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Review

# A Bibliographic Analysis of Indoor Air Quality (IAQ) in Industrial Environments

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**Abstract:** Air pollution is a major risk factor, and it still remains a global cause of death for millions of people. Indoor air quality (IAQ) plays an important role in human health as people spend most of their time in confined spaces. Many studies have recently addressed this issue, but no systematic analysis has been conducted, which is the aim of our study. We present a bibliographic analysis of articles on IAQ in industrial environments from 2010 to 2021. A total of 658 articles were collected, and 409 were used. The NVivo tool was used to analyze the collected documents both quantitatively and qualitatively. This analysis of the literature enables us to identify the most studied working environments and pollutants, the analysis tools, and the types of measurement used to provide a clear overview of the theme, which includes a comparison between the studied working environments and the state of origin of the authors. Our analysis of each working environment and the related frequently cited pollutants provides a clear approach to identifying the specific areas of focus when improving the quality of the air in a specific working environment. In addition, a research gap and future research areas have been identified in the conclusions.

**Keywords:** indoor air quality; industrial environment; bibliographic analysis

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## 1. Introduction

In recent years, people have been forced to spend more time than ever before in confined spaces. The outbreaks of SARS-CoV-2, declared a pandemic by the Word Health Organization (WHO) [1], have caused a global health and socio-economic crisis [2] that forced governments to impose various lockdown measures (including social distancing and the mandatory use of protective masks) in an attempt to flatten the epidemic curve [3]. While information is provided by the media almost every day about the health risk caused by air pollution that is now out of control, it is difficult to accept that the air contained in homes or confined spaces can also be considered a real threat to one's psycho-physical well-being [4]. On average, individuals spend approximately 90% of their time indoors without being aware of the indoor environment's conditions and their potential effects on health [5]. Adverse health conditions through household air pollution were supposed to be responsible for the premature deaths of 2.31 million people in 2019, according to the *Global Burden of Disease* [6] study. To put this in context, this is three times the number of death related to unsafe sanitation, which caused 756,588 in 2019 [6]. This makes this risk factor one of the largest environmental contributors to ill health [7]. Long exposure to air pollution can damage the respiratory system [8] and reduce life expectancy [9]. In addition to these commonly known effects, an impact on cognitive performance has also recently been recognized [10]. Given the aforementioned data, the significance of indoor air pollution for human health is clear. However, its effects vary drastically according to the level of development: household air pollution is supposed to be responsible for almost

10% of deaths in low- and middle-income countries and for 7.7% of global mortality [7,11]. Major differences in national death rates can be clearly observed, and they are much higher in low-income countries, particularly those of sub-Saharan Africa and Asia [12]. The issue of indoor air pollution, therefore, has a clear economic subdivision: it has been almost completely eliminated in high-income countries, but it remains a major environmental and health problem in countries with lower incomes. For example, in [13], the authors demonstrated how human development and poverty are major influencing factors for air quality and how relatively poor economic performance is, in part, a consequence of long periods of political instability and weak governance, in addition to corruption, which is a common problem for emerging countries. The data indicate that poor air quality is one of the largest environmental contributors to the poor health of individuals [14].

However, it should be recognized that although indoor air pollution is still a major mortality risk factor and one of the main risk factors in low-income countries, significant progress has been made globally in recent decades [7]. The number of annual deaths worldwide from indoor air pollution fell by more than 1 million since 1990, when an estimated 2.7 million died prematurely, to 1.6 million by 2017, as Figure 1 shows [6]. Thus, despite the population growth over recent decades, the total number of deaths from indoor air pollution is in decline. There is not any single explanation for this phenomenon, but the recognition of the various adverse impacts of air pollution on human health and the consequent social and economic costs [15] must be an influencing factor. Industrial buildings can be considered a key context for examining indoor air quality for the following reasons:

(1) Workers spend a large amount of time indoors, with about 1720 h per year spent at work for a full-time employee;
(2) Poor air quality has been associated with a loss of productivity in simulated task environments and with declines in cognitive scores [16,17];
(3) Many people are often concentrated in small spaces in workplaces, which increases their exposure;
(4) Industrial buildings often contain significant sources of atmospheric pollutants and are in locations that also have problems in terms of the quality of the outdoor air (Fung et al. [18]; Meadow et al. [19], Kuo and Shen [20],; Jones et al. [21]; Baek et al. [22])

Strategically operating building heating, ventilation, and air-conditioning (HVAC) systems can improve IAQ and reduce the risk of infection from airborne viral particles [23–26]. In addition, a very high level of a single pollutant can lead to damage, even if all other conditions are ideal [27].

Recently, air quality in sports gained a lot of attention in the literature, with two bibliometric analyses on the theme. The first one studied indoor environments used for sports [28], while the second focused on outdoor sports [29]. Given this attention to air quality in sports environments, IAQ in working environments is even more important since the time spent working is usually higher.

However, even if IAQ has gained increasing interest due to its effect on the health of individuals, there is only one bibliometric analysis related to IAQ in general terms that focuses on its past and present trends [30]. At the same time, in this work [30], the indoor working environments, relative pollutants, and instruments exploited were not included in the analysis, while these are the main focus of our work.

Therefore, this study aims to investigate and analyze the results obtained in studies of indoor air pollution in various workplace contexts through a bibliometric analysis. The conclusions regarding issues such as the most cited pollutants, most used keywords, most studied countries, commonly used instruments, and leading authors are presented. The results presented in this paper are obtained using the bibliometric analysis software NVivo [31]. The research implications and a summary of the main findings are then given, and we conclude with an acknowledgment of the limitations and suggestions for future research.

## 2. Bibliometric Method

Bibliometrics is a research area of information and library sciences in which bibliographic data derived from scientific publications are quantitatively analyzed [32,33]. The purpose of bibliometrics is to highlight the nature and development of a research domain [34] and thus classify and provide a representative overview of a set of bibliographic documents [35]. The dataset for this analysis was developed by drawing on the databases of ScienceDirect, Taylor & Francis, Web of Science, MDPI, and ResearchGate. The papers considered were published between 2010 and 2021. Approaches and technologies aimed at the control and analysis of indoor air quality evolve very quickly, so this time frame was chosen to ensure the analysis is as current as possible. The first step in the data-collection process was to identify the keywords and determine the inclusion and exclusion criteria. Two groups of search terms were formed. The first (Group A) refers to the main topics of the research, and the second (Group B) represents the type of environment considered. Both are reported in Table 1.

**Table 1.** Groups of searched terms.

| Group "A" | | Group "B" |
|---|---|---|
| Air Quality<br>OR<br>Pollution<br>OR<br>Pollutants<br>OR<br>Emissions<br>OR<br>Exposure<br>OR<br>Chemicals | AND | Industrial environment<br>OR<br>Indoor<br>OR<br>Work environment |

We took an operational approach to select a suitable sample of papers for review:

1. Identification of the papers using the keywords.
2. Screening and abstract control.
3. Eligibility by applying content criteria.
4. Full-text assessment.

The general scheme and relative screening of the papers are illustrated in Figure 1.
The following content exclusion criteria were applied:

- Articles that analyze schools, means of transport, restaurants, and spaces used for sports activities.
- Use of biological methods for the analysis of pollutants, such as blood, saliva, urine analysis, etc.
- Review articles containing no information on pollutants or relevant results.

A total of 656 articles were identified using search terms, and 409 met all of our inclusion criteria. Table 2 shows the number of papers distributed by year of publication and indicates that more than 50% of the papers collected over the past 12 years were published in the last 5 years, which highlights the increasing interest in the literature. We considered papers published up until March 2021, and thus the percentage of publications in this final year is relatively low.

