire, sheet, pipe, paints, bearings, solder, antifriction metals, pewter, hair dyes, insecticides, pigments, ammunition, cable sheathing, weights for lifting, weight belts for diving, lead crystal glass, radiation protection and lipstick making [7–13].

Lead can be ingested from various sources, including lead paint and house dust contaminated by lead paint [14], and enters various sink points such as soil [15], drinking water [16], air and food [17]. Most of the crops and crop products grown in metal-polluted soils could be hazardous if consumed by living things [18]. Lead, a systemic toxicant affecting virtually each organ system, chiefly affects the central nervous system, principally, the developing brain [19]. It also produces various deleterious effects on the hematopoietic, renal and reproductive organs, mainly through increased oxidative stress [20]. The absence of mobile forms of lead eliminates the toxic risk both in the trophic chain and its migration downwards the soil profile [21]. The study of chemical speciation of dissolved and particulate elements (Pb, Zn, Cu, Cr, As and Sn) in the mining wastewater, showed that lead was predominantly present in the non-residual fractions of the surface water [22,23].

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Several methods have been developed for removal of lead from industrial wastewater as reported in literature such as chemical precipitation, electrochemical reduction, ion-exchange, reverse osmosis, membrane separation and adsorption [24,25]. Adsorption is projected as an economical and effective method for the retention of lead ions from aqueous industrial wastes because of its simplicity, effectiveness and economic in removal of heavy metals from aqueous solution [24]. Lead can be removed from soils via bench-scale soil washing techniques [26]. Teleosts biomass (fish scales) is a potential biomass to remove Pb^{2+} ions from synthetic solutions so also with lead contaminated water aqueous solutions by bacterial strain isolated from soil [27]. Researchers have found the natural sources of lead removal such as organic chelating acids [28], electrokinetic remediation technique [29] and specific lactic acid bacteria [30] to be effective solutions. Ashraf et al. [31] found the cheapest method of lead treatment of synthetic solution to be the use of teleost biomass. The study found that the use of protonated biomass with hydrocholoric acid treatment to be highly effective in lead removal as compared with other chemicals. The phytoremediation with Chinese brake ferns (*Pteris vittata*) and Indian mustard (*Brassica juncea*) has also been researched [32]. The following nine plant species such as (*Cyperus rotundus, Imperata cylindrica, Lycopodium cernuum, Melastoma malabathricum, Mimosa pudica, Nelumbo nucifera, Phragmites australis, Pteris vittata* and *Salvinia molesta*) can be used for remediation of lead (Pb), and also copper (Cu), zinc (Zn), arsenic (As) and tin (Sn) from contaminated tin tailings [33]. The zeolite is a potential material and can conveniently be processed as adsorbents for the removal of environmental pollutants [34]. Natural phosphate as treatment has also been evaluated by researchers [35]. The feasibility of lead removal through biological sulfate reduction process was investigated and found that lead removal of 85%–95% was attained [36]. The removal of lead from battery manufacturing wastewater by egg shells by adsorption isotherm demonstrated a descending lead removal efficiency in natural duck egg shell, natural hen egg shell, boiled duck egg shell and boiled hen egg shell, respectively [37].

Bibliometric analysis can provide an overall examination and quantitative viewpoint of a particular research topic supported by large amount of literature information. In particular, it can put in to reviewing the evolution and development trend of a scientific discipline, to identify hotspots and emerging ideas of a field, and to evaluate the performance and influence of different countries or journals. As a result, a better understanding of *status quo* can be achieved and future research directions can be identified from outcomes of bibliometric analysis. Bibliometric methods are widely used in recent days to reveal the research trends in topic such as estuary pollution [38], biosorption technology in water treatment [39], soil contamination [40], drinking water [41], air pollution [42], food-borne disease [43], solid waste research [44], world aerosol research [45], lead in drinking water [46], groundwater research [47], global environmental assessment research [48], arsenic in drinking water [49]. Huang et al. [50] did a bibliometric analysis to reveal research trends on nitrate removal and also Ye et al. [51] on sulfate removal research recently.

In this research, a bibliometric analysis of publication on the lead removal research during the period of 1991–2015 was performed. The analysis includes the year wise publication output, citations trend and productive journals. The study also analyzes the country-wise contribution, prolific authors and institute in lead removal research. Further, analysis of top occurred words in title as well as author supplied keywords was also performed to reveal the trends in research. Author and institution contributions were evaluated using *Y*-index based on the information of first author and corresponding author articles.

