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BIBLIOMETRIC ANALYSIS OF RESEARCH TRENDS ON AIR POLLUTION AND ITS IMPACT ON BRAIN HEALTH, 2013–2023

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ABSTRACT

Bibliometric Analysis Of Research Trends On Air Pollution And Its Impact On Brain Health, 2013–2023. *This study analyzes global trends related to the impact of air pollution on brain health using the bibliometric method. Data was collected from the Scopus database with the keyword "air pollution AND brain health" in the 2013–2023 time frame, resulting in 200 publications that were analyzed using Harzing's Publish or Perish and visualized with VOSviewer. The analysis shows that the United States, China, and several European countries dominated the research contribution, with a significant increase in publications in 2020 and 2021. Keyword visualization identified key themes, including the impact of fine particulate matter (PM2.5) on the risk of neurological disorders such as dementia and Alzheimer's, as well as the link between air pollution and brain inflammation and mental health. Although this issue is increasingly relevant globally, similar research in Indonesia is still very limited, especially regarding the direct impact of air pollution on brain health. These limitations create significant opportunities for further studies focusing on Indonesia's population, especially in cities with high pollution levels. This study provides in-depth insights into the direction of global research and highlights the need for further studies in Indonesia, which can contribute to the development of evidence-based environmental health policies to reduce the impact of pollution on public health.*

INTRODUCTION

In the past decade, awareness of the adverse effects of air pollution on human health—particularly brain health—has increased significantly[1–3]. Air pollution in Indonesia, especially in major cities such as Jakarta, continues to rise, with PM2.5 identified as one of the primary pollutants. According to recent data, the average PM2.5 concentration in the Greater Jakarta (Jabodetabek) area is 42.5 μg/m^3, with substantial variation across regions. This condition has led to health impacts in the form of respiratory disorders and cognitive decline [4-8]. Pollutant particles, including particulate matter such as PM2.5 and chemical compounds like nitrogen dioxide (NO_2), can induce oxidative stress and inflammation, which in turn damage brain tissue[9–13]. This phenomenon is of growing concern in densely populated urban areas, where air pollution concentrations tend to be higher[14].

Studies focusing on the neurological aspects of air pollution have demonstrated a strong correlation between long-term exposure and an increased risk of cognitive impairment and neurodegenerative diseases, including Alzheimer's and Parkinson's diseases[4,15-18]. These

findings align with the research conducted by Feigin (2016), which revealed that stroke and various cerebrovascular diseases can be exacerbated by airborne pollutants, thereby accelerating nerve cell damage in the brain[19-22].

A bibliometric approach using Harzing's Publish or Perish and VOSviewer was employed to describe and understand the development of research in this area. Harzing's Publish or Perish was instrumental in collecting relevant publication and citation data from scientific databases [23]. while VOSviewer was utilized to visualize relationships between keywords, authors, and publications[24]. By employing these tools, this bibliometric analysis not only enables the tracking of research directions and patterns over time but also provides an intuitive means of identifying conceptual linkages within the field[25]. Through such visualizations, it is expected that collaboration networks among researchers, connections between frequently co-studied topics, and underexplored areas in the domain of air pollution and its impact on brain health will become apparent[26].

The research trend is further illustrated by the steady increase in publications addressing air pollution and brain health from 2013 to 2023. Data indicate that the number of articles highlighting this topic has consistently grown, reflecting a heightened global concern over environmental health issues. In his analysis, Murray (2013) asserted that the disease burden caused by air pollution is not limited to respiratory disorders but also includes neurological impairments that affect population quality of life[27]. Furthermore, Maher et al. (2016) identified magnetite particles in the human brain associated with air pollution, underscoring that pollutants not only impair lung function but can also penetrate the blood–brain barrier and cause direct brain damage. This provides compelling evidence that pollutants can directly interfere with brain structure and function, thereby increasing the risk of neurological dysfunction[18].