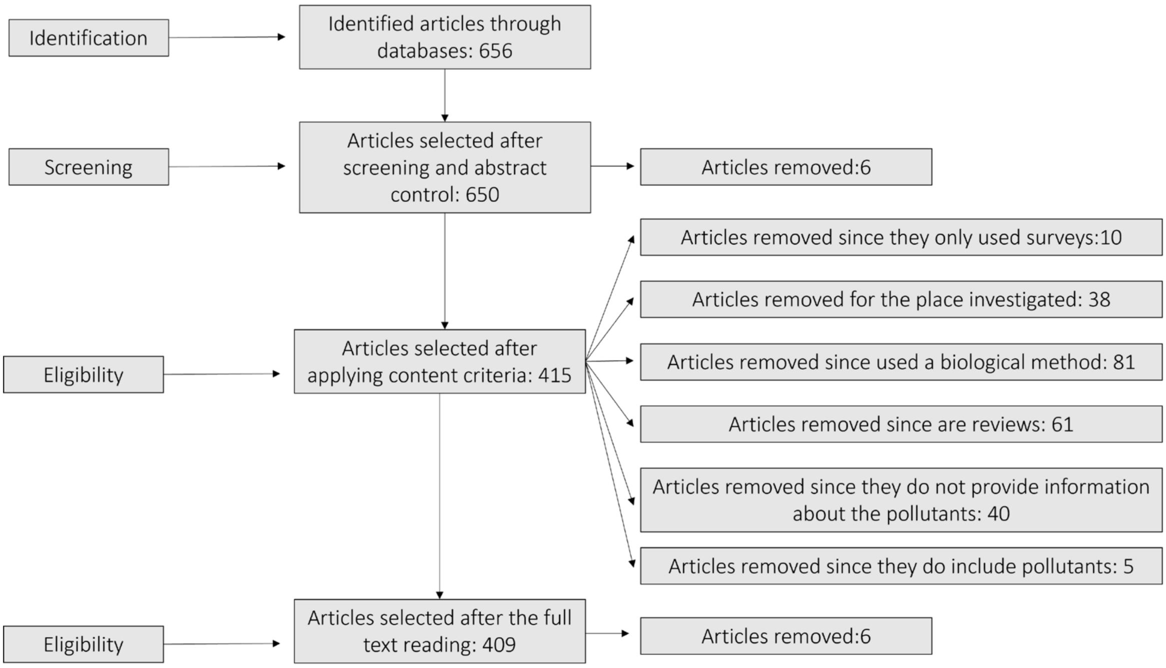

**Figure 1.** Operational approach for the selection of papers and screening flowchart.

**Table 2.** Number of annual published articles between 2010 and 2021.

| Year | Count | Percentage (%) | Accumulated Percentage (%) |
|---|---|---|---|
| 2010 | 4 | 0.98 | 0.98 |
| 2011 | 25 | 6.10 | 7.08 |
| 2012 | 34 | 8.29 | 15.37 |
| 2013 | 29 | 7.07 | 22.44 |
| 2014 | 34 | 8.29 | 30.73 |
| 2015 | 34 | 8.29 | 39.02 |
| 2016 | 33 | 8.05 | 47.07 |
| 2017 | 35 | 8.54 | 55.61 |
| 2018 | 49 | 12.20 | 67.81 |
| 2019 | 65 | 15.85 | 83.66 |
| 2020 | 60 | 14.63 | 98.29 |
| 2021 | 7 | 1.71 | 100.00 |

After collecting the literature, a bibliographic database file was created to generate bibliographic tables using NVivo software. This is a type of qualitative data analysis (QDA) software produced by QSR International [31]. NVivo provides a qualitative method of collecting open data and for identifying qualitative insights such as interviews, survey responses, magazine articles, and social media and web content, in which in-depth levels of analysis on small or large volumes of data are required.

We selected sub-categories to represent the various working environments and grouped industries within the same broad area together. Table 3 gives these groupings.

**Table 3.** Specific industry grouping.

| Industry Macro Category | Specific Industry |
|---|---|
| Food | Coffee-processing factories |
| | Water bottling |
| | Food production factory |
| | Food and beverage plant |
| | Grain industry |
| | Fish-processing industry |
| | Swine production |
| | Sugar industry |
| | Cheese factory |
| | Grain and animal feed production industry |
| Waste | Waste electrical and electronic equipment (WEEE) treatment facility |
| | E-waste dismantling workshop |
| | E-waste recycling workshops |
| | Recycling process for waste TV |
| | Mobile e-waste recycling plant |
| | E-waste processing workshops |
| | Battery-recycling industries |
| | Recycling process of waste printed circuit board |
| Mines | Metal mines |
| | Chrysotile mine and processing factories |
| | Gold miners |
| | Taconite mines |
| | Potash mines |
| | Sangan iron ore mines |
| | Platinum mines |
| | Underground mines |
| | Coal mines |
| | Artisanal mercury mining communities |
| Textiles | Shoe-manufacturing facilities |
| | Clothes-manufacturing factories |
| | Facility that produces rain jackets |
| | Integrated textile factory |
| | Texile industry |
| | Textile dyeing, chemical manufacturer |
| | Bra cup manufacturing facility |
| | Rubber footwear industries |
| | Textile-processing workers |
| Office | Office building |
| | Office room |
| | Green office buildings |
| | Mass timber office building |
| | Open-plan offices |
| | Commercial office |
| | Urban office |
| | Nuclear research center |
| | Dental office |

## 3. Results

This section may be divided into sub-headings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

### 3.1. Pollutants

From our NVivo analysis, we identified a total of 153 types of pollutants examined in the literature. Figure 2 shows the number of times a pollutant was considered in the collected papers.