2. Methodology

The data used in this study are derived from the Science Citation Expanded Index of Web of Science. A total of 3,745 journals are indexed in Science Citation Expanded Index of Web of Science. The following keywords were used: "lead removal", "removal of lead", "lead reduction", "reduction of lead", "lead reduce", reduce lead" in title or author keyword or abstract of the articles indexed in Science Citation Expanded Index of Web of Science from 1991 to 2015 on 26 October, 2016. A total of 1,609 documents were found as a result of the search strategy that includes following document types: articles (1,532; 95.21%), review (32; 1.89%), meeting abstracts (19; 1.89%), editorial material (8; 0.49%), letter (6; 0.37%), news items (6; 0.37%), note (5; 0.31%) and correction (1; 0.6%). Information about 1,532 articles such as title, author, journal, citation, author affiliation, abstract and institute affiliation were downloaded into the Microsoft Excel spreadsheet. Articles originating from England, Scotland, Northern Ireland and Wales were reorganized as being one country. Further, manual coding was performed to analysis purposes and analysis was done using Microsoft Excel 2007.

Articles originating from Hong Kong published after 1997 were included in China. Articles from Federal Republic of Germany (Fed Rep Ger) and Germany were reclassified as being from Germany. In Web of Science, corresponding author is coded as "reprint author"; however, the research shown in this article uses the term "corresponding author" and similarly, corresponding institute and country is determined by the addresses of the corresponding author. The impact factor of the journals provided in this article is derived from the Journal Citation Report 2015. In SCI-EXPANDED database, the corresponding author is labeled as the "reprint author", and this study uses the term "corresponding author". In a single author article where authorship is not specified, the single author is classified as the first author and the corresponding author [52]. Pearson correlation coefficient was used to know the correlation between number of articles of the country and the GDP ranking and also impact factor of the journal and average citations per article.

3. Results and discussion

3.1. Publication output and scientific descriptors

Publication output determines the number of articles published over a period of time and the nature of articles as presented in Table 1. A total of 1,532 articles were published during the period of 1991–2015, where the number of articles published per year had increased from 11 in 1991 to 147 in 2015, which is 13 times more than the year 1991. Although the number of articles published between 1991 and 2010 were less than 100 articles per year, the number had increased from

2011 onwards and crossed 100 number marks. This rising of articles over the years suggested an increase in the research activities on lead removal in recent times. Citations are indicators of the impact of the articles on fellow researchers in a field [42]. The average number of citations received per article had ranged between 2.67 and 85.70 for the articles published during the years 2015 and 1994, respectively, where the average citations received per year stood at 21.50. The citation counts per year had kept increasing for about 20 years, from the initial year 1991 up to 2009 suggesting sustained number of articles were published on lead removal research. The older publications could continuously receive the citations as they are cited in newer publications up to 2009. The articles published after 2009 had showed declining trend for number of citations received from their average number of citations (16.14) to 2.67 for the year 2015. The articles published after 2011 were relatively new and they need some time to be referred and cited in future research of significance [43].

With increase in number of articles a corresponding increase in number of references was also noticed for all the publications. During 1991, the number of references used was 141 for 11 articles and it had increased to 5,636 references for the 147 articles published during 2015, although the average references per article were 28.70. It is clear from the table that the average number of references had increased from 12.82 (1991) to 38.34 (2015). The average number of references per paper increases over time. This is the function of specialty growth. The network of base knowledge in the specialty gets more intricate as it grows and fills in the blanks, so authors of later papers have to cite more marker references to describe the position of the contribution of their papers in the network of base knowledge in the specialty [53]. The increase in number of references indicates that the lead removal research is growing continuously. Pearson correlation coefficient was used to know the correlation between average references consulted and average citations rate of the articles published on lead removal. We have found that the value of R is –0.2491. Although technically a negative correlation, the relationship between the variables is only weak. Also, there was increase in number of pages of literature published on lead removal. A total of 13,180 pages of literature were published on lead removal research during 1991–2015, it was mere 93 pages during 1991 and it reached to 1,365 pages during 2015, however, there was no much increase of average number of pages per article (8.60), it ranged between 7.18 and 9.85 from 1991 to 2015. The number of articles published and average citations per article was displayed in Fig. 1; it reveals the trends in the publication on lead removal. Fig. 1 indicates the exponential growth in literature on lead removal for the period under the study and the average citations per article were not constant, the articles published in the year 1994 have greater rate of average citations (85.7). It confirms that the articles published in the year 1994 were brought novel ideas, which become basis for the further research on lead removal in later years. Similar increase was observed in case of nitrate removal [50] and sulfate removal [51].

Table 1
Publication output and scientific descriptors of article on lead removal 1991–2015

