Global Research Trends in Health Effects of Volatile Organic Compounds during the Last 16 Years: A Bibliometric Analysis

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ABSTRACT

In recent years, the health effects of volatile organic compounds (VOCs) have attracted increasing attention. However, there is no published literature conducting a bibliometric analysis to explore the tendency. The purpose of this study is to provide a bibliometric analysis of the research on the health effects of VOCs over the past 16 years.

Based on the data retrieved from the Web of Science Core Collection database, several bibliometric indicators mainly including topics (keywords), journals, co-citation relationship, leading countries and institutions were evaluated. Among the 1,035 articles, the top three high-yield years were 2018 ($n = 122$), 2016 ($n = 120$), and 2017 ($n = 105$). Through co-citation analysis, TOP 10 clusters were obtained (respectively, BTEX, VOCs, indoor air, radon, indoor chemistry, VOC, photocatalytic oxidation, urinary metabolites of volatile organic compounds, fungal volatiles and nitrogen dioxide). Then, by constructing co-occurrence network of keywords, we revealed that “exposure” and “emissions” are two hotspots in the literature examined. Also, the results demonstrated that USA is the leading country ($n = 294$) and TSINGHUA UNIV. is the leading institution ($n = 24$). Moreover, the top three popular journals publishing the topic on health effects of VOCs were identified, respectively *Atmos. Environ.*, *Environ. Sci. Technol.* and *Indoor Air*.

Notably, in the literature examined, the most common diseases potentially associated with VOCs are mainly involved in the respiratory system, blood system and inflammation.

Therefore, this study assessed publications on health effects of VOCs using bibliometric approaches, which provided the research status and trends of the topic and potential hints to future investigation in this field.

Keywords: Bibliometric analysis; Volatile organic compounds (VOCs); Health effect; Web of Science (WoS).

INTRODUCTION

Volatile organic compounds (VOCs), as defined by the US Environmental Protection Agency (U.S. EPA), refer to organic compounds with low initial boiling point (less than or equal to 250°C) at a standard atmospheric pressure of

101.3 kPa (<https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds>). Generally, VOCs are divided into alkanes, alkenes, alkynes, aromatic hydrocarbons, oxygen containing organic compounds (including aldehydes, ketones, alcohols and ethers), halogenated hydrocarbons, nitrogenous compounds, sulfur compounds and other categories (Kansal, 2009). VOCs exist everywhere in the environment, such as mines, oil fields, industry, agriculture, civil, aerospace, transportation, municipal construction and military national defense (Nieuwenhuijsen, 2016; Guerra *et al.*, 2017).

Since the occurrence of photochemical smog disaster in Los Angeles (Brown *et al.*, 2007), VOCs have gradually attracted more and more attentions. Under the action of ultraviolet light, VOCs originated from motor vehicle exhaust gases, industrial discharges and fuel combustion

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products eventually become toxic gases that may cause disease or death (Baek *et al.*, 2015). Na *et al.* (2004) and Alvim *et al.* (2018) found that controlling VOCs emissions can effectively reduce photochemical smog. In addition to the strong photochemical activity, VOCs can promote formation of secondary organic aerosol (SOA), the main source of PM_{2.5} in the atmosphere (Kourtchev *et al.*, 2016; Widiana *et al.*, 2017). Additionally, VOCs can cause devastating damage to the atmospheric ozone layer even at low levels and may even trigger a “greenhouse effect” (Franco *et al.*, 2014).

Apart from the adverse environmental impacts, VOCs exposure also causes harmful health effects. Previous studies have disclosed that VOCs may increase the risk of irritation, allergic sensitization, acute and chronic respiratory diseases, lung function damage and gene mutation (Hua *et al.*, 2018; Kwon *et al.*, 2018). Moreover, VOCs emissions are also strongly correlated with brain cancer, nervous system, endocrine system and skin diseases (Sarigiannis *et al.*, 2011). Specifically, Benzene, the main component of VOC, increases the risk of leukemia, skin cancer and other tumors, birth defects and neurocognitive impairment (15). Also, exposure to low levels of VOCs in ordinary life may increase the risk of asthma and rhinitis (Jang *et al.*, 2007).

In recent years, with the aim of analyzing the scholarly impact and characteristics of publications within a specific research field, bibliometrics has been widely used as an effective quantitative research method (Ellegaard and Wallin, 2015). Through bibliometric analysis, a snapshot providing cross-sectional view of the current state and trends of specific research topic can be depicted (Ellegaard, 2018).