With the growing scale of international collaboration, seminal articles on air pollution and brain health have been published in high-impact journals such as The Lancet, JAMA, and Proceedings of the National Academy of Sciences. For example, a study by Livingston et al. (2020) published in The Lancet emphasized the importance of multidisciplinary approaches to understanding and addressing health issues caused by air pollution[28]. Meanwhile, research by Maher et al. (2016) offered robust evidence on the deposition of airborne particles in the brain, and Feigin (2016) demonstrated that air pollution contributes to an increased risk of vascular-related cognitive impairment[18–19]. Bibliometric data reveal that the United States, the United Kingdom, and several European countries are the primary contributors to this field, reflecting a high level of engagement in understanding and mitigating the public health impacts of air pollution.

This study aims to analyze global research trends on the impact of air pollution on brain health using bibliometric methods. Specifically, it seeks to identify the growth of publications from 2013 to 2023, determine the leading contributing countries, and map dominant keywords and thematic clusters within this body of research. By leveraging Publish or Perish and VOSviewer, this study also seeks to visualize author networks and thematic relationships, thereby identifying potential research gaps in the field.

Although similar studies have been conducted in developed countries, research explicitly examining the direct impact of air pollution on brain health remains scarce in Indonesia. Such studies are essential to support evidence-based public health policy. Therefore, this research also aims to provide a foundation for further investigations in Indonesia, where air pollution levels in several major cities are considerable, yet scholarly attention to its neurological consequences remains limited. By examining the relationship between air pollution and cognitive disorders, this study is expected to contribute to the formulation of more effective policies to mitigate the health impacts of air pollution in Indonesia.

MATERIALS AND RESEARCH METHODS

This study employs a bibliometric method—an analytical approach that applies mathematical and statistical techniques to identify patterns within scientific publications and related sources. The use of bibliometric analysis allows publication metadata to be transformed into visual representations that facilitate a clearer understanding of the subject under investigation. Through bibliometric visualization, the study can identify dominant topics, research trends, and collaborative relationships among researchers and institutions (Yulianingsih et al., 2020). In this article, the application of bibliometric methods aims to illustrate the research development trends concerning air pollution and its impact on brain health, while simultaneously identifying relational patterns within the topic. Bibliometric analysis also assists in uncovering underexplored areas, thereby opening opportunities for further research.

The Harzing's Publish or Perish application was used for data collection and processing, enabling the extraction of essential metadata such as citation counts, author names, year of publication, and authors' country of origin. These data were stored in CSV (Comma-Separated Values) format to facilitate grouping and further analysis, as well as in RIS (Research Information System) format, which was then integrated into Mendeley to complete the necessary citation and metadata records. Additional data processing was conducted in Microsoft Excel to compile publication distributions based on specific variables, such as citation counts per article and contributing countries. The articles selected for this study were those published between 2013 and 2023 that are relevant to the topic of air pollution and its impact on brain health. Publications unrelated to PM2.5 or not focusing on the cognitive effects of air pollution were excluded from the analysis.

Subsequently, VOSviewer was employed to analyze relationships among keywords, temporal trends, and researcher collaboration networks. This software maps keywords that frequently co-occur in publications, producing co-occurrence visualizations that help identify primary research topics. Furthermore, author network maps allow for the visualization of collaboration patterns based on connections between various researchers in the field. VOSviewer visualizations revealed clusters of research topics focusing on the relationship between PM2.5 and cognitive impairment. These visualizations also highlight active collaboration among researchers from developed countries, reflecting the significant international attention to this issue.

In this study, data were sourced exclusively from Scopus, as it is one of the largest academic databases encompassing articles from international journals. Harzing's Publish or Perish was chosen to measure article citations and their impact in the field, providing a more accurate depiction of the global volume of research on air pollution and brain health. The Scopus dataset included various document types, such as original research articles, review articles, notes, editorials, conference papers, and short surveys. The majority of retrieved data consisted of original articles, indicating that research in this field is predominantly driven by primary, empirical studies. This pattern demonstrates a consistent effort by researchers to directly investigate and expand knowledge concerning air pollution and brain health.

Through this approach, the study was able to identify publication trends, frequently examined research topics, and collaboration patterns among contributing researchers. The results are visually presented through keyword co-occurrence diagrams, graphs of publication distribution by country, and author collaboration network maps, providing in-depth insights into the direction and dynamics of research in air pollution and brain health. Moreover, analysis of frequently co-occurring keywords—such as PM2.5, neuroinflammation, and Alzheimer's disease—indicates that the majority of studies focus on the impact of air pollution on the central nervous system and its direct association with neurodegenerative diseases.