PY	TA	TC	NR	PG	TC/TA	NR/TA	PG/TA
1991	11	281	141	93	25.55	12.82	8.45
1992	10	89	157	79	8.90	15.70	7.90
1993	15	154	171	121	10.27	11.40	8.07
1994	20	1,714	371	238	85.70	18.55	11.90
1995	27	265	365	219	9.81	13.52	8.11
1996	22	712	445	158	32.36	20.23	7.18
1997	38	1,452	757	301	38.21	19.92	7.92
1998	54	1,257	1,087	471	23.28	20.13	8.72
1999	47	1,634	834	403	34.77	17.74	8.57
2000	45	945	880	371	21.00	19.56	8.24
2001	39	1,549	918	384	39.72	23.54	9.85
2002	41	1,876	1,120	389	45.76	27.32	9.49
2003	48	1,857	1,218	434	38.69	25.38	9.04
2004	44	2,025	1,225	378	46.02	27.84	8.59
2005	62	2,043	1,430	498	32.95	23.06	8.03
2006	65	1,800	1,691	525	27.69	26.02	8.08
2007	68	2,184	1,886	604	32.12	27.74	8.88
2008	81	2,200	2,411	670	27.16	29.77	8.27
2009	92	2,367	2,639	692	25.73	28.68	7.52
2010	92	1,715	2,787	703	18.64	30.29	7.64
2011	111	1,791	3,617	976	16.14	32.59	8.79
2012	106	1,343	3,616	886	12.67	34.11	8.36
2013	127	804	4,377	1,129	6.33	34.46	8.89
2014	120	493	4,196	1,093	4.11	34.97	9.11
2015	147	392	5,636	1,365	2.67	38.34	9.29
Total	1,532	32,942	43,975	13,180	21.50	28.70	8.60

PY, publication year; TA, total articles; TC, total citations; NR, number of references; PG, page counts; TC/TA, average citations per article; NR/TA, average references per article; PG/TA, average page counts per article.

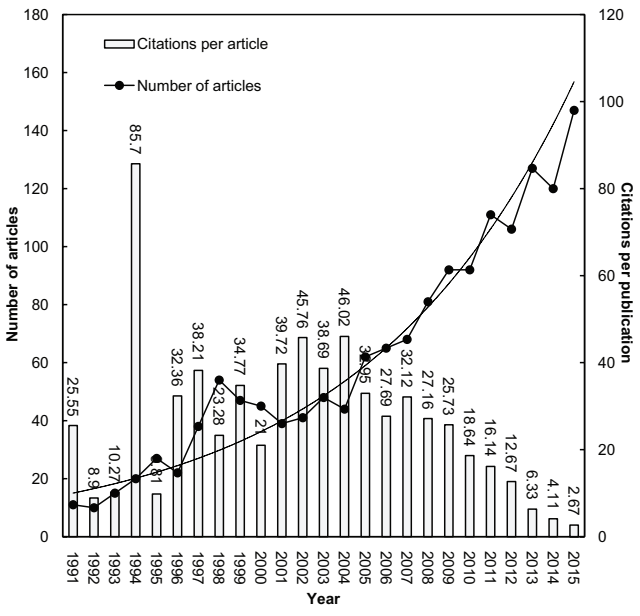

Fig. 1. Number of article and average citations per article over year.

3.2. Most productive journals on lead removal research

A total of 1,532 articles were published during the period of 1991–2015 in 566 journals. Publications on lead removal research by different journals are presented in Table 2. The journals that have published a minimum of 15 articles on lead removal research were classified here and there are 15 such journals with publications between 15 and 77. The *Journal of Hazardous Materials* had accounted for 77 articles with a share of 5.03% out of 1,532 total articles and stood first. The other important journals were *Chemical Engineering Journal* (44 articles and 2.87%), *Pace-Pacing and Clinical Electrophysiology* (41 articles and 2.68%), *Separation Science and Technology* (38 articles and 2.48%) and *Desalination and Water Treatment* (37 articles and 2.42%). These are the five major journals involved in publication of lead removal research; remaining 10 other journals had contributed between 15 and 22 articles.

In case of sulfate removal research, *Journal of Biological Chemistry* and *Applied and Environmental Microbiology* were the leading journals [51] and *Water Research* and *Applied and Environmental Microbiology* were the most productive journals on the nitrate removal research [50]. The *Science of the Total Environment* was the most productive journal in case of the research on lead in drinking water [46]. *Environmental Sciences and Ecology* was most active journal in non-point source pollution [54]. In case of soil contamination, the *Chemosphere* was the most productive journal followed by the *Journal of Hazardous Materials* [40]. *Atmospheric Environment* was the major contributor in case of air pollution research [42]. *Science of the Total Environment* was the most active journal in soil monitoring research [55]. The *Global Biogeochemical Cycles* was the most productive journal in case of carbon cycling research [56].

It was also observed that majority of the articles were published in journals with high impact factor, as per journal citation report 2015 (JCR2015), these journals had the impact factor between lowest of 1.064 to highest of 5.999 with a journal ranking of 430 (*Water Research*) and 5,648 (*Water Science and Technology*), respectively. The total citations received during the period had ranged between highest 4,894 numbers for the *Journal of Hazardous Materials* and a lowest of 32 numbers for *Asian Journal of Chemistry*. Similarly, the average citations per article ranged from highest, 79.59 numbers published by *Bioresource Technology* to lowest numbers, 1.88 published by *Asian Journal of Chemistry*. The top five journals with highest citations per article on lead removal research were, *Bioresource Technology*, *Water Research*, *Journal of Colloid and Interface Science*, *Journal of Hazardous Materials* and *Separation and Purification Technology*.