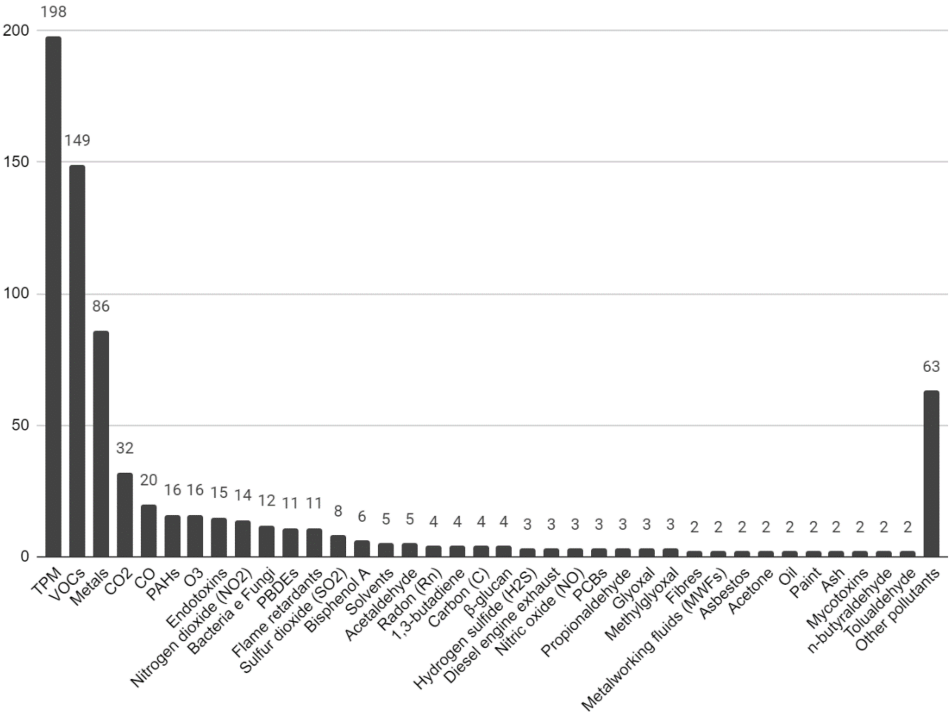

**Figure 2.** Pollutants and relative number of articles where they were investigated.

The group "Other pollutants" includes the 63 that have only been detected once, such as Cytochrome P450 2E1 (CYP2E1) [36], Polytetrafluoroethylene (PTFE), Acrylamide [37], Hydrochloric acid [38], Nitric acid ($HNO_3$) [39], Isocyanic acid [40], Selenium (Se), Triglycidyl Isocyanurate (TGIC) [41], and Vinyl chloride monomer [42]. As the graph shows, the first three categories of TPM (Total Particulate Matter), VOCs (Volatile Organic Compounds), and Metals correspond to 59.81% of the total investigated pollutants in indoor environments. Nurul et al. [43] assessed the levels of particulate matter (($PM_{2.5}$, $PM_{10}$, and Total Particulate Matter (TPM)) and traced metal dust concentrations in different sections of a steel plant and compared them with the occupational exposure values. Particulate matter is classified according to the size of the particle: coarse particulate matter, $PM_{10}$ (particles with a diameter of 10 micrometers (μm) or less); fine particulate matter, $PM_{2.5}$ (particles with a diameter of 2.5 micrometers (μm) or less); $PM_1$ (particles with a diameter of 1 micrometer (μm) or less); and ultrafine particulate matter, $PM_{0.1}$ (particles with a diameter of 100 nanometers (nm) or less). The findings showed that chromium and cobalt exposure exceeded the recommended limit by one to three times, but nickel exposure and particulate matter ($PM_{2.5}$, $PM_{10}$, and TPM) did not exceed the limit [44]. Unacceptable work conditions, such as a lack of engineering control, and unsafe behavior, such as no respiratory mask use, were found to be potential contributors to the higher exposure to metal dust among the workers. Improvements in working conditions and in safety behavior are thus required to ensure the well-being of these workers. The authors of [45] reported the occupational inhalation exposure of workers to VOCs in the Kuwaiti printing industry. VOCs are particularly dangerous to human health [46]. The researchers' results indicate that efforts to reduce worker exposure to VOCs in recent years have been successful, but there is still much to be completed to protect them. Unexpected findings included the use of the carcinogen vinyl chloride and 1,2-Dichlorotetrafluoroethane (CFC-114), which is banned under the Montreal Protocol, in printing activities. Lapses in safety procedures were observed, including the failure to use ventilation systems or closing doors between work areas, indicating that management and worker education should remain a priority. These categories can be considered macro-areas containing different variants of the same main element. The composition of each macro-area is shown below. Figure 3 shows the elements that appear in the "VOCs" macro-area. Many authors (41.6%) who analyze VOCs do not provide information about their composition. Formaldehyde is the focus of many studies, as a typical pollutant of indoor environments, and is found in materials used for the insulation of buildings and furnishings. BTEXs (Benzene, Toluene, Ethylbenzene, Xylene) are also widely studied, such as Benzene [36,37], Styrene [47,48], and Toluene [49]. Tetrachloroethylene and Trichloroethylene are also analyzed to a lesser extent.

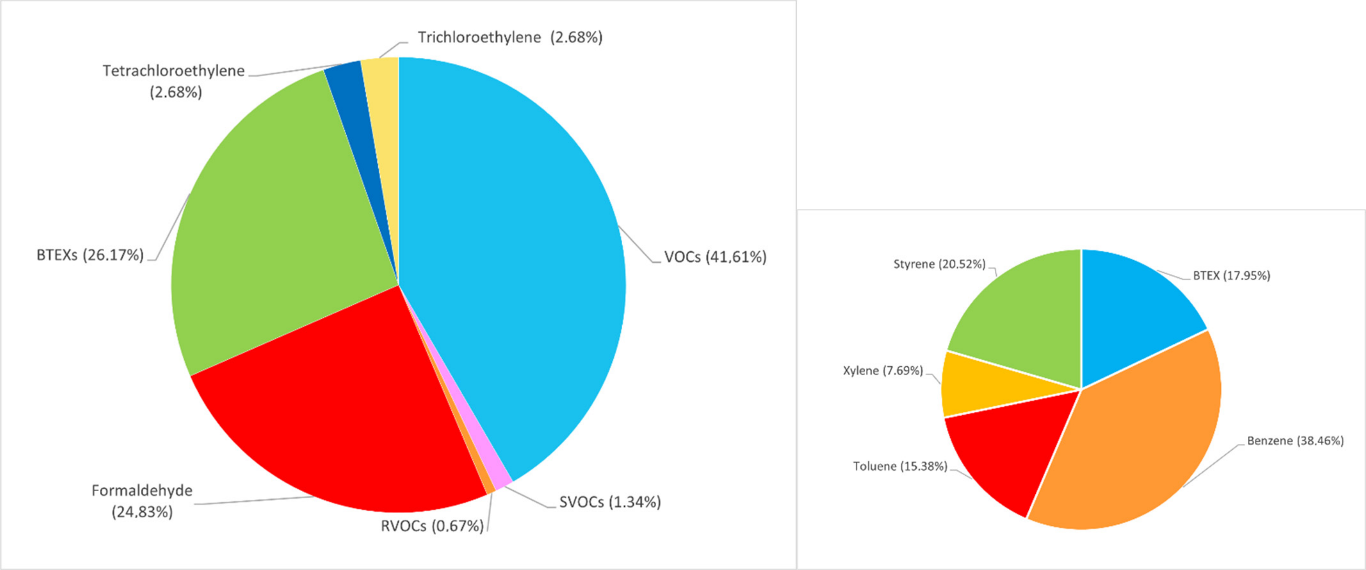

**Figure 3.** Composition of the "VOCs" macro-area on the left and of BTEXs on the right.

The macro-area of TPM consists of the two sub-categories of PM (55.05%) and Dust (44.95%). Figure 4 shows the composition of the "PM" macro-area. $PM_{2.5}$ (44.0%) and $PM_{10}$ (31.2%) are the most often considered PMs in terms of both the indoor and the outdoor environment. The authors of [50–52] carried out an analysis of the hazard quotient (HQ, or quotient of danger) and the cancer risk (CR) of $PM_{2.5}$ in cases of chronic exposure. Five offices were considered, and a comparison was made between the indoor and outdoor environments. The hazard quotient (HQ) associated with $PM_{2.5}$ was, in all five cases, higher in the indoor than in the outdoor environment. The authors of [53] analyzed the air quality level in 13 open-plan administrative offices (OAOs) and 12 open-plan research offices (OROs) in China. The concentrations of $PM_{2.5}$ and $PM_{10}$ in the OAOs were 55.0 $\mu g/m^3$ and 68.8 $\mu g/m^3$, with 60.9 $\mu g/m^3$ and 74.6 $\mu g/m^3$ in the OROs, respectively. As recommended by the BS EN Standard 15251:2007 [54] and ANSI/ASHRAE Standard 62.1–2013 [55], the concentrations of $PM_{2.5}$ and $PM_{10}$ should be lower than 15 $\mu g/m^3$ and 50 $\mu g/m^3$, respectively. This therefore indicates that the concentrations of $PM_{2.5}$ and $PM_{10}$ did not satisfy the requirements of these standards. The authors of [56] studied the inhalation exposure to size-specific particulate matter (PM) among workers in an informal electronic-waste (e-waste) recovery site. Burning activities led to the highest $PM_{2.5}$ exposure (203 $\mu g\ m^3$). However, median $PM_{2.5}$ concentrations between work- and non-work-related activities were largely similar, and all individuals on the site, regardless of their activities, experienced poor air quality. $PM_{2.5}$ exposures during long periods of non-work-related activities exceeded the WHO standard in 88% of the measured data.

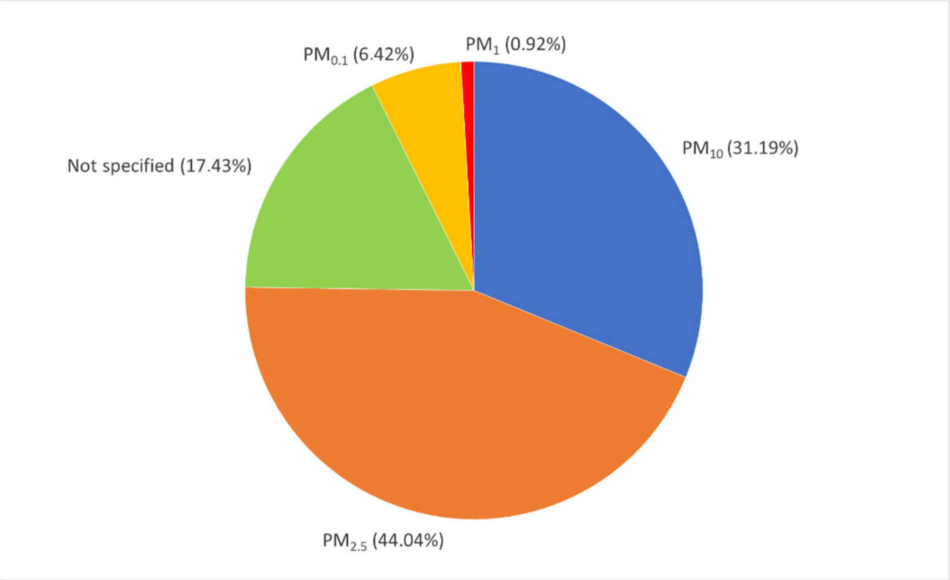

**Figure 4.** Composition of the" PMs" macro-area. PM$_{10}$ (coarse particulate matter, particles with a diameter of 10 micrometers (µm) or less); PM$_{2.5}$ (fine particulate matter, particles with a diameter of 2.5 micrometers (µm) or less); PM$_1$ (particles with a diameter of 1 micrometer (µm) or less); and PM$_{0.1}$ (ultrafine particulate matter, particles with a diameter of 100 nanometers (nm) or less).