It is important to note that this study did not involve experimental procedures or primary data collection. Rather, it constitutes a bibliometric review that focuses on analyzing previously published studies on the subject. In other words, this research synthesizes the

work of various scholars in the field of air pollution and brain health, with the primary aim of identifying trends, patterns, and potential avenues for future investigation.

RESEARCH RESULTS AND DISCUSSION

This study employed a bibliometric method to identify global publication trends concerning the impact of air pollution on brain health. The analyzed data comprised 200 publications retrieved from the Scopus database using Harzing's Publish or Perish with the keyword "air pollution AND brain health" (see Figure 1, which presents the search results), and subsequently visualized using VOSviewer. This dataset is expected to provide a solid foundation for understanding the development of studies on the effects of air pollution on the human brain over the period 2013 to 2023.

Research related to air pollution aims to examine the extent to which environmental factors influence human health, particularly in the context of the brain and nervous system. As an increasingly urgent issue in the modern era, this study offers a new perspective on the role of the environment as a risk factor for neurological diseases, which have traditionally been more widely recognized as being caused by genetic factors or aging.

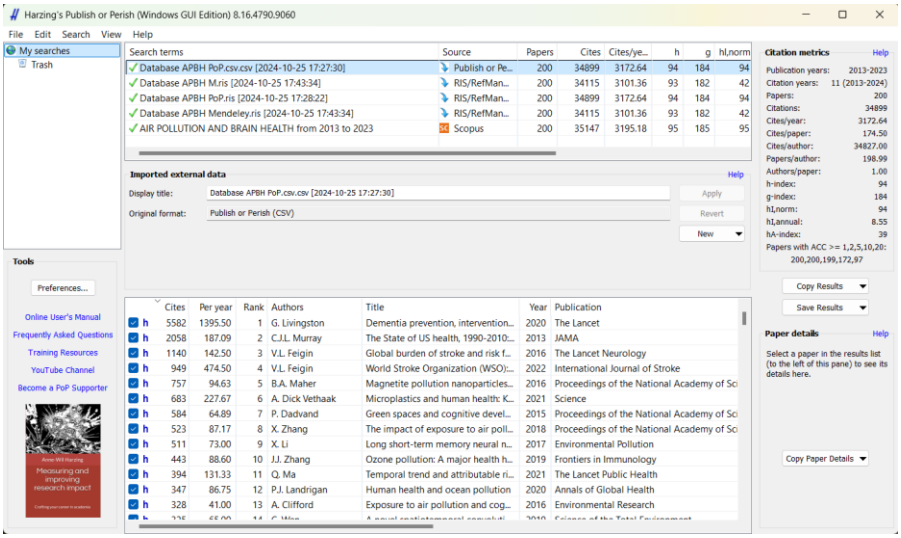

Figure 1. Search Results from the Database Using Harzing's *Publish or Perish*

The previous study by[29], titled "Long-term exposure to traffic-related particulate matter impairs cognitive function in the elderly", discusses the impact of long-term exposure to traffic-related particulate matter (PM_{10} and $PM_{2.5}$) on cognitive function in older adults, with a focus on the development of mild cognitive impairment (MCI), which may progress to Alzheimer's disease. This study is significant as it demonstrates a direct association between traffic-related air pollution exposure and the decline in cognitive function among the elderly population. It is considered relevant to the focus of the bibliometric analysis presented in this study. The article reinforces the analytical findings that fine particulate matter related to traffic is frequently associated with the risk of cognitive impairment. Moreover, it highlights the elderly as a vulnerable group, which supports the recommendation for further research in Indonesia, particularly given the high levels of traffic-related air pollution in several major cities.