The number of references published on lead removal research was highest by *Journal of Hazardous Materials* (2,719) with an average references per article of 35.31, followed by journal *Chemical Engineering Journal* (1,921) with an average of 43.66 references per article. Similarly, the highest number of pages was published by *Journal of Hazardous Materials* with 650 pages and average page counts per paper, 8.44. The journal, *Separation and Purification Technology* stood second with 562 pages and average page count of 14.79 per article. Pearson correlation coefficient was used to know the correlation between average citations recorded for the articles on lead removal and impact factor of the journal. The value of R is 0.4553. Although technically a positive correlation, the relationship between two variables is weak. This suggests that the impact factor of the

Table 2
Most productive journals with 15 or more articles on lead removal 1991–2015

Journal	TA	TA (%)	IF 2015 (R)	TC	TC/TA	NR	NR/TA	PG	PG/TA
Journal of Hazardous Materials	77	5.03	4.836 (671)	4,894	63.56	2,719	35.31	650	8.44
Chemical Engineering Journal	44	2.87	5.31 (552)	1,641	37.30	1,921	43.66	397	9.02
Pace-Pacing and Clinical Electrophysiology	41	2.68	1.156 (5,371)	770	18.78	636	15.51	228	5.56
Separation Science and Technology	38	2.48	1.083 (5,600)	710	18.68	1,103	29.03	562	14.79
Desalination and Water Treatment	37	2.42	1.272 (5,053)	140	3.78	1,172	31.68	343	9.27
Journal of Colloid and Interface Science	22	1.44	3.782 (1,111)	1,576	71.64	849	38.59	177	8.05
Separation and Purification Technology	22	1.44	3.299 (1,457)	826	37.55	622	28.27	176	8.00
Water Research	19	1.24	5.991 (430)	1,457	76.68	462	24.32	159	8.37
International Journal of Environmental Science and Technology	19	1.24	2.344 (2,589)	265	13.95	802	42.21	199	10.47
Bioresource Technology	17	1.11	4.917 (645)	1,353	79.59	437	25.71	124	7.29
Industrial and Engineering Chemistry Research	17	1.11	2.567 (2,235)	369	21.71	537	31.59	120	7.06
Asian Journal of Chemistry	17	1.11	NA	32	1.88	288	16.94	110	6.47
Environmental Science and Technology	16	1.04	5.393 (538)	422	26.38	506	31.63	102	6.38
Journal of Industrial and Engineering Chemistry	16	1.04	4.179 (915)	167	10.44	635	39.69	120	7.50
Water Air and Soil Pollution	15	0.98	1.551 (4,267)	235	15.67	500	33.33	244	16.27
Water Science and Technology	15	0.98	1.064 (5,648)	158	10.53	358	23.87	117	7.80

TA, total articles; TA (%), percentage of total articles; IF 2015 (R), impact factor as per the Journal Citation Report 2015 with rank; TC, total citations; NR, number of references; PG, page counts; TC/TA, average citations per article; NR/TA, average references per article; PG/TA, average page counts per article.

journal and average citations to the articles on particular topic is not correlated significantly. The impact factor of the journal is not clearly representative of the influence of the individual article published in the journal [57]. The publication trend in top five journals was displayed in Fig. 2. All five journals have become most active in publication of lead removal research after 2009 and the journal *Desalination and Water Treatment* was started publishing from 2009, the journal has published maximum articles on lead removal in the recent times.

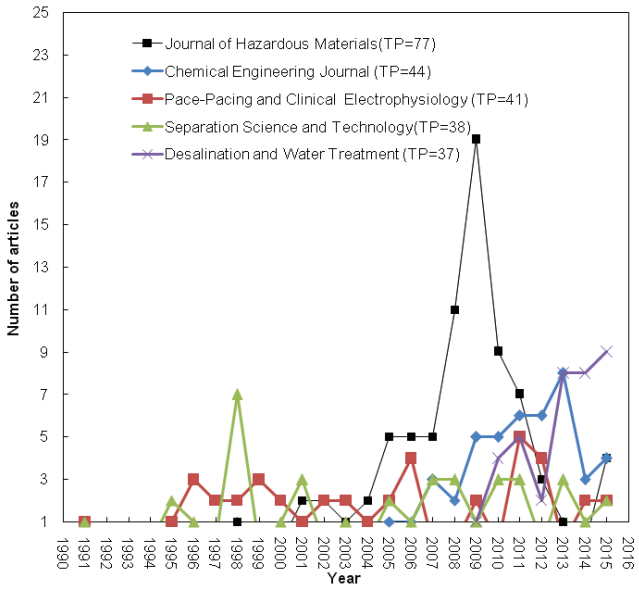

Fig. 2. Publication trends in top five journals on lead removal research.

