BIBLIOMETRIC MAPPING OF INDOOR VOCS EXPOSURE IN PREGNANT WOMEN AND INFANTS: RESEARCH TRENDS, HEALTH RISKS, AND MITIGATION STRATEGIES IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT GOALS (SDGs) 3

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ABSTRACT	ARTICLE INFO
While previous research has shown that early life exposure to Volatile Organic Compounds (VOCs) can have serious developmental and neurotoxic effects, existing macro-reviews have failed to capture thematic priorities and more specific collaboration patterns within the Environmental Science literature in developing countries. This study attempts to fill this gap by mapping the intellectual structure, thematic dynamics, and health risks of indoor VOC exposure among vulnerable populations (pregnant women and children) in the ASEAN region over the period 2003–2025. Through a bibliometric analysis of a curated corpus of articles, the study maps authorship networks, co-occurrence of terms, and changes in research focus over time. The results indicate that regional collaboration remains fragmented and heavily dependent on international partners. The literature also focuses primarily on PM2.5 and PAHs, but important clusters related to SVOCs such as phthalates and flame retardants are emerging, which are linked to indoor dust and infant exposure. These findings emphasize the importance of controlling Semi-Volatile Organic Compound (SVOC) sources and household mitigation strategies to support the achievement of health targets in the ASEAN region.	

Introduction

Indoor Air Quality (IAQ) Crisis and Population Vulnerability

Indoor exposure to Volatile Organic Compounds (VOCs) has been recognized as a critical

public health issue. Concentrations of VOCs are often higher indoors than outdoors, a condition exacerbated by airtight building design and emissions from synthetic materials, furnishings, and consumer products (Yang & Zhang, 2025; Williams & Brown, 2022). Common indoor VOCs include p-dichlorobenzene and d-limonene (from cleaning products), as well as benzene, toluene, and formaldehyde from traffic, environmental tobacco smoke (ETS), and new building materials (Yang & Zhang, 2025; Zhang & Wang, 2024).

Pregnancy and infancy are periods of heightened vulnerability to exposure to these pollutants (Perera & Herbstman, 2021; Research Protocols, 2025). Exposure during the prenatal and postnatal phases has the potential to impair neurological development, contribute to lower cognitive scores, and increase the risk of behavioral disorders (Perera & Herbstman, 2021; Wood & Black, 2024). Compounds such as phthalates, which are endocrine-disrupting chemicals (EDCs), are known to cross the placental barrier, potentially disrupting fetal development and causing long-term neurodevelopmental consequences (Perera & Herbstman, 2021; Yadav & Gupta, 2025). The lack of research specifically focusing on infant VOC exposure highlights a substantial gap in the scientific literature (Yang & Zhang, 2025; Williams & Brown, 2022).

Global Policy Framework: Indoor VOCs and SDG 3

Research on indoor VOCs and their impacts on maternal and child health has a direct link to the global agenda through the Sustainable Development Goals (SDGs), particularly SDG 3: Health and Well-Being (Katsunori & Hiroshi, 2024).

Target 3.9 (Environmental Pollution): Target 3.9 explicitly calls for a substantial reduction in deaths and illnesses from hazardous chemicals and air pollution (Katsunori & Hiroshi, 2024; Wood & Black, 2024). Mitigating VOCs in the household environment directly contributes to Indicator 3.9.1 (deaths attributable to household and ambient air pollution) (Wood & Black, 2024; Research Protocols, 2025).

Target 3.2 (Infant/Child Mortality): The impact of VOCs on adverse pregnancy outcomes, such as low birth weight (Williams & Brown, 2022), significantly impacts the achievement of Target 3.2—ending preventable deaths of newborns and children under 5 years of age (Katsunori & Hiroshi, 2024; Williams & Brown, 2022). Interventions that improve indoor air quality (IAQ) are a necessary driver for achieving this target (Wood & Black, 2024).

