Global research on air pollution between 2005 and 2014: a bibliometric study

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Abstract

Purpose – The purpose of this paper is to analyze research works on air pollution published in 2005-2014 and indexed in Web of Science Core Collection.

Design/methodology/approach – The data of research publications on "air pollution" from the Web of Science Core Collection database were collected with following search strategy: publications with terms "Air contaminat*", "Air pollut*", "pollut* air" or "contaminat* air" in their titles for the period of 2005-2014 were collected. A total of 4,424 articles were published on air pollution during the period of 2005-2014, and the data were used for creation of database in Microsoft Excel for the analysis purpose. Bibliometric analysis techniques were applied wherever necessary.

Findings – Out of 4,424 articles published on air pollution in different languages, 4,276 articles were in English. The years 2013 and 2014 showed rapid increase in number of articles published, 563 and 638, respectively. The increased number of articles resulted in an increase in number of pages published and references cited in the articles. The articles published in the year 2006 had received more number of citations (12,318), and the average citation per article for the period was 17.59. Environmental Science was the major Web of Science subject category under which a greater number of articles were published. Article entitled as "Health effects of fine particulate air pollution: Lines that connect", published in *Journal of The Air & Waste Management Association* by Pope and Dockery (2006), was the highest cited article (1,743) for the period, and the top most active journals that published huge number of articles were *Atmospheric Environment* and *Environmental Health Perspective*, with 11.79 per cent of the total articles (4,424) published.

Research limitations/implications – The findings of the study are limited to the journals covered under Web of Science Core Collection database and articles having the following keywords in their titles: "Air contaminat*", "Air pollut*", "pollut* air" or "contaminat* air".

Originality/value – This study would be useful to researchers and policy makers to get an insight into the research trends of air pollution for effective decision-making and formulation of new research proposals.

Keywords Bibliometric analysis, Pollution, Air pollution, Mapping, Citations, Research evaluation

Paper type Research paper

Introduction

Air pollution refers to the contamination of air, both inside and outside of our living environment; it can be physical, biological or chemical alteration to the air in the atmosphere (Jones, 1999; Ramanathan and Feng, 2009). The introduction of particulate matter, biological molecules and other harmful materials into the Earth's atmosphere causes pollution (Kanakidou *et al.*, 2005). Pollutants of natural or man-made origin in air bring about diseases in plants (Heagle *et al.*, 1973), animals, human beings (Becker *et al.*, 1996) and other macro and microorganisms and cause damage or death (Babich and Stotzky, 1985). As the natural and built environments become polluted, it is difficult for living organisms to survive (Bozinovic and Oleksiak, 2011; Klerks and Weis, 1987).

Causes of air pollution are many. Emission of sulfur dioxide from burning of fossil fuels (Reddy and Venkataraman, 2002; Andreae and Marlet, 2001), carbon monoxide from improper or incomplete combustion and vehicular emissions (Dickerson, 2002) and nitrogen oxides and ammonia liberation from agriculture-related activities are the most hazardous gases in the atmosphere (Heagle *et al.*, 1973). The quality of air is depleting because of the use of insecticides, pesticides and fertilizers in agricultural activities. Large amount of carbon monoxide, hydrocarbons, organic compounds and chemicals that are released into the air by manufacturing industries (Poisson *et al.*, 2000), hydrocarbons and various other chemicals that are released in to the air atmosphere by petroleum refineries, dust and other chemicals that are released during mineral extraction from the Earth (Dudka and Adriano, 1997) and household activities involving cleaning products, painting, etc. that emit toxic chemicals (Nazaroff and Weschler, 2004) and suspended particulate matter into air (Basha *et al.*, 2007) are the common pollutants of air.

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Collection Building
35/3 (2016) 84–92
 [ISSN 0160-4953]
[DOI 10.1108/CB-05-2016-0008]