3.3. Most productive countries

The country wise contribution of articles on lead removal research as presented in Table 3 shows that 17 countries had contributed for more than 31 articles during the assessment period 1991–2015. A total of the 82 countries have contributed toward lead removal research. USA stood first for the parameters such as total articles published (231), articles of first authorship (130), articles of corresponding author (235), total citations (5,893) and grass domestic product rank. This result is not surprising as the similar results were found in case of nitrate removal [50] and sulfate removal [51]. The other notable countries in this regard were China and India with more than 150 articles. China stood second with respect to number of articles (197), articles of corresponding author (177) and GDP rank. However, India stood first in average citations received per article (35.76) from a total of 5,400 citations and ranked second for first author articles published on lead removal research. However, in case of the nitrate removal [50] and sulfate removal research [51], Germany was the most productive country after USA. The other 14 countries had contributed for articles between 31 and 91. Pearson correlation coefficient was used to know the correlation between number of articles of the country and the GDP ranking. We found that the value of R is 0.1469. Although technically a positive correlation, the relationship between two variables is weak. It confirms that global GDP rank of the country and publication output on a topic is not significantly correlated. The publication trend of the articles of the top five most contributed countries was displayed in Fig. 3. The USA was the leading publisher of the articles on lead removal till 2012 and China showed rise in number of articles from 2013. Publication trend of the China and India were seen rising in the recent times, while, USA and Turkey were seen as decreasing prototype.

Table 3
Characteristics of the most productive countries (TP ≥ 31)

Country	TA (*R*)	FA (*R*)	CA (*R*)	TC	TC/TA (*R*)	GDP Rank (2016)
USA	253 (1)	130 (1)	235 (1)	5,893	23.29 (5)	1
China	197 (2)	50 (4)	177 (2)	4,123	20.93 (8)	2
India	151 (3)	74 (2)	148 (3)	5,400	35.76 (1)	7
Turkey	91 (4)	54 (3)	89 (4)	2,474	27.19 (3)	18
Iran	79 (5)	29 (6)	75 (6)	1,114	14.10 (13)	27
Japan	58 (6)	26 (8)	54 (7)	417	7.19 (15)	3
France	45 (7)	20 (10)	33 (12)	670	14.89 (11)	6
England	45 (7)	27 (7)	39 (8)	951	21.13 (7)	5
Canada	45 (7)	35 (5)	37 (9)	1,406	31.24 (2)	10
Italy	44 (8)	19 (11)	36 (10)	668	15.18 (9)	8
South Korea	43 (9)	22 (8)	39 (8)	641	14.91 (10)	11
Egypt	36 (10)	22 (8)	25 (16)	862	23.94 (4)	32
Germany	35 (11)	17 (12)	24 (17)	412	11.77 (14)	4
Poland	35 (11)	14 (14)	35 (11)	173	4.94 (16)	25
Spain	33 (12)	10 (16)	27 (15)	699	21.18 (6)	14
Mexico	32 (13)	15 (13)	30 (13)	471	14.72 (13)	15
Pakistan	31 (14)	13 (15)	29 (14)	460	14.84 (12)	41

TA, total articles; FA, first author articles; CA, corresponding author articles; TC, total citations; TC/TA, average citations per article; *R*, rank. The value of *R* is 0.1469. Although technically a positive correlation, the relationship between the variables is weak (nb. the nearer the value is to zero, the weaker the relationship). The value of R^2, the coefficient of determination, is 0.0216.

3.4. Top most prolific authors and institutions

Authors who have contributed for more than 31 articles on lead removal research during 1991–2015 were analyzed and presented in Table 4. A total of 5,007 unique authors were involved in the publication of 1,532 articles. There were 16 authors in this classification with a number of articles published between 7 and 11. It has been accepted that the first author is the person who contributes most to the work and writing of the article [58] and also corresponding author is perceived as one contributing significantly to the article independently of the author position [59]. "Kutarski, A" from Medical University Lublin, Department of Cardiology, Poland, contributed for highest number of articles (11) and ranked at second place in case of first author articles and fifth in case of corresponding author for articles published in Science Citation Indexed journals on lead removal. "Martin-Lara, MA" from University of Granada, Department of Chemical Engineering, Granada, Spain, stood second with 10 articles. Two to three top most prolific authors were from Poland, Spain, China, USA and Croatia and single contributors from India, Canada and Singapore. The author "Gupta, VK" was from Indian Institute of Technology, Roorkee, India, ranked fifth in case of total articles and first rank in first author articles and second in the corresponding author articles.

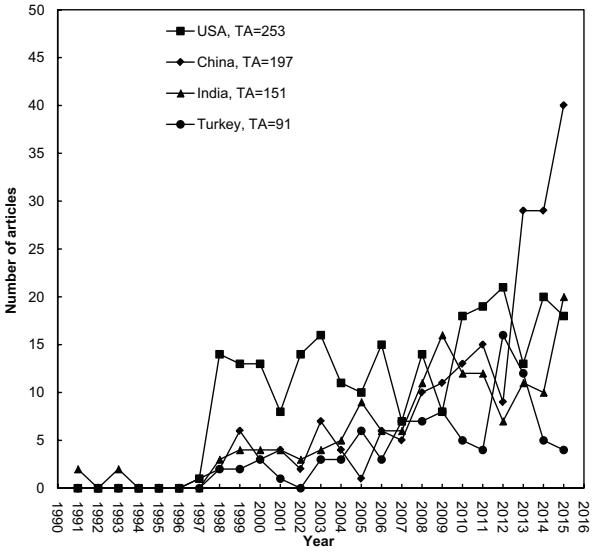

Fig. 3. Comparison of trend in publication of articles by four countries (USA, China, India and Turkey).