Figure 5 shows the composition of the "Dust" macro-area. Most of the studies did not specify the dust composition, but in those that did, the most detected type of dust was silica dust. In many industries (mineral, fuel–energy, metal, chemical, and construction), workers are exposed to silica dust, and thus assessing this exposure is essential to avoid adverse health consequences (such as silicosis, pneumoconiosis, chronic kidney disfunction, and other general respiratory problems) [57–60]. Unfortunately, monitoring for silica requires expensive equipment, health and safety staff with the knowledge to conduct the monitoring, and an available laboratory to perform the analysis, making it particularly difficult to perform monitoring in low- and middle-income countries [61]. The authors of [62] analyzed mortality levels in 29 mines in China and their relationship to silica exposure. The cohort included 74,040 employees, of which 49,309 (66.6%) were found to be exposed to silica dust, and 19,516 deaths were reported. Workers exposed to silica had significantly elevated mortality from all causes of death compared with the national mortality rate in China, as measured by the standardized mortality ratio (SMR). These findings highlight the importance of effective controls of silica dust exposure in workers. Safety management along with a quantitative assessment of dust exposure can play an important role in reducing dust concentrations at vulnerable sites.

Figure 6 shows the composition of the "Metals" macro-area. The incidence of studies that investigated metals is well-balanced in terms of types of metal. Lead was investigated in 12.8% of the studies, for example, by [63]; mercury was investigated in 11.6%, for example, by [64]; the presence and effects of chromium were evaluated, for example, by [65]; and [66] analyzed the exposure to solid chemical agents in biomass-fired power plants and the associated health effects. The MIXIE program was used to evaluate the risks the workers faced from the metals. The results suggest that multiple 4exposures to different metals are associated with an increased risk of cancer, central nervous system disorders, and upper and lower respiratory tract irritation. The increased cancer risk can be explained by the combined effects of As, Be, Cd, and Pb; central nervous system disorders by those of Mn, Pb, and Se; irritation of the upper respiratory tract by those of Al, As, and Se; and irritation of the lower respiratory tract by the combined effects of Be, Cd, Mn, and Se. The most evident exposure-associated health risk of multiple exposures to metals was that of cancer.

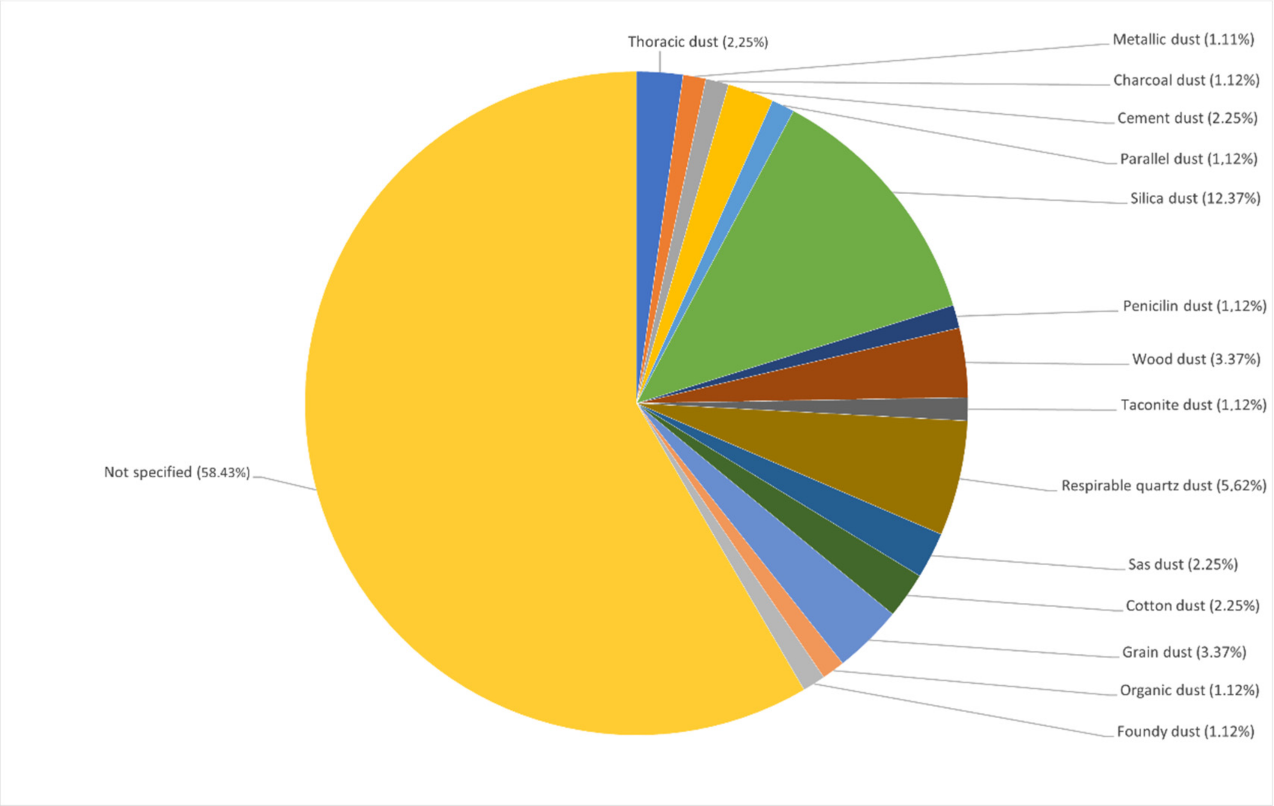

**Figure 5.** Composition of the "Dust" macro-area.

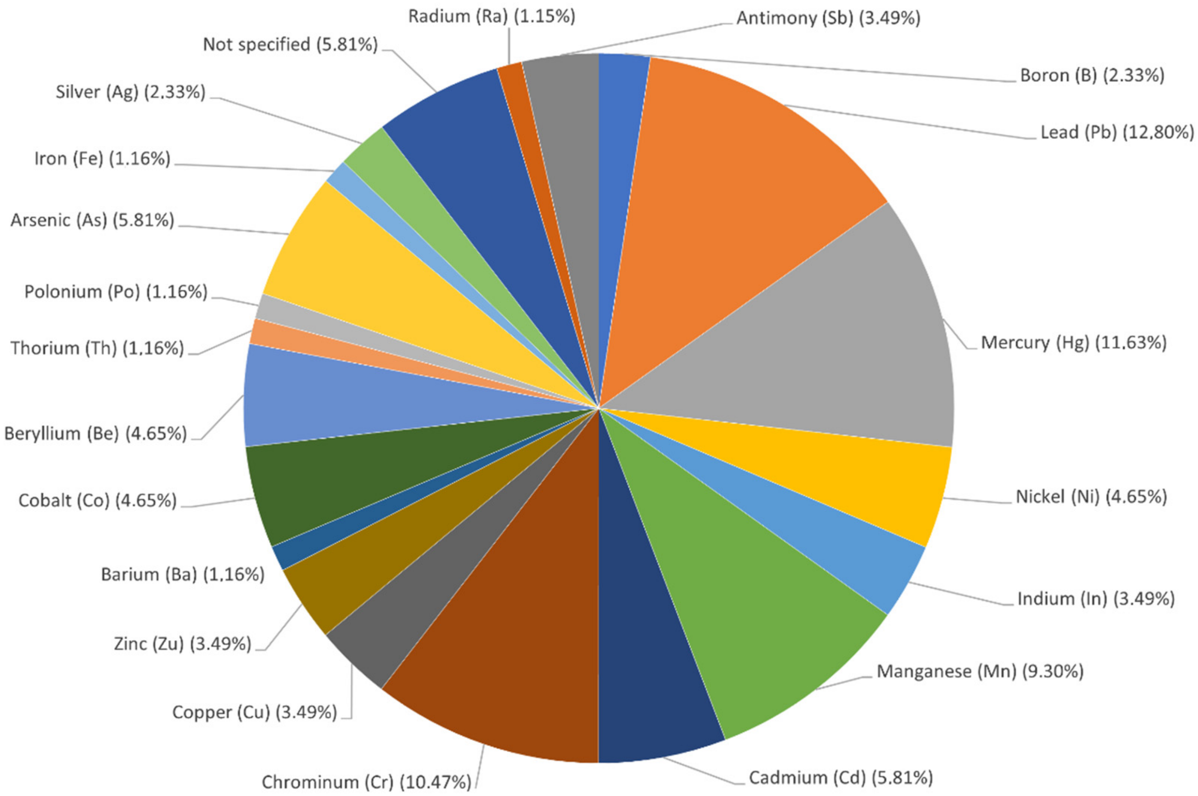

**Figure 6.** Composition of the "Metals" macro-area.

### 3.2. Indoor Working Environments

We identified 263 types of indoor working environments. Table 4 shows the top 16 most analyzed types of environments.