Received 5 May 2016
Revised 3 August 2016
Accepted 10 August 2016

Air pollution affects living organisms in several ways. They are known to create several respiratory and other cardiopulmonary diseases along with lung cancer (Pope *et al.*, 2002). Several millions are known to have died because of ill effects of air pollution. Children in areas exposed to air pollutants are said to commonly suffer from pneumonia and asthma (Brunekreef and Holgate, 2002). Global warming is another direct effect on the environment. With increased temperatures worldwide, increase in sea levels and melting of ice from colder regions and icebergs, displacement and loss of biodiversity have already signaled an impending disaster (Blanchon and Shaw, 1995). Nitrogen oxides and sulfur oxides are released into the atmosphere during the burning of fossil fuels, resulting in acid rain (Carmichael *et al.*, 2002). Acid rain can cause great damage to humans, animals and crops. Eutrophication is another problem encountered because of air pollution (Schwarzenbach *et al.*, 2006), a condition where high amount of nitrogen gets deposited in aquatic bodies and turns itself into algae and adversely affects fish, plants and animal species(Trombulak and Frissell, 2000). Toxic chemicals present in the air can force wildlife species to move to a new place and change their habitat (Eisler, 1988). The toxic pollutants deposited over the surface of the water can also affect sea animals. Earth's ozone layer is depleting because of the presence of chlorofluorocarbons and hydrochlorofluorocarbons in the atmosphere and can cause skin- and eye-related problems (Tsai, 2002).

The knowledge about air pollution and its causes and effects on biosphere was illustrated time and again by researchers world over. Through research efforts, measures to control air pollution were addressed (Dockery *et al.*, 1993; Kampa and Castanas, 2008; Mills *et al.*, 2009; Curtis *et al.*, 2006; Bernstein *et al.*, 2004). We need to overcome this problem of air pollution to see a better tomorrow. Several attempts have been made worldwide on personal, industrial and governmental levels to curb the intensity of air pollution, as it is rising at abnormal proportions than the tolerable levels (Eisler, 1988; Trombulak and Frissell, 2000; Schwarzenbach *et al.*, 2006). We, in this paper, analyzed various research activities on air pollution and its impact on biosphere for the period 2005-2014. The knowledge structure on air pollution is obtained by the analyses of scientific research indexed in Web of Science Core Collection and formulated subject category analysis, keyword analysis, top ten cited articles, major contributing research organizations, most cited authors, citation life cycle of top ten most cited articles and most productive publications for the period 2005-2014. The review of knowledge structure of research on air pollution can be worth to researchers and policy makers to get an insight into current trends and status of air pollution research for effective decision-making and formulation of new research proposals.

Methodology

The research works carried out worldwide on air pollution are enormous. Mapping of the research outcome is important from the point of our focus on future environment conservation. In this study, we have collected the data of research publications on "air pollution" from Web of Science Core Collection with the following search strategy: publications with terms "Air contaminat*", "Air pollut*", "pollut* air" or "contaminat* air" in their titles for the period of 2005-2014 were collected; a similar search strategy was used by Guo *et al.* (2014) in case of soil contamination. Further, we restricted our search to scientific research articles, as our purpose was to analyze the trends in air pollution research at the global level for the period spanning one decade (2005-2014). A total of 4,424 articles were published on air pollution during the period of 2005-2014. A large number of articles were published in English language (4,276, 96.65 per cent), followed by French (34), German (24), Spanish (19), Italian (19), Polish (18), Portuguese (17), Chinese (7), Japanese (3), Czech (1), Korean (1), Russian (1), Serbian (1), Serbo-Croatian (1), Lithuanian (1) and Turkish (1). A total of 4,424 articles' bibliometric data were retrieved as a result of the search strategy from the database, and the same were used for creation of a database in Microsoft Excel for the analysis purpose. As in other studies (Kolle *et al.*, 2015), network analysis interface for literature studies application and VOSviewer software were used for mapping the literature (Knutas *et al.*, 2015).

Results and discussion

Publication profile and distribution

The Web of Science Core Collection retrieved literature showed that the total number of articles published on air pollution during the period of 2005-2014 was 4,424 in different languages. Table I gives the detailed picture about the year-wise distribution of articles, total citation counts, number of references and page counts, average citation counts and references and page counts per article. The number of articles had increased from 294 in 2005 to 638 in 2014, except for the year 2010 (423). The years 2013 and 2014 showed rapid increase in number of articles published, 563 and 638, respectively. The growth in the number of articles published on air pollution is an indicator for judging the significance of air pollution research globally (Kelishadi and Poursafa, 2010; Strickland *et al.*, 2009). The articles published in the preceding years 2005 and 2006 had received more number of citations (11,995 and 12,318, respectively) compared to proceeding years (Walters, 2011). Similarly, the articles published in 2005 had received highest citation counts per article (40.79) than articles published in later years up to 2014, with average citations of 17.59 per article for the period of 2005-2014. The average number of references cited for the articles had increased from 33.63 in 2005 to 41.33 in 2014; numbers of references were 9,888 in 2005 and 26,374 in 2014. The increase in number of references cited for a given year was parallel to the increase in number of publications of that year where the number of references cited for an article ranged between 33.63 and 41.33, with average citation counts of 37.76 per paper. Citations are major indicators to assess the impact of research work; the higher number of citations observed for air pollution in the literature signifies the importance of research work carried out on air pollution (Petrak, 2001). Table I shows an increase in the average number of pages of publications during the years from 2005 (10.29) to 2014 (10.66) because of an increase in number of articles published, although the number of pages per article remained almost uniform with an average of 10.10 pages per paper. From Table I, it can be interpreted that air pollution is