Distribution of Publications by Year

The distribution of publications by year is presented in Figure 2 below:

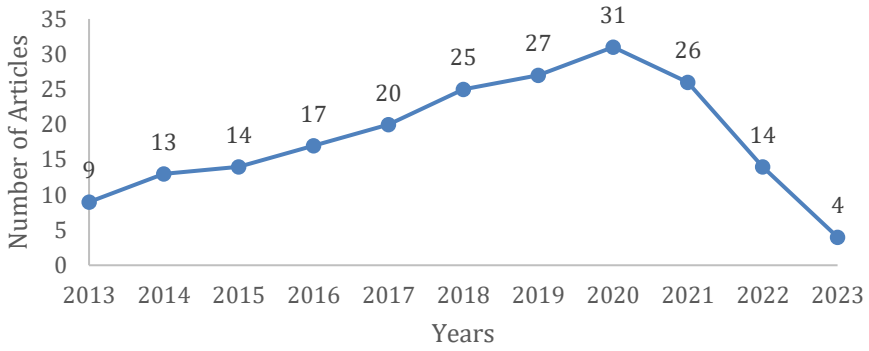

Figure 2. Distribution of Publications by Year

Based on the analysis results, there was a significant increase in the number of publications in 2020 and 2021, which may reflect growing global awareness of the link between air quality and brain health, particularly during the COVID-19 pandemic (see Figure 2 for the publication trend). These years marked a crucial period when the relationship between air pollution and brain health became a primary concern. The increase in research during this period coincided with heightened awareness among scientists and the public about health risks from industrial activities causing air pollution. This is a noteworthy finding. With the surge in research activity, the focus on air pollution as a risk factor began to shift more specifically toward brain health, indicating a clearer trend on the effects of particulate matter on cognitive function.

Distribution of Publications by Country

Visualization by country shows that the United States, China, and several European countries are the main contributors to this field of research. The United States has the highest number of publications (75 articles), followed by China (36 articles) and Italy (10 articles) (see Figure 3 for the contributing countries). The dominance of these countries reflects their capacity to support scientific research through adequate research infrastructure and their significant attention to air pollution issues. Studies in developed countries, such as the United States and those in Europe, demonstrate that emission control policies can significantly reduce the health risks associated with pollution.

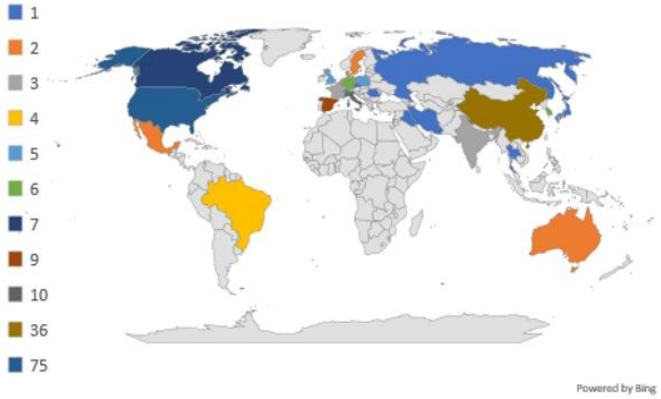

Figure 3. Distribution of Publications by Country

Conversely, research on the impact of air pollution on brain health in Indonesia remains very limited[30]. In fact, the direct correlation between pollution exposure and neurological disorders has not been extensively examined, despite the presence of high levels of air pollution in several urban areas in the country. This disparity underscores the importance of developing evidence-based policies in Indonesia to address the effects of air pollution on

brain health, while simultaneously creating significant opportunities to conduct similar studies domestically—thus offering a unique contribution (novelty) to the field.
Leading journals such as *The Lancet*, *JAMA*, and *Proceedings of the National Academy of Sciences* serve as key references on this topic, indicating that the impact of air pollution on brain health is recognized as an important public health issue. Articles by Murray (2013) and Livingston et al. (2020), published in these journals, provide valuable guidance for further research on the risk factors of air pollution affecting brain health[27].

Publications with the Highest Citation Counts

Table 1 presents the ten publications with the highest citation counts. The article authored by G. Livingston in 2020 ranks first, with 5,582 citations. This publication identifies air pollution as one of the modifiable risk factors for preventing dementia and has served as a reference for numerous studies on environmental factors affecting brain health. Its significance lies in demonstrating that air pollution not only damages physical health, such as the lungs, but also has a profound impact on the nervous system. This insight highlights the complex interplay between environmental factors and the nervous system, which is not always fully appreciated in general health sciences.