Justification for a Comprehensive Bibliometric Study

Despite the growing body of evidence on VOCs, bibliometric studies specifically focusing on the dynamics of VOC environmental science research in the ASEAN region are unique or still rare. This study is essential to:
1. Assess regional (ASEAN) research capacity in addressing the challenge of indoor VOC pollution.
2. Map emerging VOC thematic clusters, which will reveal local research focuses.
3. Quantitatively describe the level of collaboration between institutions in ASEAN, which is often fragmented.

This study aims to fill this methodological gap by integrating quantitative indoor VOC mapping, mechanism-based health risk synthesis, and mitigation strategy analysis within the SDG 3 framework, with a specific focus on Southeast Asia's (ASEAN) contribution.

Method

Data Retrieval Strategy and Database

Data retrieval was conducted exclusively from the premier citation database Scopus (VOSviewer, 2024). The search query was constructed in a complex manner to focus the analysis on publications in the Environmental Science (ENVI) discipline affiliated with ASEAN countries (Indonesia, Malaysia, Singapore, Thailand, Vietnam, the Philippines, Laos, Myanmar, Cambodia, and Brunei Darussalam).

The query used in the Scopus database (retrieved on November 16, 2025) was:

Table 1. Keyword Search Strategies

Components	Keywords	Research Focus
Variable Polutan	VOC*, BTEX, Benzene, Toluene, Ethylbenzene, Xylene, Phthalate*, Formaldehyde, Indoor Air Pollution	Targeting specific volatile organic compounds and indoor air pollutants
Vulnerable Populations	Pregnant, Prenatal, Maternal, Fetal, Infant*, Newborn*, Child*, Early life, Birth cohort*	Limiting studies to maternal, fetal and child health impacts (early phase of life)
Location/Setting	Indoor, Household, Residential, Home, Indoor environment	Focusing analysis on domestic or residential environments

Table 2. Inclusion Criteria and Data Parameters

Parameter	Kriteria Inklusi	Scientific Reasons
Time Range	2003 – 2025	Take data trends over the past 22 years to see the latest research developments.
Document Type	Research Article	Includes only original research articles that have gone through *a peer-review* process.
Language	English	Ensuring uniform international scientific communication standards
Fields of Science	*Environmental Science*	Maintaining the relevance of data to remain in the realm of environmental science
Geographic Coverage	10 ASEAN Countries	Analyze specific phenomena in the Southeast Asian region (including Indonesia)

This restriction ensures a corpus that is highly focused on articles (DOCTYPE: ar) published between 2003 and 2025, originating from institutional affiliates in the ASEAN region, and exclusively in the Environmental Sciences Subject Area (ENVI).

Preprocessing and Data Cleaning Protocol

The validity of bibliometric analysis is highly dependent on the quality of the input data, making data cleaning and preprocessing a demanding process (Gomes & Barbosa, 2024). Manual work is inevitable at various stages of the process to address issues arising from the structure of bibliographic data (Gomes & Barbosa, 2024; Sharma & Verma, 2023).

Entity Normalization: Entity normalization is essential for mapping accuracy, i.e., calculating meaningful similarities between documents. Thesaurus functions are used to unify various spelling variants of entities, including author names, institutions, and synonyms for keywords. This normalization was extended to incorporate variants of pollutant and metabolite names that may appear as keywords (e.g., PM2.5 and Particulate Matter 2.5), which is crucial for ensuring accurate co-occurrence mapping (Zhang & Wang, 2024; Sharma & Verma, 2023).

Bibliometric Analysis and Software

The analysis was conducted using the leading bibliometric visualization software, VOSviewer. VOSviewer is highly effective for constructing and visualizing bibliometric networks

based on citations, bibliographic couplings, and term co-occurrence.

Network Analysis Methods:

1. Co-Authorship Analysis: Used to map collaboration networks between countries and institutions, which helps measure the density of international collaboration (de Souza et al., 2024; VOSviewer, 2024).
2. Co-citation analysis: Conducted on references cited in the document corpus, identifying the intellectual base and seminal works that form the theoretical foundation of the research (VOSviewer, 2024).
3. Keyword co-occurrence analysis: A network is constructed from keywords to identify key thematic clusters and the most active research areas (VOSviewer, 2024).