Table I Scientific descriptors during 2005-2014

PY	TP	TC	C/PP	NR	NR/PP	PG	P/PG
2005	294	11,995	40.79	9,888	33.63	3,028	10.29
2006	329	12,318	37.44	10,906	33.14	3,397	10.32
2007	387	10,554	27.27	14,060	36.33	3,896	10.06
2008	390	9,739	24.97	14,112	36.18	4,018	10.30
2009	464	9,829	21.18	16,740	36.07	4,515	9.73
2010	423	6,999	16.54	15,208	35.95	4106	9.70
2011	479	5,951	12.42	18,424	38.46	4,695	9.80
2012	484	4,613	9.53	19,648	40.59	4,815	9.94
2013	536	4,026	7.51	21,732	40.54	5,418	10.10
2014	638	1,826	2.86	26,374	41.33	6,803	10.66
Total	4,424	77,850	17.59	167,092	37.76	44,691	10.10

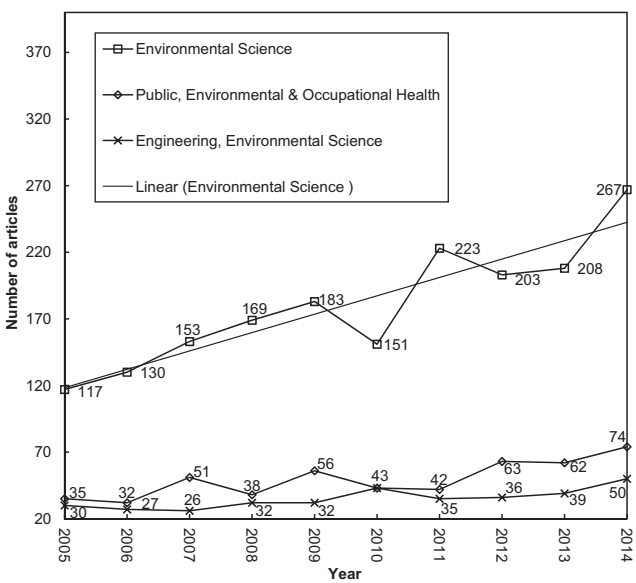
Notes: PY, publication year; TP, number of publications; TC, total citation counts; C/PP, citation counts per paper; NR, number of references; NR/PP, number of references per paper; PG, page counts; P/PG, page counts per paper

a burning research issue, and the literature is growing constantly in an exponential manner every year.

Web of Science subject category-wise analysis

The scientific literature published on air pollution for the period of 2005-2014 has been categorized under several subject categories. The major literature related to the topics such as air pollution and its impact on environment, public health, mortality, air quality, emission of gases, diseases, risks, etc. were categorized under three major subject categories in Web of Science database (Figure 1). Environmental Science was the major category under which huge number of articles was published. The number of articles in this subject continued to rise from 117 during the year 2005 to 267 during the year 2014, and the average articles published per year was 180.40. The second major subject category was Public, Environmental and Occupational Health, with an average productivity of 49.60 articles per year, followed by the subject category Engineering and Environmental Science with an average of 35 articles per year. These subject categories also indicated an increasing trend from an initial 30 to 74 publications in a span of 10 years. The number of articles published between 2009 and 2011 was on the lesser side, as against the increasing trend observed during the study. The subject category-wise analysis of articles clearly indicates that more than half of the articles are categorized under the subject category of Environmental Science in the Web of Science database.

Figure 1 Top three subject categories under huge literature categorized in Web of Science during 2005-2014



Analysis of top cited articles with citation cycle

The impact of publications can be determined by the number of citations an article receives. Ten top cited articles during the period 2005-2014 along with journals of publication are is given in Table II. It is evident from the data that the articles on air pollution mainly concerned about public health across different regions. A total of 6,023 citations were received by the top ten articles out of which four of them received more than 500 citations; however, the range was too wide (1,743 and 312). A trend of increase in citations was observed for all the articles; however, the trend reached a saturation point and declined after 2012. The saturation point indicates that the research work had become old to be represented or replaced with newer approaches of research. The article "Health effects of fine particulate air pollution: Lines that connect", published in *Journal of the Air & Waste Management Association* by Pope and Dockery (2006), received highest number of citations since its publication up to 2014. It has received 1,743 citations in 10 years and accounted for 28.93 per cent of the total citations by top ten articles. The article, "Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases", published by Dominici *et al.* (2006) in *Jama-Journal of The American Medical Association*, was the second most cited article, with 721 citations during this period.