Table 1. List of Publications with the Highest Citations

No.	Author	Article Title	Journal	Years	Number of Citations	Quartile	SJR
1	G. Livingston	Dementia prevention, intervention, and care: 2020 report of the Lancet Commission	The Lancet	2020	5582	Q1	12.11
2	C.J.L. Murray	The State of US health, 1990-2010: Burden of diseases, injuries, and risk factors	JAMA	2013	2058	Q1	5.93
3	V.L. Feigin	Global burden of stroke and risk factors in 188 countries, during 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013	The Lancet Neurology	2016	1140	Q1	8.59
4	V.L. Feigin	World Stroke Organization (WSO): Global Stroke Fact Sheet 2022	International Journal of Stroke	2022	949	Q1	1,8
5	B.A. Maher	Magnetite pollution nanoparticles in the human brain	Proceedings of the National Academy of Sciences of the United States of America	2016	757	Q1	3.74
6	A. Dick Vethaak	Microplastics and human health: Knowledge gaps should be addressed to ascertain the health risks of microplastics	Science	2021	683	Q1	11.9
7	P. Dadvand	Green spaces and cognitive development in primary schoolchildren	Proceedings of the National Academy of Sciences of the United States of America	2015	584	Q1	3.74
8	X. Zhang	The impact of exposure to air pollution on cognitive performance	Proceedings of the National Academy of Sciences of the United States of America	2018	523	Q1	3.74
9	X. Li	Long short-term memory neural network for air pollutant concentration predictions: Method development and evaluation	Environmental Pollution	2017	511	Q1	2.13
10	J.J. Zhang	Ozone pollution: A major health hazard worldwide	Frontiers in Immunology	2019	443	Q1	1.87

The author network map indicates collaboration among researchers from various countries, with several authors—such as Calderon and Torres—occupying central positions within the network (see Figure 4, which displays the author network structure). This collaboration reflects that air pollution is recognized as a global health issue requiring cross-country cooperation. This finding is significant as it underscores that air pollution has been widely acknowledged as a pressing global health concern.

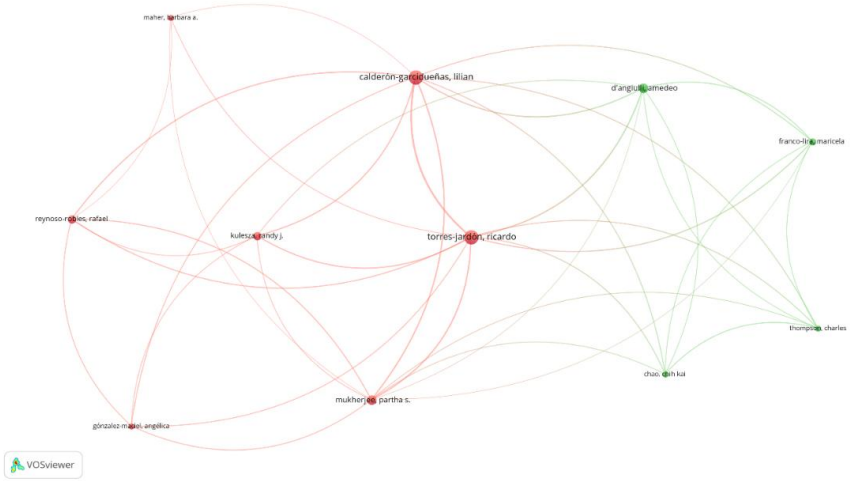

Figure 4. Network Structure by Author

The central positions of Calderon and Torres highlight their substantial contributions to the study of air pollution and health, particularly its effects on children's brain development in highly polluted urban environments[31-36].

Keyword and Cluster Visualization

The keyword visualization, generated through co-occurrence analysis, reveals that the terms *"air pollution," "particulate matter,"* and *"dementia"* occupy central positions in the bibliometric map (see Figures 5 and 6 for keyword visualizations). *Particulate matter*, particularly PM2.5, emerges as one of the most frequently studied pollutants in relation to its effects on brain health, indicating the significant risks posed by PM2.5.