Given the importance of VOCs effects on human health, some scientific researchers have focused on reviewing related literature to identify health risk of VOC exposure (Adgate *et al.*, 2004; Rumchev *et al.*, 2007; Hasan *et al.*, 2013; Widiana *et al.*, 2019). Despite of high growth rate of VOCs investigations (Wang *et al.*, 2018), there have been few attempts at the bibliometric perspective on health effects of VOCs. It is necessary to conduct a bibliometric study on the published literature on this topic. Therefore, the aim of this study is to present a comprehensive bibliometric analysis on the effects of VOCs on health as an attempt to bridge this gap.

METHODS

Data Source

Base on the Web of Science (WoS) Core Collection database (www.webofknowledge.com/WOS), we retrieved published articles on the health effects of VOCs. Although different databases may present different results, the WoS database is considered as one of the most reliable sources of literature and the most commonly used database in the field of scientific metrology (Dettori *et al.*, 2019). This database contains the world famous SCI, SSCI, A&HCI and other journal paper index. In addition, the core collection of Web of science (1985–present) has several advantages: (a) The cited references for all publications are fully indexed and searchable, (b) All authors and author

affiliates can be retrieved, (c) The Citation Reporting feature graphically understands citation activities and trends, and (d) Research trends and publication patterns can be determined by using analytical retrieval results. In order to search for articles more conveniently and quickly, we did not choose a specific year, by default, from 1985 to 2018 (Actually, the first article on the health effects of VOCs published in 2003).

Search Strategy

By searching for "VOC" and "health" in the subject, all the publications used in bibliometric analysis were extracted from the online WoS database. All electronic searches are conducted on the same day (January 31, 2019) to avoid any updating on the database (Sa'ed, 2018). Accordingly, 1035 hits were returned. The WoS database can export 500 articles at a time, so we selected the “full record and cited references” for each document in batches and exported the results in a format for subsequent analysis.

Data Analysis

In this study, a variety of analytical indicators, such as literature citations, leading countries and institutions, journal sources and distribution, and cooperation between countries and institutions, were adopted to further evaluate. Here, we only consider top-ranking options for projects with more data. In addition, the Journal's Impact Factor (IF) comes from the 2018 Journal Citation Report (JCR). The h-index (Hirsch index) was also used as a qualitative analysis to assess the scientific performance of the research in the top 10 countries on the health effects of VOCs. The h-index was proposed by George Hirsch, a physicist at the University of California, San Diego in 2005 (Mazurek, 2017). It is a hybrid quantitative indicator that can be used to assess the amount and level of academic output of a country or researcher. In addition, several specific tools were employed. MS Excel was used to analyze the annual increase in the number of documents. Citespace (5.3.R3.8.5.2018) was utilized for co-citation analysis (Synnvestedt *et al.*, 2005). Moreover, to identify the core journals (the most important journals with a high number of guidelines), co-occurrence network was constructed and visualized using VOSviewer software (version 1.6.9, <https://www.vosviewer.com/>).

RESULTS AND DISCUSSION

Co-citation Analysis

Two documents form a co-citation relationship when the two documents appear together in the bibliography of the third citation. Mining the co-citation relationship of the literature through literature data sets is usually considered as the co-citation analysis of the literature. Here, we analyze the citation of 1035 literatures in the past 16 years. By setting the “minimum visible cluster size” and using “LLR” algorithm, TOP 10 clusters were obtained (respectively, BTEX, VOCs, indoor air, radon, indoor chemistry, VOC, photocatalytic oxidation, urinary metabolites of volatile organic compounds, fungal volatiles and nitrogen dioxide).

As depicted in Fig. 1, the hot research fields in recent years are "BTEX", "VOCs", "indoor air" and so on. The result is also in agreement with previous related studies (Choi *et al.*, 2009; Schlink *et al.*, 2010; Lin *et al.*, 2017; Schupp, 2018). By analyzing the citation relationship between the scientific literature, we find that scientific literature is not isolated, but a continuous extension of intertwined system.