The author "Pan BC" was the contributor of most corresponding author articles, who belongs to the Nanjing University, China. The *Y*-index proposed by Ho [60], to evaluate the performance of author, institute and country based on the first author articles and corresponding author articles. It is concerned with number of first author publications (FP) and corresponding author publications (RP). The *Y*-index with two parameters (*j*, *h*), assesses both the publication quantity and characteristics of contribution as a single index, and is defined as:

$$j = \mathrm{FP} + \mathrm{RP} \tag{1}$$

$$h = \tan^{-1}\left(\frac{\mathrm{RP}}{\mathrm{FP}}\right) \tag{2}$$

where *j* is publication performance, which is a constant related to publication quantity, and *h* is publication characteristic, which can describe the proportion of RP to FP. *j* is the sum of FP and RP. Greater the *j* more is the contribution that the analyzed unit makes. Different values of *h* stand for different proportions of RP to FP. $h > 0.7854$ means more RP; $h = 0.7854$ means the same quantity of FP and RP; $0 < h < 0.7854$ means more FP. When $h = 0$, *j* = number of first author

Table 4
Top 16 most prolific authors (TP ≥ 31)

Author	TA (*R*)	FA (*R*)	CA (*R*)	Institute	*h*	Rank (*j*)
Kutarski, A	11 (1)	4 (2)	2 (5)	Medical University, Lublin, Poland	0.4636	6 (6)
Martin-Lara, MA	10 (2)	3 (3)	2 (5)	University of Granada, Granada, Spain	0.5880	7 (5)
Blazquez, G	9 (3)	3 (3)	4 (4)	University of Granada, Spain	0.9272	5 (7)
Calero, M	9 (3)	1 (5)	N/A	University of Granada, Spain	N/A	N/A
Reed, BE	9 (3)	3 (3)	5 (3)	W Virginia University, USA	1.0303	4 (8)
Trgo, M	9 (3)	1 (5)	4 (4)	University of Split, Croatia	1.3258	7 (5)
Blais, JF	8 (4)	N/A	8 (1)	University of Quebec, Canada	N/A	N/A
Liu, Y	8 (4)	1 (5)	2 (5)	Hunan University, China	1.1071	(3)
Malecka, B	8 (4)	5 (1)	2 (5)	Jagiellonian University, Poland	0.3805	(5)
Medvidovic, NV	8 (4)	4 (2)	2 (5)	University of Split, Croatia	0.4636	(4)
Pan, BC	8 (4)	2 (4)	8 (1)	Nanjing University, China	1.3258	2 (10)
Peric, J	8 (4)	1 (5)	N/A	University of Split, Croatia	N/A	N/A
Chen, JP	7 (5)	4 (2)	5 (3)	National University, Singapore	0.8960	3 (9)
Gupta, VK	7 (5)	5 (1)	7 (2)	Indian Institute of Technology, Roorkee, India	0.9505	1 (12)
Wilkoff, BL	7 (5)	2 (4)	2 (5)	Cleveland Clinic Foundation, USA	0.7853	8 (4)
Zhang, WM	7 (5)	2 (4)	N/A	Nanjing University, China	N/A	N/A

TA, total articles; FA, first author articles; CA, corresponding author articles; *R*, rank; *j* and *h*, constants of *Y*-index.

articles and when $h = \pi/2$, j = number of corresponding author articles [52]. As per the Y-index, "Gupta, VK" ranked first as per the j rank with h value of 0.9505 followed by "Pan, BC" (h = 1.3258; j rank = 2) and "Chen, JP" (h = 0.9505; j rank = 3).

A total of 1,587 research institutes around the globe have contributed for lead removal research (Table 5). Islamic Azad University, Dubai, contributed for maximum number of articles (22) and ranked first, followed by the Indian Institute of Technology, Roorkee, India (18) ranked at second position followed by Chinese Academy of Science, China; National University Singapore, Singapore, and Council of Scientific and Industrial Research, India, with 16 articles each stood at third position. Among the articles published as first author and corresponding author, Indian Institute of Technology, Roorkee, India, was found to be the leading institute with 18 articles (FA and CA) followed by Council of Scientific and Industrial Research, India (16). These two institutions had 100% contributions as first author and as well as corresponding author articles. Apart from Indian institutions, there were notable contributions from institutions of China (Chinese Academy of Science, Nanjing University), Spain, Turkey, Russia, Malaysia, Egypt, Singapore, Hong Kong, Poland and Pakistan.