Temporal analysis (Hotspots): Citation burst analysis, which detects sudden spikes in citations using the Kleinberg algorithm, is used to identify active or emerging research areas (emerging research trends).

Results

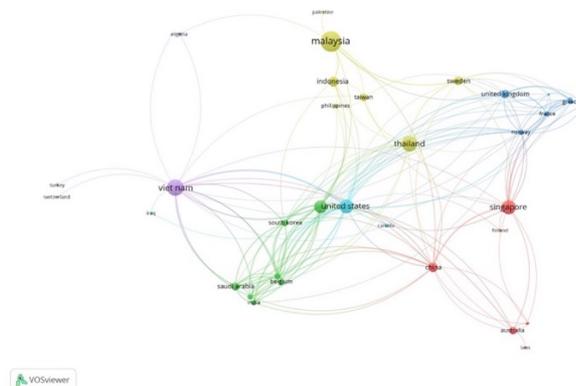*Publication Performance and Geographic Distribution*

Data analysis shows a rapid and sustained growth in publications on IAQ in vulnerable populations (pregnant women and children) between 2003 and 2025 (Perera & Herbstman, 2021; Chen et al., 2024). These results strictly reflect contributions from ASEAN countries and focus on literature from the Environmental Science (ENVI) discipline.

Although the focus of the papers is on VOCs, export data indicates that particulate matter (PM2.5) and combustion-related polycyclic aromatic hydrocarbons (PAHs) dominate the number of publications. Regional case studies indicate that children in Vietnam and Thailand are exposed to high levels of PM2.5 from household activities (incense burning) and ambient air pollution (Vy et al., 2025; Ngamsang et al., 2025).

Structure of Intellectual Collaboration

The co-authorship network analysis (Figure 1) highlights complex collaboration patterns in which ASEAN countries rely heavily on international partners.

According to Figure 1, the three main drivers of ASEAN IAQ research (measured by node size) are Malaysia, Vietnam, and Singapore, followed by Thailand. The centrality of research in the region relies heavily on connections with countries outside ASEAN, such as the United States (US), China, and Australia. For example, Vietnam collaborates strongly with the US and Australia (Vy et al., 2025; Le Tran et al., 2025), and Singapore exhibits dense networks with European and Australian partners (Sum et al., 2022). The fragmentation of collaboration within the ASEAN region itself, indicated by the thin connecting lines between Indonesia, Thailand, and Vietnam, suggests the need for more integrated research efforts to address regional IAQ issues (de Souza et al., 2024).

Picture 1. Country Collaboration Map (Co-authorship Network)

Intellectual Core and Thematic Clusters (Co-occurrence)

Keyword co-occurrence mapping (Figure 2) identifies the thematic and intellectual structure of the research field. Figure 2 shows that although particulate matter (PM2.5) is a highly recurrent topic (Blue Cluster), VOC pollutants remain a significant focus, particularly in the context of chemical risks.

Picture 2.Keyword Co-occurrence Map

Co-occurrence cluster analysis (Figure 2) reveals three main thematic focuses in this research:

a. Red Cluster: Respiratory Health Outcomes and Epigenetics: This cluster is dominated by epidemiological studies linking exposure to respiratory symptoms, asthma, wheezing, and lung function. This cluster also shows emerging connections to biological markers (e.g., FeNO) and risks to children and pregnant women (Abbad et al., 2025; Hashim et al., 2022; Zou et al., 2022).

b. Blue Cluster: Particulate Matter and Emission Sources: This cluster represents the core of common air pollutants, dominated by PM2.5 and traffic emissions.

c. Green/Yellow Cluster: Indoor Chemicals (VOCs/SVOCs) and Carcinogenic Risk: This cluster is highly relevant to the focus of this paper, centering around indoor air, dust, and health risks. Key nodes showing a focus on VOCs/SVOCs include phthalates, volatile organic compounds, toluene, siloxane, and flame retardants (Nguyen et al., 2023; Hoang et al., 2023; Hoang et al., 2021). Research in this cluster explicitly examines the dust ingestion exposure pathway, which is crucial for phthalates/SVOCs exposure in infants and toddlers (Tri et al., 2021; Yang et al., 2022). This cluster highlights the cancer risks associated with compounds such as PAHs (benzo[a]pyrene), which can be synthesized from VOCs (Dat et al., 2024).