The citation life cycle of top ten most cited articles is presented in Figure 2 as retrieved by Web of Science database, which clearly suggests that the health hazards of air pollution are largely associated with particulate matter present in air (Pope and Dockery, 2006; Dominici *et al.*, 2006; Pope *et al.*, 2009; Laden *et al.*, 2006) have received the highest number of

Table II Top ten cited articles with their year wise break up of citation counts

Title	Authors	Source title	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total citations	Average citations per year
Health effects of fine particulate air pollution: Lines that connect	Pope and Dockery (2006)	*Journal of the Air & Waste Management Association*	0	3	57	124	142	193	227	252	247	251	1,743	174.3
Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases	Dominici *et al.* (2006)	*Jama-Journal of the American Medical Association*	0	14	46	70	68	68	80	96	98	99	721	72.1
Long-term exposure to air pollution and incidence of cardiovascular events in women	Miller *et al.* (2007)	*New England Journal of Medicine*	0	0	28	59	86	63	85	80	78	89	640	71.11
Fine-Particulate Air Pollution and Life Expectancy in the United States.	Pope *et al.* (2009)	*New England Journal of Medicine*	0	0	0	0	31	57	72	103	111	98	550	78.57
Reduction in fine particulate air pollution and mortality - Extended follow-up of the Harvard six cities study	Laden *et al.* (2006)	*American Journal of Respiratory and Critical Care Medicine*	0	11	35	38	44	48	73	67	62	46	472	47.2
Secondary organic aerosol formation from anthropogenic air pollution: Rapid and higher than expected	Volkamer *et al.* (2006)	*Geophysical Research Letters*	0	3	34	55	70	64	59	37	52	47	454	45.4
Spatial analysis of air pollution and mortality in Los Angeles	Jerrett *et al.* (2005b)	*Epidemiology*	1	18	40	42	61	37	40	38	56	37	400	36.36
A review and evaluation of intra urban air pollution exposure models	Jerrett *et al.* (2005a)	*Journal of Exposure Analysis and Environmental Epidemiology*	5	8	23	35	40	27	46	27	65	59	381	34.64
Ambient air pollution and atherosclerosis in Los Angeles	Künzli *et al.* (2005)	*Environmental Health Perspectives*	8	26	36	32	47	35	50	39	35	19	350	31.82
Human health effects of air pollution	Kampa and Castanas (2008)	*Environmental Pollution*	0	0	0	4	22	32	25	35	47	69	312	39

Figure 2 Citation life cycle of top cited articles on air pollution during 2005-2014

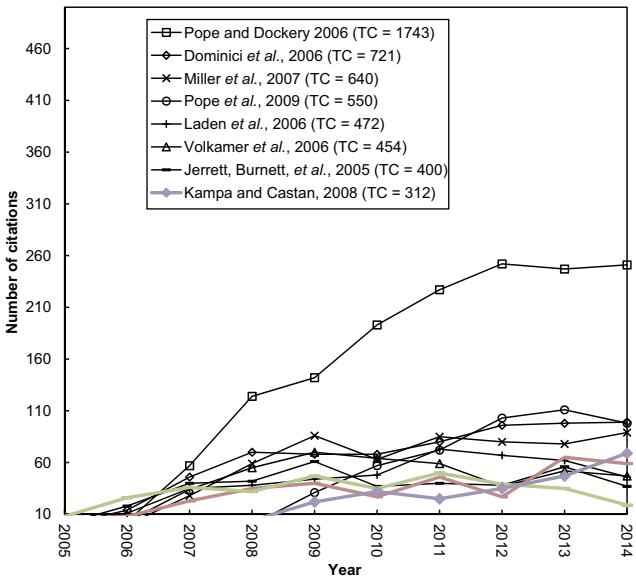
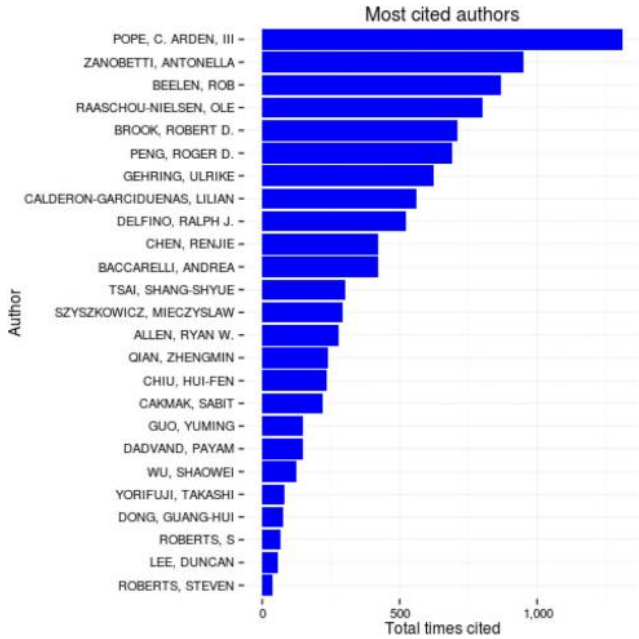