Co-occurrence Network of Keyword

Generally, keywords are the "key words" in the paper, representing the characteristics of the paper, or the most meaningful words. By clustering the keywords appearing in these literatures, the relationship between the words can be reflected. If some keywords are repeated in these documents, the keywords may represent the research hotspots in this field (Li *et al.*, 2015). Based on the keywords data, the co-occurrence network of keywords was constructed and visualized in Fig. 2. Obviously, the keyword of "volatile organic compounds" is located in the center of the network and accounts for a large proportion (according to statistics, the total number of the occurrence reaches up to 234). Subsequently, "exposure" and "emissions" also occupy a central position in the network, which may signify the research trends and hotspots in the literature examined.

Besides, according to the chronological order, Hong Kong may have paid more attention to the research topic of VOC in this area in the past few years. Notably, "China" has also begun to pay attention to this issue in recent years. Although there is no ambient air quality standard regulating the VOCs in the GB3095-1996 version or the GB3095-2012 version, we believe that China's research in this area will promote the progress in near future.

Analysis of Leading Nation and Institution

To identify the leading countries in this research field, the information of individual nation and institution was examined. Based on the total co-citation of articles from each country and institution, the leading nations and institutions in this research field were illustrated in the heatmap (Figs. 3(a) and 3(b) respectively). The results demonstrated that 74 countries have participated in the study on health effects of VOCs. Through counting the number of documents published by each country, it is unveiled that USA is dominant in both the number of literature and the total amount of citation ($n = 293$, total citations = 5585), followed by China ($n = 152$, total citations = 2470) and Germany ($n = 89$, total citations = 1562). Similarly, a total of 1,435 institutions participated in the research field. "Tsinghua Univ." occupied the leading position ($n = 24$, total citations = 597), followed by "Univ. Texas" ($n = 6$, total citations = 448) and "Hong Kong Polytech Univ." ($n = 9$, total citations = 420).

Usually, the traditional indicators for assessing the personal influence of scientists are the total number of works (including papers and monographs), the total number of citations and the average citation rate (Patience *et al.*, 2017). Each method has unique advantages, but also has its inevitable defects. Further, we introduced an additional indicator (h-index). When a scholar's h-index is h , which means that there are at least h papers of this scholar has been cited for h times (Aksnes *et al.*, 2019). Conceivably, when two people with a similar h-indexes, they are comparable in terms of overall scientific influence even if their total number of works or the number of citations is very divergent. Accordingly, h-index was utilized to

Fig. 1. TOP 10 co-citation clusters of Literature. The co-citation clusters are shown in the figure. The software (CiteSpace) detected the co-citation clusters, and then put a different color on each cluster.

Fig. 2. Co-occurrence network of Keywords. This figure shows Vosviewer's overlay visualization of keyword co-occurrence. The color bar in the bottom right corner denotes the timeline. Each node in the network represents a keyword, and the size of the circle indicates the occurrence frequency. The more times the two keywords appear together, the closer they are in the network.

evaluate the influence of the countries and institutions. The detailed information of the TOP 10 frequently cited countries is provided in Table 1 (the information comes from VOSviewer statistics, and the difference between the web of science core set and the VOSviewer data is marked in the red). The results revealed that USA harbors highest h-index ($h = 40$), followed by China ($n = 24$) and Germany ($n = 23$). This is consistent with our forgoing findings through analysis of co-citation of articles.

Analysis of Cooperation among Different Countries or Different Institutions

Based on the data of countries and institutions in the literature, cooperation networks among different countries and institutions were constructed. As shown in Fig. 4, the results indicated that there are few connections among different countries or different institutions. It may imply that cross-country or cross-unit cooperation is still relatively rare, and most of the articles are written by researchers from the same country or institution. For the cross-country cooperation, the research topics mainly focused on biofumigation, formaldehyde and indoor air. But, the hot issues in cross-unit cooperation mainly enclosed “PM”, “human health” and “indoor air quality”. Notably, many high-quality articles are completed by cooperation between countries or institutions. To achieve better in scientific research, cross-country or cross-unit cooperation might be a useful strategy.

Analysis of Journal Published

Journal analysis is also one of the most important indicators of bibliometrics. We analyzed the source journals of the references of these 1035 articles and obtained the network of source journals (Fig. 5). As demonstrated in the figure, there are six categories of journals marked in different colors, respectively, which are purple (environmental science journal), green (environmental engineering journal), red (environmental science and ecology journal), sky blue (engineering technology journals), blue (research method journals), and yellow (comprehensive journals). For the individual journal, Atmospheric Environment (Atmos. Environ., IF = 3.708) colonized the largest proportion, followed by Environmental Science & Technology (Environ. Sci. Technol., IF = 6.653) and Indoor Air (IF = 4.396). This may suggest that the topic on health effects of VOCs are also attractive to the editors/reviews in top journal such as Environ. Sci. Technol.