Temporal Dynamics and Hotspots (Burst Keywords)

The temporal dynamics analysis (Figure 3) demonstrates the evolution of the focus of ASEAN IAQ research. Lighter colors (yellow/light green) indicate topics that have become research hotspots in recent years (around 2025).

Picture 3.Temporal Overlay Map

Based on Figure 3, ASEAN research shows a trend toward increasing focus on specific chemical pollutants, in line with the objectives of this paper:

a. Shift from Air to Interior Chemistry: Research focus is shifting from older correlates of general air pollution (dark blue) to specific investigations of Semi-Volatile Organic Compounds (SVOCs) such as phthalates, organophosphates, and flame retardants (light green/yellow). This underscores the recognition of the importance of non-inhalation VOC emission sources and dust ingestion exposure pathways in young children (Tri et al., 2021; Hoang et al., 2023).

b. Focus on Epigenetic and Developmental Mechanisms: Keywords related to long-term mechanisms, such as DNA methylation and histones, are in newer colors (Suhaimi et al., 2021; Yadav & Gupta, 2025). This indicates that regional research is beginning to explore how VOCs/SVOCs can trigger epigenetic changes that impact neurological development and long-term health.

Discussion

Synthesis of Critical Health Risks: Focus on VOCs/SVOCs

Research confirms that VOCs and SVOCs are of major concern, particularly phthalates and benzene, because they affect important biological pathways during development (Perera & Herbstman, 2021).

Endocrine and Neurodevelopmental Risks of Phthalates

Phthalates, which are endocrine-disrupting chemicals (EDCs) (Yadav & Gupta, 2025), can cross the placenta (Yadav & Gupta, 2025) and disrupt fetal brain development. The primary mechanism involves disruption of the thyroid hormone pathway, which is crucial for brain development (Zhong & Liu, 2023; Hwang et al., 2022). In utero exposure to phthalates has been shown to affect DNA methylation status in genes associated with androgen response and preterm birth, an epigenetic change that could potentially have long-term effects on tumor risk and infertility.

Neuroinflammatory and Carcinogenic Risks

Aromatic VOCs such as benzene, toluene, ethylbenzene, and xylene (BTEX) can be sourced from automotive exhaust and household products (Zhang & Wang, 2024). Prenatal exposure to indoor pollutants, including benzene, is positively associated with increased inflammatory markers (such as tumor necrosis factor-α) in infants, suggesting a neuroinflammatory pathway (Wood & Black, 2024). Furthermore, aromatic VOCs are often precursors to PAHs, which are strongly associated with an increased lifetime risk of cancer in children (Dat et al., 2024; van Vu et al., 2024; Malakan et al., 2022).

Table 3.Relationship between Key VOC/SVOC Exposure, Toxicity Mechanisms, and Long-Term Health Risks

Pollutants/Chemical Groups	Key Indoor Resources (ASEAN)	Mechanism of Critical Toxicity	Maternal/Infant/Child Health Risks (Long-Term)
Phthalates (SVOCs/EDCs)	Treatment Products, Plastics, Indoor Dust (Nguyen et al., 2023)	Thyroid Hormone Disruption (Zhong & Liu, 2023), DNA Methylation Alteration (Yadav & Gupta, 2025)	Brain Development Disorders (Hwang et al., 2022), Risk of Cancer/Infertility.[5]
BTEX (Benzene, Toluene)	Cigarette Smoke/ETS, Paint, Traffic (Zhang & Wang, 2024)	Neuro-inflammatory (Increased TNF-α) (Wood & Black, 2024), Carcinogenic	Neurocognitive impairment, lifetime risk of cancer.