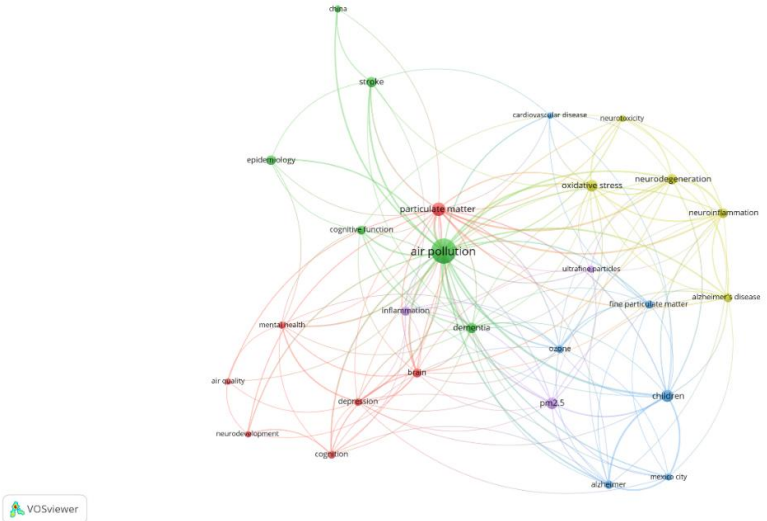

Figure 5. Keyword Network Structure Based on Co-occurrence

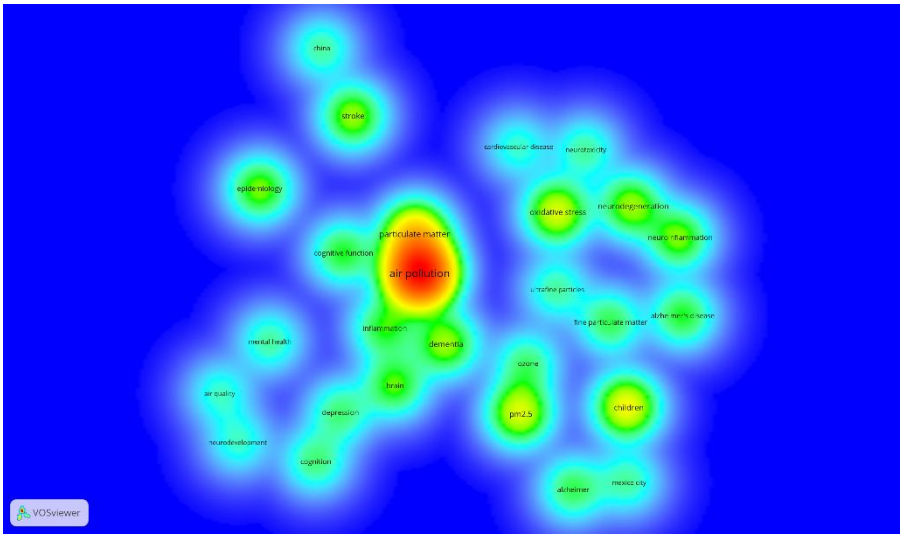

Figure 6. Keyword Density Visualization Based on Co-occurrence

The study by Maher et al. (2016) demonstrated that PM2.5 particles can enter the brain through the respiratory tract and bloodstream, causing damage to brain structures and accelerating neurodegenerative processes such as Alzheimer's disease[18]. This visualization not only illustrates that the primary research focus is on the direct impact of particulate matter on brain function but also opens opportunities for further exploration of other types of pollutants that may play a role in brain damage mechanisms.
The keyword clusters indicate five main research groups, as presented in Table 2.

Table 2. Keyword Term Clusters

No.	*Cluster*	Keyword
1.	*Cluster* 1 (7 item)	*Air quality, brain, cognition, depression, mental health, neurodevelopment, particulate matter*
2.	*Cluster* 2 (6 item)	*Air pollution, China, cognitive function, dementia, epidemiology, stroke*
3.	*Cluster* 3 (6 item)	*Alzheimer, cardiovascular disease, children, fine particulate matter, Mexico city, ozone*
4.	*Cluster* 4 (5 item)	*Alzheimer's disease, neurodegeneration, neuroinflammation, neurotoxicity, oxidative stress*
5.	*Cluster* 5 (3 item)	*Inflammation, $pm_{2.5}$, ultrafine particulate*

Cluster 1: Focuses on the relationship between air quality and mental health, including depression and neurodevelopment. This cluster highlights the impact of air quality on the mental health of urban populations exposed to high levels of pollution.
Cluster 2: Relates to the epidemiology of dementia, cognitive function, and neurodegenerative risk, demonstrating the long-term association between air pollution exposure and dementia risk among the elderly.
Cluster 3: Covers cardiovascular diseases and risks for children in highly polluted areas such as Mexico City, underscoring the impact of pollution on vulnerable groups.
Cluster 4: Centers on brain inflammation and neurodegenerative diseases such as Alzheimer's. Long-term exposure to PM2.5 has been shown to increase inflammation, which in turn leads to brain tissue damage.
Cluster 5: Links PM2.5 to brain inflammation, with strong potential to trigger neurological damage. Research in this cluster suggests that the neurological health risks posed by PM2.5 remain understudied, particularly in developing countries.