**Table 4.** Top sixteen working environments most analyzed.

| Indoor Working Environment | N. Citations | Percentage (%) |
|---|---|---|
| Office | 37 | 8.71 |
| E-waste | 26 | 6.12 |
| Mine | 22 | 5.18 |
| Food | 22 | 5.18 |
| Textile | 15 | 3.53 |
| Cement factory | 13 | 3.06 |
| Petroleum refinery | 12 | 2.82 |
| Steel industry | 11 | 2.59 |
| Paint factory | 9 | 2.12 |
| Plastic factory | 9 | 2.12 |
| Recycling facility | 9 | 2.12 |
| Vehicle manufacturing | 8 | 1.88 |
| Hospital | 7 | 1.65 |
| Printing industry | 6 | 1.41 |
| Foundry | 6 | 1.41 |
| Wastewater treatment plant | 6 | 1.41 |
| Others | 207 | 48.71 |

The remaining 48.71% includes working environments investigated less than six times, such as ceramics, wood, and fertilizers; and 93 considered one environment each (or 21.88% of the total), such as silicon production, fireworks plants, and the porcelain industry. As described in the Materials and Methods section, the five categories of Office, E-Waste, Mines, Food, and Textiles are macro-areas that contain working environments that share specific characteristics. For the five most analyzed categories (Office, E-waste, Mines, and Food), further research was carried out on the pollutants detected in each specific area. The 16 working environments were examined in 218 papers, amounting to 53% of the total. The 247 papers focusing on the remaining 47% of indoor environments mean that the percentage of investigations into each environment was less than 0.5%, which highlights the increasing interest in this research area. At the same time, Table 4 highlighted the scarcity of studies related to a highly potentially polluted working environment from an aerial perspective, such as in the Printing Industry, where only six studies took place, which was also the case for Wastewater Treatment Plants.

#### 3.2.1. Office

Much of the time spent indoors is within offices [67]. Many studies have confirmed that indoor environmental quality (IEQ), measured in terms of thermal comfort, air quality, and brightness, has a significant impact on occupant comfort, health, and productivity [68–72]. Good IEQ should therefore be ensured in offices. Many new offices are now located in green buildings [73], which provide a better indoor environment with less energy consumption [74] than traditional approaches. With the rapid development of this new type of building, the question of whether or not the specific IEQ performance meets the high expectations is a subject of debate. Several studies have been conducted to evaluate the actual IEQ performance of green buildings [70,75,76]. Some researchers have found that green buildings have good IEQ performance, such as [77], who showed that green buildings typically have a higher IEQ performance than non-green buildings. However, others have argued that green buildings do not show higher IEQ levels than conventional buildings or when compared to standard guidelines. For example, [78] found no differences between green buildings and conventional buildings in terms of thermal comfort and air quality. Thus, no final conclusions can be drawn, and it is unclear whether green office buildings really perform better in terms of IEQ and thus increase employee satisfaction or work performance [79–84]. Some evidence suggests that although green buildings can achieve energy efficiency targets [85], unintended consequences may reduce the quality of indoor environments and reduce occupant satisfaction [86]. For example, green buildings with airtight envelopes and poorly thought-out ventilation systems can lead to poor air quality and consequently increase the health problems and discomfort of occupants [87–91]. Table 5 shows the pollutants detected most often in the working environments that are part of the "Office" macro-area.

**Table 5.** Pollutants most detected in "Office" working environment.

| Pollutant | N. Detection | Percentage (%) |
|---|---|---|
| PM | 17 | 22.67 |
| VOCs | 17 | 22.67 |
| CO2 | 13 | 17.33 |
| Metals | 5 | 6.67 |
| O3 | 5 | 6.67 |
| CO | 4 | 5.33 |
| Others | 14 | 18.67 |

The results for the Office macro-area are in line with those reported in Figure 2, which shows that the most investigated pollutants are PMs, VOCs, and $CO_2$. The remaining 18.67% include pollutants detected less than four times. The relatively high presence of $CO_{2\text{ in}}$ in offices is because the spaces are typically smaller than in industrial working environments, and the production of $CO_2$ from the workers cannot be ignored. The $CO_2$ concentration can be estimated based on the number of occupants, the ventilation rate, and the external $CO_2$ concentration, as suggested by the literature [92,93]. The obtained results are also in line with those in Figures 3 and 4. The macro-area "PM" includes 10 detections for $PM_{2.5}$, 5 for $PM_{10}$, 1 detection for $PM_{1,}$ and the type of PM is not specified in the remaining studies. The "VOCs" macro-area consists of seven detections of Formaldehyde, one of RVOCs (Reactive Volatile Organic Compound), one of TVOCs (total volatile organic compounds), and eight detections for unspecified VOCs. The "Metals" macro-area includes one detection of chromium (CR), one detection of cobalt (Co), one detection of indium (In), one detection of lead (Pb), and one detection of mercury (Hg). This highlights the limited variation in the metal pollutants analyzed in the literature.

### 3.2.2. E-Waste

Electric and electronic waste (e-waste) is currently the fastest-growing type of toxic waste (about 4% per year) in global terms [94,95]. Most components of electrical and electronic appliances, particularly printed circuit boards (PCBAs), are recycled [96]. However, several toxic components of electrical and electronic waste end up in the air, water, soil, or on workers, causing damage to human health and the environment [97–99]. The main pollutants detected during the e-waste recycling process are heavy metals and potentially harmful organic substances [98,100]. Metals are usually present in the various substances emitted, as experiments conducted in laboratories have also revealed [101]. Table 6 shows the pollutants analyzed for the "E-Waste" macro-area. The most detected pollutant is represented by the "Metals" macro-area, which alone corresponds to 36.96% of the total pollutants. This includes four detections of lead (Pb), three detections of cadmium (Cd), three of copper (Cu), two of chromium (Cr), two of zinc (Zn), two measurements of mercury (Hg), and one of nickel (Ni). The PM macro-area consists of three $PM_{2.5}$ detections, two of $PM_{10}$, one of $PM_{0.1}$, and three unspecified PM detections. The types of VOCs are not specified. The extensive presence of PBDEs is interesting, as out of the 10 total PBDEs detections, only 7 were in the "E-Waste" macro-area, as Figure 2 shows. PBDEs are a type of persistent organic pollutants, or POPs, and are used for various commercial purposes, mainly as a flame retardant (FR). The high presence of PBDEs in this macro area is understandable, as the "E-Waste" macro-area is composed exclusively of waste of electrical and electronic equipment, or WEEE, and PBDEs are mainly used in these types of equipment, including molded modules, electrical components, electrical connectors, automobile interior parts connectors, home appliances, and other flame-retardant applications.

**Table 6.** Pollutants most detected in "E-Waste" working environment.

| Pollutant | N. Detection | Percentage (%) |
|---|---|---|
| Metals | 17 | 36.96 |
| PM | 9 | 19.57 |
| PBDEs | 8 | 17.39 |
| VOCs | 4 | 8.70 |
| Flame retardants | 3 | 6.52 |
| PAHs | 3 | 6.52 |
| PCBs | 2 | 4.35 |

### 3.2.3. Mines

Table 7 shows the pollutants most often detected in the "Mines" macro-area and indicates that the remaining 20.68% consists of the pollutants detected only once. Dust represents 44.83% of the total pollutants investigated in mines, and 4 of the 13 measurements are of crystalline silica dust. Exposure to dust is inevitable in mines because the process of extracting minerals involves breaking rocks. This dust can penetrate the alveoli of the pulmonary system and can cause respiratory impairment [102]. Most of the dust generated from the extraction processing is silica [103]. Silica appears in different forms and is one of the most common minerals in the Earth's crust [104]. Crystalline silica dust can appear at almost all stages of the manufacturing processes of many mining industries [105], and so it is natural that many studies focus on these pollutants in mines.