Figure 3 Most cited authors for the period of 2005-2014



citations. Air pollution of hospital admission was found to have direct effects on cardiovascular and respiratory diseases (Dominici *et al.*, 2006). Incidence of cardiovascular problems in women (ascertained to be caused by long-term exposure to air pollution; Miller *et al.*, 2007) and occurrence of atherosclerosis (cause by ambient air pollution; Kunzli *et al.*, 2005) were the other studies that figured in the top cited articles, in addition to the incidences of air pollution in Los Angeles, which was analyzed by Jerrett *et al.* (2005a) and Kunzli *et al.* (2005).

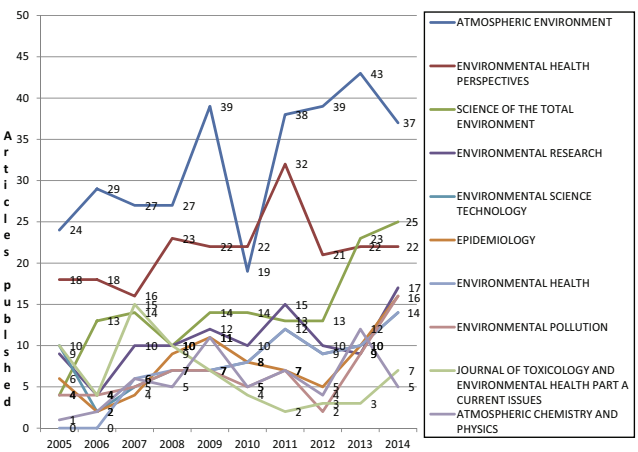
Top cited authors of air pollution research

Citations are the indicators of credentials of a research and researcher; the activeness of top 25 productive researchers in the field of air pollution for the period between 2005 and 2014 was worked out and is presented in Figure 3. The citations since the publication from 2005 up to 2014 showed that 1 researcher received citations more than 1,000 (Pope, CA), 8 researchers received citations between 500 and 1,000 and 16 researchers received citations less than 500. "Pope, C.A." was the leading and most cited author with close to 1,500 citations, followed by "Zanobetti, A", "Beelen, R", "Raaschou-Nielsen, D", "Brock, R. D", "Feng, R. D", "Gehring, U", "Caldovon-Garsiduenas, L" and "Delfino, R. J", with citations more than 500 in a descending order. The articles published during the early part of assessment period had received more citations, as against the articles published in the later part of 2005-2014. These are the most active researchers in the field of air pollution in the world based on the citation statistics.

Top active journals of air pollution

One of the main objectives of publication is to disseminate the knowledge among the fellow researchers and, in turn, avoid duplication of research. Several journals were observed that are more active in publishing the research findings on air pollution (Figure 4). The top most active journal in the publication of research findings on air pollution was *Atmospheric Environment* with 322 articles, followed by *Environmental Health Perspective* with 200 articles and *Science of Total Environment* with 142 articles. These journals had published almost 15 per cent research findings on the air pollution subject for the period of 2005-2014. These are followed by other multi-disciplinary journals such as *Environmental Research*, *Environmental Science Technology*, *Epidemiology*, *Environmental Health*, *Environmental Pollution*, *Journal of Toxicology and Environmental Health* and *Atmospheric Chemistry and Physics*. All these journals had published considerable number of articles every year; however, the journals *Atmospheric Environment*, *Environmental Health Perspective* and *Science of Total Environment* were the most active ones in that order. The journals *Atmospheric Environment* and *Environmental*

Figure 4 Most active journals of air pollution research



Health Perspective accounted for more than 50 per cent of publications (522), which is 11.79 per cent of total articles (4,424) published by all journals put together on air pollution during 2005-2014 period, as documented in the Web of Science database.