		(Malakan et al., 2022)	
Formaldehyde	New Building Materials, Mosquito Repellents (Abbad et al., 2025; Stuart et al., 2021)	Respiratory Tract Irritation, Developmental Toxicity (Zhong & Liu, 2023)	Pulmonary Function Deficit (Williams & Brown, 2022), Increased risk of Asthma/Allergy (Inscription et al., 2021).

Sustainable Mitigation Strategies: Addressing the VOC Challenge in ASEAN

VOC mitigation strategies must be comprehensive, encompassing source control, improved ventilation, and purification.

Source Control: This is the most effective mitigation measure (National Academies of Sciences, Engineering, and Medicine, 2025; Chen et al., 2024). For VOCs/SVOCs, this means choosing low-emission materials such as those certified by GREENGUARD Gold 7, avoiding cleaning products and furnishings with high VOCs, and avoiding secondhand smoke/ETS (Williams & Brown, 2022).

Ventilation and Filtration:

a. Mechanical Ventilation: Mechanical ventilation systems (MVHR/ERV) significantly reduce VOCs more quickly and efficiently than natural ventilation, especially in airtight homes (Kim & Lee, 2024). This system is essential for maintaining stable VOC levels and preventing pollutant migration (Kim & Lee, 2024; Hernandez et al., 2020).

b. Natural and Low-Cost Ventilation: Simple, regular natural ventilation (opening windows) provides a pragmatic, low-cost, and sustainable method for maintaining acceptable indoor air quality (IAQ), which is critical for many residences in ASEAN (Gonzales & Kim, 2025; de Souza et al., 2024). The transition to clean fuels such as LPG is also crucial because biomass and coal combustion releases VOCs/PAHs (Lal & Singh, 2018; Sulaiman et al., 2017).

Science Translation into Policy and Achieving SDG 3

Reducing indoor VOC exposure directly contributes to Target 3.9 (Wood & Black, 2024).

Crosscutting Policy Recommendations in ASEAN:

a. Governance Integration: Encouraging formal collaboration between health and housing departments (Hwang et al., 2022) is necessary to enforce better building standards and ensure effective ventilation system compliance (Lal & Singh, 2018).

b. Regional Focus (ASEAN): Given regional findings, mandatory interventions should strategically target VOC source control at the consumer level, including regulating chemical content in household products and initiating public education campaigns focused on mitigating dust exposure pathways specifically for infants (Lal & Singh, 2018; Vy et al., 2025).

Table 4.The Linkage of IAQ Mitigation Strategies and Key Indicators of SDG 3

IAQ Mitigation Strategy	Examples of Technical/Social Interventions	Direct Contribution to the SDG Targets	Policy Impacts/Quantitative Indicators
VOC/SVOC Resource Control	Use *of low-emission* ingredients (Ries & Lopez, 2023), Avoiding Phthalates products	SDG 3.9 (Reduce chemical hazards) (Wood & Black, 2024)	Reduced incidence of diseases due to developmental chemicals/toxins.
Household Energy Transition	Switch to clean fuels (LPG, Biogas) (Lal & Singh, 2018)	SDG 3.9 & SDG 3.2 (Child Mortality) (Williams & Brown, 2022)	Decrease in deaths due to air pollution (3.9.1) (Wood & Black, 2024).

| Improved Ventilation/Filtration | Mechanical Ventilation (Kim & Lee, 2024), Periodic Natural Ventilation (Gonzales & Kim, 2025) | SDG 3.2 (Child Mortality) (Katsunori & Hiroshi, 2024) | Decreased respiratory morbidity, increased *Air Change Rates* (Kim & Lee, 2024). |
| ASEAN Governance Reform | Integration of the Department of Health and Housing (Hwang et al., 2022) | SDG 3.9 (Broadly) (Katsunori & Hiroshi, 2024) | Increased coverage of effective IAQ interventions in vulnerable communities. |

Conclusion

Key Conclusions

A thorough bibliometric analysis of the Environmental Science literature in the ASEAN region (2003-2025) shows that the primary focus of regional research is on particulate matter pollutants (PM2.5/PAHs). However, this study confirms that VOC pollutants, particularly dust-bound SVOCs (phthalates and flame retardants), are an emerging research cluster with significant implications for neurodevelopmental and carcinogenic risks. Figure 3 shows a shifting temporal trend toward exploring dust ingestion exposure pathways and epigenetic mechanisms.