**Table 7.** Pollutants most detected in "Mines" working environment.

| Pollutant | N. Detection | Percentage (%) |
|---|---|---|
| Dust | 13 | 44.83 |
| Metals | 8 | 27.59 |
| Diesel Particulate Matter | 2 | 6.90 |
| Other | 6 | 20.68 |

### 3.2.4. Food

Table 8 shows the pollutants detected at least twice in the "Food" working environments. The remaining 31.11% (corresponding to 14 elements) includes pollutants detected only once, and 8.89% of the total pollutants are endotoxins. These are produced by Gram-negative bacteria and represent a widespread environmental contaminant in numerous industrial and agricultural settings [106]. Endotoxin-induced inflammation leading to immune system upregulation has been proposed as a likely anti-carcinogenic mechanism [107]. However, more recent studies provide conflicting evidence regarding the effect of endotoxin exposure on lung cancer. Exposure to endotoxins has been studied in several industries associated with organic dust exposure, such as food [108–110].

**Table 8.** Pollutants most detected in "Food" working environment.

| Pollutant | N. Detection | Percentage (%) |
|---|---|---|
| Dust | 9 | 20.00 |
| VOCs | 5 | 11.11 |
| Endotoxin | 4 | 8.89 |
| Bacteria or Fungi | 4 | 8.89 |

**Table 8.** *Cont.*

| Pollutant | N. Detection | Percentage (%) |
|---|---|---|
| CO | 3 | 6.67 |
| $O_3$ | 2 | 4.44 |
| $CO_2$ | 2 | 4.44 |
| β-glucan | 2 | 4.44 |
| Other | 14 | 31.11 |

### 3.2.5. Textile

The textile and clothing industries are the main sources of economic growth and social development in many developing countries and elsewhere. This sector contributes about 15% of the total GDP of some low-income countries and creates jobs for 35% to 90% of the total workforce in manufacturing industries [111]. Less-developed countries such as Bangladesh, Cambodia, and Lesotho all have very high shares of total manufacturing employment in the T&C industry (77%, 90%, and 89%, respectively) [111]. In China, the textile sector plays a fundamental role in the national economy, and in 2017, China's textile exports reached a value of about USD 110 billion, representing 37.2% of the global market share, followed by the European Union and India [112]. Table 9 shows the pollutants most often detected for the "Textile" macro-area.

**Table 9.** Pollutants most detected in "Textile" working environment.

| Pollutant | N. Detection | Percentage (%) |
|---|---|---|
| VOCs | 10 | 33.33 |
| Dust | 5 | 16.67 |
| Endotoxin | 2 | 6.67 |
| Other | 13 | 43.33 |

The remaining 43.33% (corresponding to 13 elements) includes all the pollutants detected only once. Like other types of industrial activities, the textile industry releases toxic substances into the environment, thus contributing to environmental pollution, and in particular, water pollution and toxic gases emitted by wastewater. According to the China Environment Statistical Yearbook, more than 1.8 billion tons of wastewater were produced in 2015, containing dyes, heavy metal ions, solvents, and other pollutants [113]. The most detected pollutant in the studies was VOCs, which contribute 33.33% of the total pollutants. Of the 10 detections of VOCs, 3 are of benzene, 3 of formaldehyde, 2 of trichloroethylene, and 2 of unspecified VOCs. Although wastewater can be purified through various technologies and treatments, the VOCs present in fabrics, surfaces, detergents, and solvents can be emitted into the environment during these treatments [114,115]. The second-most detected pollutant is dust, at 16.67%. Exposure to cotton dust in the textile industry is associated with work-specific and non-work-specific respiratory symptoms. In addition, cotton dust is often contaminated with Gram-negative bacteria, which contain endotoxins [116]. Thus, the third-most detected pollutants are endotoxins, at 6.67%, which are released into the air during the processing of cotton [117]. The detections of trichlorethylene are also interesting. Trichlorethylene is a synthetic product that, at room temperature, appears as a non-flammable, colorless liquid with a characteristic (sweetish) odor [118]. This is considered a group-one carcinogen (confirmed as carcinogenic to humans) [119]. In the textile sector, it was used as a solvent for dry cleaning until it was replaced in the 1950s by tetrachlorethylene [120]. Even today, however, it can be found in hardware stores, and is used as a stain remover. The recommendation is that it should only be used when wearing appropriate personal protective equipment (PPE), such as masks, gloves and protective goggles, to avoid any possible contact.

### 3.3. Authors

Table 10 shows the authors who have published 3 or more articles out of the 371 identified, and 32 have published more than 1 article on the subject.

**Table 10.** Authors with most published articles.

| Authors | N. Articles | Percentage (%) | Affiliation |
|---|---|---|---|
| Jie Guo | 4 | 0.98 | School of Environmental Science and Engineering, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China |
| Samson Wakuma Abaya | 3 | 0.73 | Department of Preventive Medicine, School of Public Health, College of Health Sciences, Addis Ababa, Ethiopia University, PO Box 9086, Addis Ababa, Ethiopia |
| Solange Costa | 3 | 0.73 | Department of Environmental Health, National Institute of Health, Rua Alexandre Herculano n° 321, Porto 4000-055, Portugal |
| Ranran Liu | 3 | 0.73 | State Key Laboratory of Organic Geochemistry and Guangdong Key Laboratory of Environmental Protection and Resources Utilization, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China |
| Anne Straumfors | 3 | 0.73 | Department of Chemical and Biological Work Environment, National Institute of Occupational Health, PO Box 8149 Dep, Oslo N-0033, Norway |
| Others | 393 | 96.09 | - |

The authors shown in Table 10 cover only 3.91% of the total, and the remaining 96.9% (corresponding to 366 authors) includes all who have published fewer than 3 articles. Jie Guo focused his investigations in China and mainly investigated the recycling and disposal processes of electrical waste, including televisions and printed circuit boards [121–124]. The keywords most used in his articles are risk assessment, particle pollution, recycling process, electronic waste, fumes, particulate matter, thermal degradation, pollution emission, pollution control, and PBDEs. The three keywords of "Fumes", "Particulate matter", and "PBDEs" are connected, and in fact, many researchers [125–127] have studied the airborne and floor pollution caused by the WPCB de-soldering processes in WEEE recycling areas. They report that particulate matter (PM) and polybrominated diphenyl ethers (PBDEs) are two key pollutants contained in the fumes emitted during the WPCB de-soldering process. Samson Wakuma Abaya focused on dust exposure and the health problems of workers in coffee and water bottling factories in Ethiopia [128–130]. The keywords most used in his works are coffee dust, exposure determinants, personal exposure, primary coffee factory, lung function, and respiratory symptoms. The keywords are in line with the findings of this study, as in the "Food" macro-area, the most detected pollutant is "Dust". Solange Costa focused on the exposure to formaldehyde of those working in laboratories [131–133]. Ranran Liu examined emissions of harmful substances at dismantling and recycling sites for electronic waste and assessed their implications for the health of workers [134–136]. The keywords most used in Liu's works are E-waste recycling, E-waste dismantling, human exposure, and pollution patterns. Anne Straumfors focused her investigations on Norway. In her first two works, she studied the distribution of grain dust in industries that produce animal feed and process grain [137,138]. The keywords most used by Straumfors are bacteria, endotoxin, exposure assessment, fungal spores, and grain industry. The presence of "endotoxin" among these keywords is not surprising, and it supports the results presented in Table 8 for the "Food" macro area, in addition to the presence of bacterial and fungal spores. In her third study, she analyzed exposure to wood dust in sawmills [139].

### *3.4. Journals*

Table 11 shows the top 16 journals that have published the majority of the analyzed articles. The *International Journal of Environmental Research and Public Health* has published the most. This covers environmental sciences and engineering, public health, environmental health, occupational hygiene, economic and global health research, etc.

**Table 11.** Journals that published more papers.

| Journals | N. Papers | Percentage (%) |
|---|---|---|
| *International Journal of Environmental Research and Public Health* | 23 | 5.62 |
| *Science of the Total Environment* | 19 | 4.65 |
| *Annals of Work Exposures and Health* | 18 | 4.40 |
| *Journal of Occupational and Environmental Hygiene* | 15 | 3.67 |
| *Ann. Occupational Hygiene* | 15 | 3.67 |
| *Environmental Science and Pollution Research* | 15 | 3.67 |
| *Journal of Hazardous Materials* | 12 | 2.93 |
| *International Archives of Occupational and Environmental Health* | 12 | 2.93 |
| *Environment International* | 11 | 2.69 |
| *Environmental Research* | 10 | 2.44 |
| *Ecotoxicology and Environmental Safety* | 9 | 2.20 |
| *Industrial Health* | 9 | 2.20 |
| *Building and Environment* | 9 | 2.20 |
| *Toxicology Letters* | 8 | 1.96 |
| *Toxicology and Industrial Health* | 8 | 1.96 |
| *International Journal of Hygiene and Environmental Health* | 8 | 1.96 |

### *3.5. Country of Origin of the Authors and States Analyzed*

The authors' countries of origin were compared with those in which the investigations on indoor air quality were conducted. Tables 12 and 13 show the top ten countries of origin of the authors and those of analyses for the highest number of citations, respectively.