Indian Institute of Technology, Roorkee, India, has published all articles as first as well as corresponding author articles in lead removal research and had the highest j of Y-index (j = 32, h = 0.7853), followed by the Council of Scientific and Industrial Research, India, which ranked second for first author articles and corresponding author articles, but ranked third for total articles. National University, Singapore, was ranked second for corresponding author articles and ranked third for total articles and had third highest j of Y-index (j = 29, Y = 0.888). Islamic Azad University, Dubai, was ranked first for total articles and third for first author's articles and

Table 5
Characteristics of the 22 most productive institutions (TP ≥ 8)

Institute	TA (*R*)	%	FA (*R*)	% (TA/FA)	CA (*R*)	% (TA/CA)	*h*	Rank (*j*)
Islamic Azad University, Dubai	22 (1)	1.44	14 (3)	64	14 (3)	63	0.7853	4 (28)
Indian Institute Technology, Roorkee, India	18 (2)	1.17	18 (1)	100	18 (1)	100	0.7853	1 (36)
Chinese Academy Sciences, Beijing, China	16 (3)	1.04	10 (6)	63	10 (5)	62	0.7853	6 (20)
National University, Singapore	16 (3)	1.04	13 (4)	81	16 (2)	100	0.888	3 (29)
Council for Scientific and Industrial Research, India	16 (3)	1.04	16 (2)	100	16 (2)	100	0.7853	2 (32)
Nanjing University, Nanjing, China	12 (4)	0.78	12 (5)	100	12 (4)	100	0.7853	5 (24)
Ondokuz Mayis University, Turkey	12 (4)	0.78	8 (8)	67	8 (7)	66	0.7853	9 (16)
University of Malaya, Kuala Lumpur, Malaysia	11 (5)	0.72	9 (7)	82	9 (6)	81	0.7853	7 (18)
Eskisehir Osmangazi University, Turkey	10 (6)	0.65	8 (8)	80	9 (6)	90	0.8441	8 (17)
University of Granada, Spain	10 (6)	0.65	10 (6)	100	10 (5)	100	0.7853	6 (20)
Harvard University, Cambridge, USA	9 (7)	0.59	2 (13)	22	2 (12)	22	0.7853	17 (04)
Hunan University, Hunan Sheng, China	9 (7)	0.59	8 (8)	89	8 (7)	88	0.7853	9 (16)
Hong Kong Polytechnic University, Hong Kong (China)	8 (8)	0.52	5 (11)	63	5 (10)	62	0.7853	14 (10)
King Fahd University Petroleum and Minerals, Dhahran, Saudi Arabia	8 (8)	0.52	5 (11)	63	4 (11)	50	0.8960	15 (9)
Quaid I Azam University, Islamabad, Pakistan	8 (8)	0.52	1 (14)	13	1 (13)	12	0.7853	18 (2)
Russian Academy of Sciences, Moscow, Russia	8 (8)	0.52	4 (12)	50	7 (8)	87	1.051	13 (11)
Sichuan University, Sichuan, China	8 (8)	0.52	8 (8)	100	8 (7)	100	0.7853	9 (16)
University of Alexandria, Alexandria, Egypt	8 (8)	0.52	5 (11)	100	5 (10)	62	0.785398	14 (10)
University of Johannesburg, Johannesburg, South Africa	8 (8)	0.52	7 (9)	88	6 (9)	75	0.708626	10 (13)
University of Punjab, Chandigarh, India	8 (8)	0.52	5 (11)	63	6 (9)	75	0.876058	12 (11)
University of Quebec, Quebec, Canada	8 (8)	0.52	8 (8)	100	8 (7)	100	0.785398	9 (16)
University of Split, Split, Croatia	8 (8)	0.52	6 (10)	75	6 (9)	75	0.785398	11 (12)

TA, total articles; FA, first author articles; CA, corresponding author articles; % (TA/FA), percentage of first author articles; % (TA/CA), percentage of corresponding author articles; *R*, rank; *j* and *h*, constants of *Y*-index.

corresponding author's articles and had fourth highest *j* of *Y*-index (*j* = 28, *Y* = 0.7853). Of the 22 institutes, five were from China, three from India, two from Turkey and one each from USA, Dubai, Singapore, Malaysia, Spain, Saudi Arabia, Pakistan, Russia, Egypt, South Africa, Canada and Croatia. This result is surprising as in case of nitrate removal [50] and sulfate removal [45], the most of the top contributed institutes were from the USA followed by the China. It confirms that China has accelerated research on environmental issue in the last decade by investing more funds for research, especially environmental related topics.