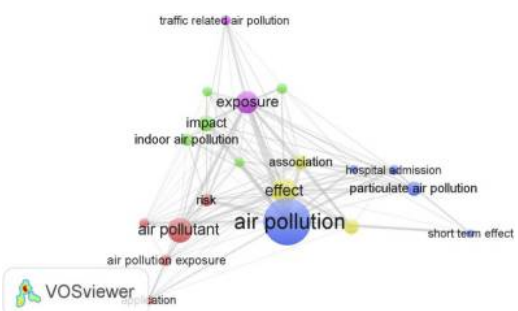
Cluster analysis of air pollution research

The clusters of air pollution research were constructed using VOSviewer software. The keyword that appeared more than 50 times in the titles of articles only was considered for cluster analysis. The keywords were grouped under five major clusters, as shown in Table III. The keywords are grouped under five clusters, namely air pollutant, impact, air pollution, ambient air pollution and exposure, as indicated by Figure 5. In the cluster, air pollution had appeared in 1,768 articles, followed by air pollutant in 507, impact in 199, exposure in 398 and ambient air pollution in 187 articles. The cluster with keywords particulate air pollution, hospital admission, its short term effects and incidences of air pollution in Taiwan

Table III Cluster profile of keyword analysis

Clusters	Key words in the title of articles	No. of appearances
Cluster 1	Air pollutant	506
	Air pollution exposure	100
	Application	68
	Influence	82
	Risk	136
Cluster 2	Impact	199
	Indoor air pollution	132
	Outdoor air pollution	89
	Relationship	79
	Urban air pollution	77
Cluster 3	Air pollution	1,768
	Hospital admission	79
	Particulate air pollution	169
	Short-term effect	53
	Taiwan	55
Cluster 4	Ambient air pollution	187
	Association	167
	Effect	526
Cluster 5	Exposure	397
	Traffic related air pollution	80

Figure 5 Keywords occurred in titles of air pollution articles



(Yeh *et al.*, 2011; Liang *et al.*, 2009) formed the major group, suggesting the effects of air pollution in different parts of the world (Kampa and Castanas, 2008). The second major cluster with five key words, namely, air pollutant, air pollution exposure, application, influence and risk, is the second largest group of papers published on exposure to pollution of different types and the risks associated with it (Pope *et al.*, 2011; Kingham *et al.*, 2013; Gordon *et al.*, 2014). The third major cluster with papers of keywords of impact, indoor air pollution (Bernstein *et al.*, 2008), outdoor air pollution (Guarnieri and Balmes, 2014), relationship and urban air pollution (Tang and Wang, 2007) indicates that these are the areas of research published during the period between 2005 and 2014, and that they formed the third position in terms of numbers. The fourth and fifth clusters of papers focused on exposure to pollution under ambient conditions, pollution due to traffic, their association and effects (Chen *et al.*, 2009; Hoek *et al.*, 2002; Beelen *et al.*, 2008).

Conclusion

In this paper, we evaluated the research works on air pollution published in 2005-2014 collected from Web of Science Core Collection. The trends in publication of literature on air pollution kept increasing in a linear manner. Almost 96 per cent of the articles were in English language. The literature is growing in a rapid phase every year along with citations, because of the relevance of the research in the present context of environmental conservation. Most of the articles are published in the journals that are specifically devoted for research dissemination on air than of multidisciplinary. *Atmospheric Environment* and *Environmental Health Perspective* are the two dominant journals; they published 11.79 per cent air pollution research of the total articles published. The article "Health effects of fine particulate air pollution: Lines that connect", published in *Journal of The Air & Waste Management Association* and contributed by Pope and Dockery (2006), was a highly cited article. Major literature was confined to *air pollution, indoor air pollution, outdoor air pollution, air pollutants, particulate air pollution, ambient air pollution* and *air pollution exposure. Particulate air pollution, indoor air pollution* and *risks* of air pollution on humans are the major current hot topics for research on air pollution. The results of this study are practical to researchers and scientists in understanding trends in air pollution research during 2005-2014. The major limitation of the study is the publication data and citation details collected for the study were confined to publications that are indexed in the Web of Science Core Collection.

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