Tables 12 and 13 indicate that despite the change in the number of citations, the countries that appear the most remain the same (China, the USA, Iran, Italy, and Poland). However, the countries of origin of the authors and those in which the analyses took place differ. Thus, some authors decided to conduct their analyses in countries other than their own. Table 14 shows these particular cases and the differences.

**Table 12.** Top ten countries of origin of the authors.

| State | N. Citations | Percentage (%) |
|---|---|---|
| China | 63 | 15.33 |
| USA | 48 | 11.68 |
| Iran | 32 | 7.79 |
| Italy | 21 | 5.11 |
| Poland | 17 | 4.14 |
| Norway | 15 | 3.65 |
| Portugal | 13 | 3.16 |
| Sweden | 13 | 3.16 |
| France | 13 | 3.16 |
| South Korea | 12 | 2.92 |

**Table 13.** Top ten countries in which studies took place.

| State | N. Citations | Percentage (%) |
|---|---|---|
| China | 65 | 15.78 |
| USA | 42 | 10.58 |
| Iran | 32 | 8.06 |
| Italy | 21 | 5.29 |
| Poland | 17 | 4.28 |
| Portugal | 13 | 3.27 |
| Sweden | 12 | 3.02 |
| South Korea | 12 | 3.02 |
| France | 12 | 3.02 |
| Norway | 12 | 3.02 |

**Table 14.** Differences between the countries of origin of the authors and those under analysis.

| State | N. Citations | | Percentage (%) | |
|---|---|---|---|---|
| | Authors' State of Origin | Case Study | Authors' State of Origin | Case Study |
| China | 63 | 65 | 15.33 | 15.78 |
| USA | 48 | 42 | 11.68 | 10.19 |
| Finland | 10 | 9 | 2.43 | 2.18 |
| Sweden | 13 | 12 | 3.16 | 2.91 |
| France | 13 | 12 | 3.16 | 2.91 |
| Norway | 15 | 12 | 3.65 | 2.91 |
| Spain | 9 | 10 | 2.19 | 2.43 |
| Denmark | 8 | 6 | 1.95 | 1.46 |
| Different states | 0 | 7 | 0.00 | 1.70 |
| Egypt | 4 | 5 | 0.97 | 1.21 |
| Russian Federation | 4 | 5 | 0.97 | 1.21 |
| United Kingdom | 7 | 6 | 1.70 | 1.46 |
| South Africa | 5 | 4 | 1.22 | 0.97 |
| Brazil | 6 | 5 | 1.46 | 1.21 |
| Nepal | 2 | 6 | 0.49 | 1.46 |
| Tanzania | 1 | 5 | 0.24 | 1.21 |
| Canada | 3 | 4 | 0.73 | 0.97 |
| Nigeria | 2 | 3 | 0.49 | 0.73 |
| Australia | 3 | 1 | 0.73 | 0.24 |
| Vietnam | 1 | 2 | 0.24 | 0.49 |
| Saudi Arabia | 1 | 2 | 0.24 | 0.49 |
| Greece | 2 | 1 | 0.49 | 0.24 |
| Hungary | 3 | 1 | 0.73 | 0.24 |
| Jordan | 2 | 1 | 0.49 | 0.24 |
| Kuwait | 0 | 1 | 0.00 | 0.24 |
| Bolivia | 0 | 1 | 0.00 | 0.24 |
| Bangladesh | 1 | 0 | 0.24 | 0.00 |
| Netherlands | 2 | 1 | 0.49 | 0.24 |

Table 14 shows these particular cases and the differences.

The wording "*Different states*" is used for searches carried out in multiple states. China appears to be the most analyzed country, accounting for 15.78% of the total. Its rapid urbanization and the expansion of industrial activities mean that huge amounts of VOCs are emitted into the atmosphere from various sources, such as vehicle emissions, solvent use, and the petrochemical industry [140–142]. In addition, a large workforce surplus resulted from the urbanization process and began to flow toward the cities. A new group of migrant workers emerged, who were considered special and vulnerable. Cheap labor, extensive work, and weak environmental regulations have led to many industries with high levels of pollution. These industries are often labor-intensive, and workers suffer from environmental and occupational exposure risks. By the end of 2014, a total of 168.21 million migrant workers left their homes to work in other cities, which was an increase of 1.3% from 2013 [143]. The top five countries in the number of studies and number of authors, as Tables 12 and 13 show, are the same: China, the USA, Iran, and Italy.

However, as visible in Table 14, some authors conducted their research in countries other than their own, particularly countries in South-West Asia, South Asia, West and East Africa, and South America. This is understandable, and as stated previously, the issue of indoor air pollution is more serious in sub-Saharan Africa and Asia [7].

At the same time, there is a scarcity of work in low-income countries; for example, as visible, no studies were conducted in Bangladesh, even if the air pollution there is a problem not only in working places but also in households [144]. Thus, an improvement in the literature regarding air quality in workplaces located in low-income countries is required.

### 3.6. Keywords

The keywords used by the authors to describe their articles were examined, and the most cited keywords were identified, which amounted to 1028 keywords used 7050 times (Figure 7). Keywords used more than 20 times are listed in Table 15.

**Table 15.** Keywords used more than 20 times.

| Keyword | N. Citations | Percentage (%) |
|---|---|---|
| Exposure | 407 | 5.78 |
| Occupational | 220 | 3.13 |
| Air | 161 | 2.29 |
| Assessment | 145 | 2.06 |
| Dust | 131 | 1.86 |
| Risk | 121 | 1.72 |
| Health | 108 | 1.53 |
| Indoor | 89 | 1.26 |
| Pollution | 62 | 0.88 |
| Quality | 62 | 0.88 |
| Workers | 62 | 0.88 |
| Waste | 58 | 0.82 |
| Industry | 56 | 0.80 |
| Monitoring | 51 | 0.72 |
| Respiratory | 46 | 0.65 |
| Lung | 44 | 0.63 |
| Organic | 44 | 0.63 |
| Environmental | 42 | 0.60 |
| Matter | 37 | 0.53 |
| Cancer | 36 | 0.51 |
| Particulate | 36 | 0.51 |
| Compounds | 36 | 0.51 |
| VOCs | 35 | 0.50 |
| Volatile | 35 | 0.50 |
| Carbon | 35 | 0.50 |
| Function | 32 | 0.45 |
| Particles | 32 | 0.45 |
| Symptoms | 32 | 0.45 |
| Building | 30 | 0.43 |
| Industrial | 30 | 0.43 |

**Table 15.** *Cont.*

| Keyword | N. Citations | Percentage (%) |
|---|---|---|
| Nanoparticles | 30 | 0.43 |
| Plant | 30 | 0.43 |
| Recycling | 30 | 0.43 |
| Acid | 28 | 0.40 |
| Benzene | 28 | 0.40 |
| Hygiene | 28 | 0.40 |
| Metals | 28 | 0.40 |
| Respirable | 28 | 0.40 |
| Emission | 26 | 0.37 |
| Workplace | 26 | 0.37 |
| Endotoxin | 25 | 0.36 |
| Particle | 25 | 0.36 |
| Personal | 25 | 0.36 |
| Metal | 24 | 0.34 |
| PAHs | 24 | 0.34 |
| Silica | 24 | 0.34 |
| Work | 24 | 0.34 |
| Biological | 22 | 0.31 |
| Cement | 22 | 0.31 |
| Formaldehyde | 22 | 0.31 |
| Office | 21 | 0.30 |
| $PM_{2.5}$ | 21 | 0.30 |

All of the keywords identified in this research (see Table 3 in the Materials and Methods Section) also appear among the most used keywords. Six of these are among those shown in Table 15: "Exposure", "Air", "Indoor", "Pollution", "Quality", and "Industrial". The most used keyword combinations are: "Occupational exposure", which appears 148 times; "Exposure assessment" (54 times); "Indoor air" (62 times); "Air quality" (54 times); "Indoor air quality" (32 times); and "Air pollution" (29 times). The frequency of these combinations confirms the similarity in the data set of the papers collected.