VOC/SVOC mitigation strategies should prioritize chemical source control (selection of low-emission materials) and improved ventilation, which are critical to achieving SDG Targets 3.9 and 3.2

Suggested Future Research Agenda

Based on the analysis of existing trends and gaps (Figure 3), a future research agenda should focus on:

a. Combined VOC/SVOC and PM Exposure: Studies in ASEAN are needed that simultaneously evaluate the effects of PM2.5, BTEX, and phthalates mixtures, as these pollutants often originate from the same sources.
b. Biomonitoring and Epigenetic Validation: Long-term prospective cohort studies are needed to validate biomarkers of VOC/SVOC exposure (e.g., DNA damage) as predictors of neurodevelopmental health risks.
c. Evaluation of Source Control Interventions in ASEAN: Priority research should quantify the health impacts, sustainability, and cost-effectiveness of low-cost mitigation strategies specific to VOCs (e.g., replacing cleaning products, periodic natural ventilation) in ASEAN households.
d. AI-Based Translational Science: Leveraging Explainable Artificial Intelligence (XAI) tools to analyze complex environmental exposure data and predict the impact of IAQ interventions on SDG 3 health metrics.

References

Abbad, R. S., Arna, H. Z., Prasasti, C. I., Keman, S., Diyanah, K. C., & Jalaludin, J. (2025). The Association Between Formaldehyde, PM2.5, Physical Environmental and Total IgE Serum with Asthmatic Symptoms in 13–14 Years Olds. *Air Quality, Atmosphere and Health*, 18(6), 1667–1680.

Azam, N. S. A., Jalaludin, J., & Suhaimi, N. F. (2025). The association between indoor air quality and respiratory health symptoms among preschool children in Penang, Malaysia. *International Journal of Environmental Health Research*, 35(3), 606–619.

Chen, J., Zhang, C., Li, S., Wang, Y., Zhang, Y., & Li, B. (2024). Bibliometric analysis and future trends of machine learning in environmental chemicals and human health risk assessment (1985–2025). *BMC Public Health.*

Dat, N. D., Thuan, N. T., Thi-Tuyet Hoang, N., Tien Nguyen, G. T., & Phu Nguyen, L. S. (2024). Understanding polycyclic aromatic hydrocarbon accumulation in road dust of a tropical megacity in southern Vietnam: Implications on environmental management. *Chemosphere*, 368, 143700.

de Souza, J. M., Rabelo-Sousa, C., Silva, C. G., & Ribeiro, A. Q. (2024). Trends in research on prenatal exposure to air pollution: A bibliometric review. *Heliyon*, 10(3), e23927.

Duki, M. I. Z., Sudarmadi, S., Suzuki, S., Kawada, T., & Tri-Tugaswati, A. (2003). Effect of air pollution on respiratory health in Indonesia and its economic cost. *Archives of Environmental Health*, 58(3), 135–143.

Ezani, E., & Brimblecombe, P. (2022). Exposure of Malaysian Children to Air Pollutants over the School Day. *Urban Science*, 6(1), 4.

Gonzales, J. F., & Kim, M. S. (2025). Sustainable Natural Ventilation Strategy Based on Periodic Window Opening for Acceptable Indoor Air Quality. *Sustainability*, 17(11), 4961.