3.5. Frequently used words in the title of the articles

The 25 most frequently used words in the title of the articles on lead removal research are presented in Table 6. The title of the article indicates the content of the article and also the words used to frame title can be an indicator of the content. Hence, we have analyzed the top 25 words appeared most frequently in the 1,532 articles. The word "lead removal" had appeared in 138 articles with 3.70% and takes the first rank followed by the words "Lead Ion" (84 articles and 2.25%), "effect" (70 articles and 1.88%), "reduction" (56 articles and 1.50%). The following words appeared in the articles between 17 or more times were "heavy metal", "synthesis", "equilibrium", "lead extraction", "lead exposure", "child", "kinetic study" and "surface". The removal of lead from wastewater can be performed using different kind of methods and techniques [61–63]. Different types of techniques were also employed to remove the lead ion as documented in the literature [64–66]. Lead exposure by women during pregnancy may have affected the maternal and child health [67] and also children's [68]. Occupational and environmental exposures to lead remain a serious problem in many developing and industrializing countries, as well as in some developed countries [69]. Epidemiologic studies have shown an association between blood lead levels and blood pressure, and hypertension is a cardinal feature of lead nephropathy [70]. Lead poisoning is an important environmental disease that can have life-long adverse health effects and key strategy for preventing lead poisoning is to identify and control or eliminate lead sources [71].

3.6. Analysis of most frequently appeared author supplied keywords

The most frequently appeared author supplied keywords was presented in Table 7. There were 25 most frequently appeared keywords used to indicate the content of the articles on lead removal research for the period of 1991 to 2015. Of the 1,532 articles, only 1,204 articles had contained author supplied keywords. The keyword "lead" appeared for 376 times with 11.97%, followed by "adsorption" (232 times and

Table 6
Most frequently appeared top 25 words in title of the articles

Word in title	Appeared in number of article's title	% of 3,729 (Rank)
Lead removal	138	3.70 (1)
Lead ion	84	2.25 (2)
Effect	70	1.88 (3)
Application	61	1.64 (4)
Reduction	56	1.50 (5)
Soil	47	1.26 (6)
Characterization	42	1.13 (7)
Extraction	40	1.07 (8)
Heavy metal	37	0.99 (9)
Treatment	34	0.91 (10)
Synthesis	31	0.83 (11)
Equilibrium	30	0.80 (12)
Lead extraction	29	0.78 (13)
Evaluation	28	0.75 (14)
Pacemaker	26	0.70 (15)
Lead exposure	24	0.64 (16)
Mechanism	22	0.59 (17)
Child	20	0.54 (18)
Development	20	0.54 (19)
Impact	19	0.51 (20)
Kinetic study	19	0.51 (21)
Surface	19	0.51 (22)
Poly	18	0.48 (23)
Metal	17	0.46 (24)
Recovery	17	0.46 (25)

Table 7
Most frequently appeared top 25 author keywords

Author keyword	No. of times occurred	% of 3,141 (Rank)
Lead	376	11.97 (1)
Adsorption	232	7.39 (2)
Lead removal	122	3.88 (3)
Biosorption	92	2.93 (4)
Heavy metals	81	2.58 (5)
Kinetics	71	2.26 (6)
Isotherm	45	1.43 (7)
Heavy metal	41	1.31 (8)
Activated carbon	39	1.24 (9)
Removal	38	1.21 (10)
Sorption	37	1.18 (11)
Cadmium	36	1.15 (12)
Copper	31	0.99 (13)
Wastewater	31	0.99 (14)
Lead extraction	28	0.89 (15)
Ion exchange	25	0.80 (16)
Isotherms	25	0.80 (17)
Thermodynamics	23	0.73 (18)
Lead(II)	21	0.67 (19)
Pacemaker	19	0.60 (20)
Wastewater treatment	19	0.60 (21)
Adsorbent	18	0.57 (22)
Lead ions	18	0.57 (23)
Pb(II)	18	0.57 (24)
Zinc	18	0.57 (25)

7.39%), "lead removal" (122 times and 3.88%) "biosorption" (92 times and 2.93%) and "kinetics" (71 times and 2.26%). Other keywords of prominence were "isotherm", "heavy metal", "activated carbon", "sorption", "parameter", "cadmium", "copper", "thermodynamics", "ion exchange" and "wastewater". The major portion of the research was on the removal of lead using adsorption method [72,73] and biosorption [74,75]. Heavy metals also removed using activated carbon [76,77] and ion-exchange [78] and also sorption [79,80].

4. Conclusions

Publication output during the period 1991–2015 showed increase in the number of articles published per year from 11 to 147 and the articles published during 1994 had received highest citations and there was increase in number of references and number pages along with the number of publications. Fifteen journals have published at least 15 articles on lead removal research, where the *Journal of Hazardous Materials* had accounted for maximum publications (77 articles and 4,894 citations) and stood first and it was the journal, *Bioresource Technology*, which received highest average citations per article (79.59), highest impact factor (JCR2015; 5.999). The country wise contribution of articles on lead removal research showed that, 17 countries had contributed for more than 31 articles, USA stood first for total articles published (231), articles of first authorship (130), articles of corresponding author (235), total citations (5893) and grass domestic product. Similarly, 16 authors have contributed for more than 31 articles "Kutarski, A" from Medical University Lublin, Department of Cardiology, Poland, being the leading author with 11 articles and ranked at sixth position for over all contribution to lead removal research while "Gupta, VK" from Indian Institute of Technology, Roorkee, India, stood first rank as per the *Y*-index. "Islamic Azad University" with maximum number of articles (22) was the leading institute on lead removal research.

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