### 3.7. Measuring Instruments

A total of 426 cited instruments were divided between active and passive. Devices that include a pump are referred to as "active" monitors, and those that do not include a pump are "passive" monitors.

As visible in Table 16, we found that most of the papers took a passive measurement approach. Passive samplers have several advantages over more traditional indoor-air sampling techniques. The sampling protocols are simple as passive samplers are small and lightweight; they operate without the risk of power loss, clogging, or leaks; and provide accurate results for a range of sampling durations, from daily to quarterly, for various compounds [145,146]. The author of [42] explored a new biological monitoring method for workers in the plastics industry to measure their exposure to the vinyl chloride monomer. He applied an active method in which personal sampling was conducted using a pump with a low flow of 50 mL/min for a period of 200 min. The authors of [147] used both active and passive methods to examine the exposure of benzene in petrochemical plants. Shift-long passive sampling with organic vapor monitors (OVM 3500, 3MUSA). A pump (Gillian LFS-113, Gillian, Cincinnati, OH, USA) was then used to estimate external benzene inhalation. Yousefian et al. [148] studied the concentration of BTEX compounds in municipal solid waste facilities. The measurements were taken using passive BTEX samplers. Glass pipe sorbent tubes were pre-packed with activated charcoal and were open at both ends. The air samples were then diffused into the sorbent tubes through a cellulose acetate diffusion barrier.

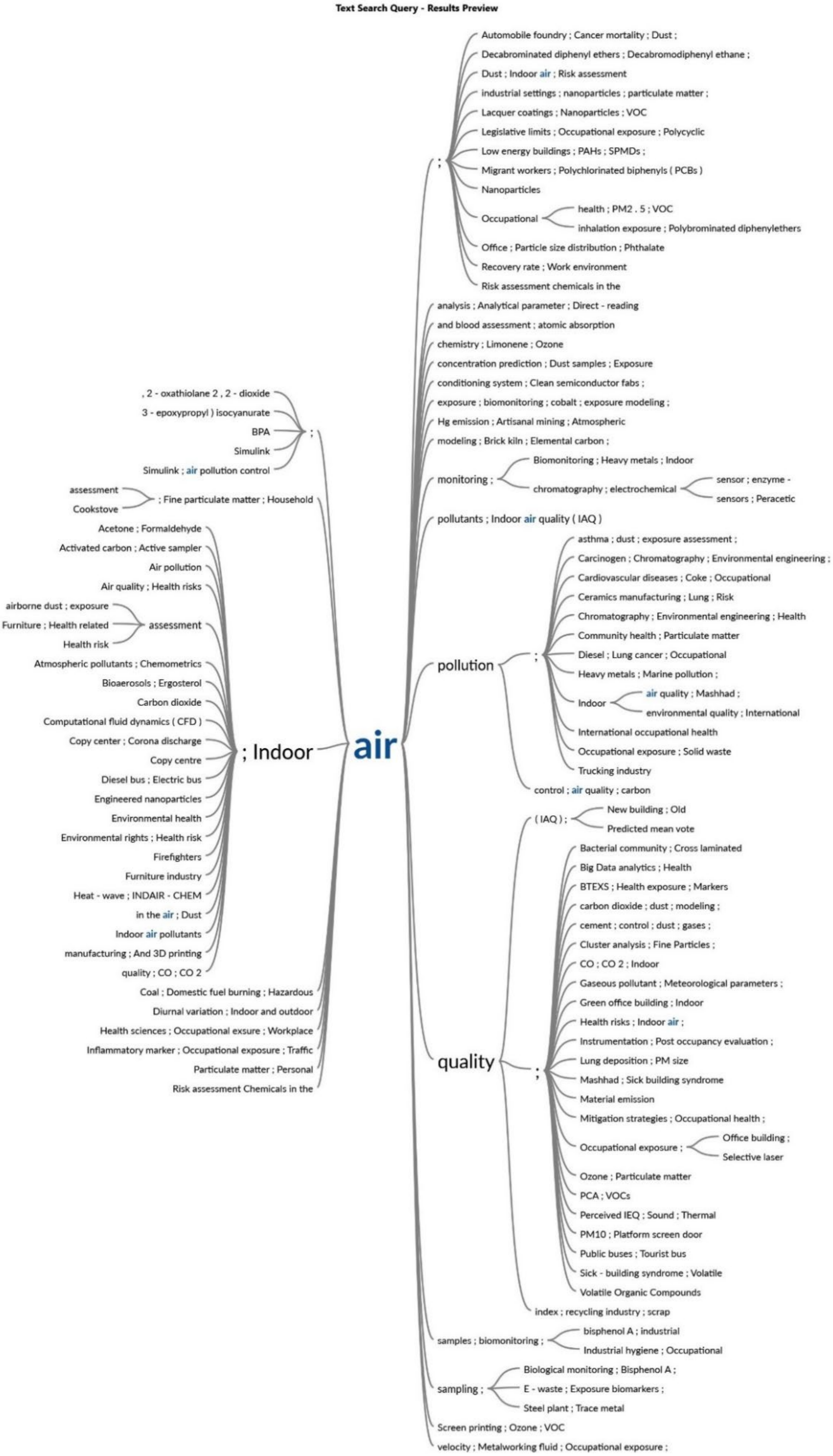

**Figure 7.** Keywords linked to the keyword "Air" (Figure from NVivo).

**Table 16.** Measuring instruments used.

| Measure Approach | N. Citations | Percentage (%) |
|---|---|---|
| Active | 126 | 29.58 |
| Passive | 300 | 70.42 |

## 4. Conclusions

In this study, we present a bibliometric analysis of indoor air quality in industrial environments that includes 409 articles. For each article, the following characteristics were analyzed:

- ✓ The working environment under consideration.
- ✓ The pollutants detected.
- ✓ The instruments and the types of measurements used.
- ✓ The country in which the study took place.
- ✓ Paper's attributes: author's name, the journal of publication, the year of publication, and the author's country of origin.

We thus identified and confirmed the various approaches in the literature through a structured method. We first identified the most-investigated air pollutants, which are TPM, VOCs, and Metals, that alone correspond to 59.81% of the total investigated pollutants. We individuated a total of 263 working environments, from which we derived five macros areas of the working environment: Offices, E-Waste, Mines, Food, and Textiles. For each one of these macros' areas, we have identified the most investigated pollutants and the reasons behind the investigations. We found that the most analyzed working environment was Offices, followed by E-Waste, Mines, Food, and Textiles. This focus on offices is understandable, as most people spend about 90% of their time indoors [149,150].

In Offices, PMs were the most detected pollutants, along with VOCs. Outdoor air pollution is the main source of PMs in offices [151], and PMs level can be harmful; for example, a Beijing office can reach a $PM_{2.5}$ level of 100 $\mu g/m^3$, while the limit recommended by the National Ambient Air Quality Standard (NAAQS) is 35 $\mu g/m^3$ [152]. We have also provided a clear view of the most exploited instruments for air quality monitoring, which are passive samplers since, compared to active ones are small and lightweight, they operate without the risk of power loss, clogging, or leaks and provide accurate results for a range of sampling durations, from daily to quarterly, for various compounds [145].

Our study provides a clear overview of the situation of air quality in industrial environments and its effects on human health, as well as a comprehensive outline of what the problems are and where they lie. Conclusions and further research directions include:

- ➢ We collected and analyzed a considerable number of works related to IAQ in the working environment, 409, and among them, 50% were conducted in the last 12 years, confirming the increasing interest in the theme.
- ➢ We identified a huge number of different working environments analyzed, namely, 263. However, except for the five macro-categories studied here in depth (Offices, E-Waste, Mines, Food, Textile), the other working environments have been investigated at most 12 times, even for highly potentially polluted ones such as a Petroleum Refinery (only 12 studies), Printing Industry, or Waste water Treatment Plant (only 6 studies). Thus, there is a clear need for in-depth studies of IAQ in the working environments identified here.
- ➢ As can be noticed in Tables 12 and 13, the top five countries in which studies took place are the same as the top five states of origin of the authors. In addition, in both rankings, there is a scarcity of low-income countries. As visible in Table 14, for example, no studies were conducted in Bangladesh, even if air pollution there is a problem not only in the working environment but also in the household [144], indicating how the literature on IAQ in working environments in low-income countries needs to be improved.

- ➢ The analysis of each macro-category and frequently cited pollutants provides a clear approach to identifying the specific areas of focus when improving air quality, supporting both practitioners and academics (Tables 5–9).

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