Key Findings and Research Implications
Overall, this analysis reveals that PM2.5 exposure is closely associated with the risk of neurological disorders such as dementia and Alzheimer's disease. The study also identifies opportunities for advancing research in Indonesia, where air pollution levels in several major

cities exceed safe thresholds. The results demonstrate a significant relationship between PM2.5 concentrations and cognitive decline among populations living in high-pollution areas. These findings align with previous studies linking air pollution to reduced cognitive function, but differ from Maher et al. (2016), which focused solely on short-term pollution exposure; the present study provides stronger evidence of long-term impacts on brain health[37-39].

Evidence that air pollution affects not only the respiratory system but also causes cognitive impairment highlights the urgent need to strengthen air pollution control policies in major Indonesian cities to safeguard brain health, particularly among the elderly, who are more vulnerable to cognitive decline. Additionally, longitudinal research or long-term monitoring is required to produce evidence-based outcomes that can inform more effective health policies addressing air pollution and its neurological effects.

Suggested future research topics include "The Impact of Air Pollution on Cognitive Impairment Risk among Urban Populations in Indonesia" or "The Relationship between PM2.5 and Oxidative Stress in Brain Tissue: A Case Study in Highly Polluted Indonesian Cities." This research also opens avenues for in-depth investigations into other pollutants, such as ultrafine particles, which, despite limited current research, may have significant potential to impair brain function[40].

One limitation of this study is its geographical scope, which only includes major cities with high air pollution levels. Therefore, the findings may not fully represent conditions in rural areas or regions with low air pollution.

CONCLUSIONS AND RECOMMENDATIONS

This study reveals that air pollution has a significant impact on brain health and also has direct implications for the development of evidence-based policies for environmental health in Indonesia. This research successfully mapped the trends and patterns of studies related to air pollution and its impact on brain health using a bibliometric method with the assistance of Harzing's Publish or Perish and VOSviewer applications. Based on the analysis of 200 publications obtained from the Scopus database, there was a significant increase in the number of publications in 2020 and 2021, reflecting the growing global attention to the relationship between air pollution and brain health risks, particularly amid the increasing environmental health problems.

The United States, China, and several European countries became the main contributors in this research, with publications dominated by original articles. Cluster analysis showed five main topics that became the focus of research, including the relationship between air pollution and depression, neuroinflammation, and neurodegenerative development. This study shows that PM2.5 has a significant impact on the risk of neurological disorders, such as dementia and Alzheimer's disease. Keyword visualization also indicated that air quality, dementia risk, and the impact of pollution on mental health are the main topics in this research.

Air pollution, especially PM2.5, has a significant impact on the decline of cognitive function. These findings emphasize the need to improve air pollution control policies in Indonesia to protect public brain health. In addition, further research is needed to explore the long-term effects of air pollution on brain health, particularly in more vulnerable populations such as children and the elderly.

In Indonesia, research on the impact of air pollution on brain health is still very limited, and even the direct link between pollution exposure and neurological disorders has not been extensively examined in depth. This indicates a significant research opportunity, as well as a novelty to develop studies related to this topic. To address the limitations of data in Indonesia, future research can adopt low-cost sensor-based air quality monitoring methods that are easier to implement in major cities. In addition, a cohort approach involving brain health monitoring in individuals with high pollution exposure can help identify direct relationships between air quality and neurological risks in urban environments.

Based on these findings, the recommendations that can be proposed are:
(1)Strengthening air pollution control policies, including restrictions on emissions from motor vehicles and industries; (2)Increasing public awareness of the dangers of air pollution to brain health; (3)Developing further research that examines the impact of air pollution on various age groups and other vulnerable groups.

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