Diseases Potentially Associated with VOCs

Long-term exposure to VOCs is harmful to human health. To detect the most common diseases potentially associated with VOCs in the literature examined, the disease names in keywords were extracted and analyzed. The network of the diseases potentially associated with VOCs are constructed. As displayed in Fig. 6, top 10 diseases are, respectively, sickle cell disease, lung cancer, anemia, asthma, acute chest syndrome, breath, vaso-occlusive crisis, sickle cell

Rank	Country	Documents	Citations	h-index
1	USA	293(294)	5585	40
2	China	152	2470	24
3	Germany	89(90)	1562	23
4	England	46	966	15
5	France	53(54)	920	16
6	Italy	45	786	14
7	Canada	50(51)	662	14
8	South Korea	55	646	14
9	Australia	27(28)	638	9
10	Netherlands	30	637	14

Fig. 4. Cooperation Network among different countries and institutions. In this figure, a timeline view of national and regional cooperation networks is shown, with countries or institutions of the same cluster located on the same horizontal line. The size of the circle represents the number of documents in the cluster.

Fig. 5. Network of source journals. Each circle represents a source journal. The size of the circle denotes the number of articles on health effects of VOCs published in corresponding journal. The smaller the distance between the two journals, the more the number of co-citations is.

Fig. 6. The network of the diseases potentially associated with VOCs. The size of the circle designates the frequency of the disease names in keywords. The smaller the distance between the two diseases, the more the number of co-citations is.

Fig. 7. The number of literature publication and citation frequency during the past 16 years.

anemia, inflammation and COPD. The results showed that these top diseases are mainly involved in the respiratory system, blood system and inflammation. This finding is consistent with previous related studies (Casset, 2008; Chambers *et al.*, 2011; Madureira *et al.*, 2015). Noteworthy, many other diseases (such as stroke, stress and colon cancer) also emerged in the network. So, the exposure of VOCs is closely associated with our health, and may lead to many possible hazards. In the future, we can further explore which VOCs are mainly related to Top diseases and explore the mechanism behind them.

CONCLUSIONS

General Trend

In this study, by setting the start time “as default” and the termination time to 2018, 1035 articles on health effects of VOCs were retrieved. The number of annual publication and citation frequency are shown in Fig. 7. In recent years, the research in this area has attracted more and more attention of scholars. The topic of VOCs’ effects on health has gradually become a hot research field.

Furthermore, several bibliometric indicators mainly including topics (keywords), journals, co-citation relationship, leading countries and institutions were evaluated. Among the 1,035 articles, the top three high-yield years were 2018 ($n = 122$), 2016 ($n = 120$), and 2017 ($n = 105$). Through co-citation analysis, TOP 10 clusters were obtained (respectively, BTEX, VOCs, indoor air, radon, indoor chemistry, VOC, photocatalytic oxidation, urinary metabolites of volatile organic compounds, fungal volatiles and nitrogen dioxide). Then, by constructing co-occurrence network of keywords, we revealed that “exposure” and “emissions” are two hotspots in the literature examined. Also, the results demonstrated that USA is the leading country ($n = 294$) and TSINGHUA UNIV is the leading institution ($n = 24$). Moreover, the top three popular journals publishing the topic on health effects of VOCs were identified, respectively

Atmos. Environ., Environ. Sci. Technol. and Indoor Air. Consequently, in the literature examined, the most common diseases potentially associated with VOCs are mainly involved in the respiratory system, blood system and inflammation.

Limitations

This study also has some limitations. First, to facilitate analysis, only web of science core collection database is considered. Thus, the articles involved in other databases (such as Scopus and Google Scholar) will be omitted. Secondly, when judging leading countries and institutions, we rely on the size of citations, while in the field of bibliometrics, the number of citations usually accumulates with the number and time of the literature. This is a well-known principle in sociology, named as “Matthew effect” (Merton, 1968). This may result in the omission of the high-quality articles that may be highly quoted in the future, hence affecting the final judgment.

Overall, although there are still some shortcomings in this study, it seems unable to avoid currently. Using bibliometric approaches, the study evaluated publications on health effects of VOCs, which provided the research status and trends of the topic and potential hints to future investigations in this field.

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