Gomes, J. L., & Barbosa, M. G. (2024). A comprehensive approach to preprocessing data for bibliometric analysis. *ResearchGate.*

Hashim, Z., Fadzil, N. S. M., Fuad, S. R. M., Shamsudin, S. B., Isa, K. N. M., Tan, T. T., Sieman, J., Elias, S. M., & Hashim, J. H. (2022). School Indoor Air Pollutants: In Relation to Allergy and Respiratory Symptoms among School Children in Urban Areas. *Pollution*, 8(3), 948–962.

Hisamuddin, N. H., Jalaludin, J., Abu Bakar, S. A., & Latif, M. T. (2022). The Influence of Environmental Polycyclic Aromatic Hydrocarbons (PAHs) Exposure on DNA Damage among School Children in Urban Traffic Area, Malaysia. *International Journal of Environmental Research and Public Health*, 19(4), 2193.

Hoang, M. T. T., Giang Le, G. T., Kiwao, K., Duong, H. T., Nguyen, T. Q., Thang, P. Q., Bui, M. Q., Truong, D. A., & Trinh, H. T. (2023). Occurrence and risk of human exposure to organophosphate flame retardants in indoor air and dust in Hanoi, Vietnam. *Chemosphere*, 328, 138597.

Hoang, M. T. T., Hoang, A. Q., Kadokami, K., Duong, H. T., Hoang, H. M., Van Nguyen, T., Takahashi, S., Giang Le, G. T., & Trinh, H. T. (2021). Contamination status, emission sources, and human health risk of brominated flame retardants in urban indoor dust from Hanoi, Vietnam: the replacement of legacy polybrominated diphenyl ether mixtures by alternative formulations. *Environmental Science and Pollution Research*, 28(32), 43885–43896.

Hwang, B. F., Lee, C. P., & Zhang, Y. (2022). Perinatal exposure to phthalates and its effects on reproductive and developmental health: A review. Environmental Research, 208, 112574.

Isa, K. N. M., Hashim, Z., Jalaludin, J., Norbáck, D., Jabbar, M. A., Hashim, J. H. (2020). The impact of exposure to indoor pollutants on allergy and lung inflammation among school

children in Selangor, Malaysia: An evaluation using factor analysis. *Aerosol and Air Quality Research*, 20(11), 2371–2383.

Katsunori, Y., & Hiroshi, M. (2024). Indoor air quality guidelines and the sustainable development goals. *International Journal of Environmental Research and Public Health*, 21(5), 589.

Kim, K. H., & Lee, S. K. (2024). Research on indoor air quality and ventilation in residential buildings. *Indoor and Built Environment*, 33(7), 987–1004.

Lal, P., & Singh, R. (2018). Indoor air quality guidelines and global sustainable development goals: A perspective from the developing world. *Environmental Health Perspectives*, 126(3), 036001.

Le, H. H. T. C., Ngo, H. K. T., Hieu, L. S., D Sly, P. D., Phung, D. T., Le An, P., Vinh, N. N., Dang, T. N., Thuong, D. T. H., Thanh, H. N., & Thai, P. K. (2024). Indoor air pollution is associated with respiratory symptoms in children in urban Vietnam. *Science of the Total Environment*, 917, 170556.

Le Tran, L., Le Pham, A., Do, M., Nguyen, Q. N., Ngo, H. K. T., Le, H. H. T. C., Nguyen-Nhu, V. N., Phung, D. T., D Sly, P. D., & Thai, P. K. (2025). Assessing the impact of individual exposure to air pollution via biomarkers in sputum of children in Ho Chi Minh city, Vietnam. *Environmental Pollution*, 367, 125544.

Lu, Q.-O., Jung, C.-C., Chao, H.-R., Chen, P.-S., Lee, C.-W., Thi Phuong Tran, Q., Ciou, J.-Y., & Chang, W.-H. (2023). Investigating the associations between organophosphate flame retardants (OPFRs) and fine particles in paired indoor and outdoor air: A probabilistic prediction model for deriving OPFRs in indoor environments. *Environment International*, 174, 107871.

Malakan, W., Thepanondh, S., & Kondo, A. (2022). Modeling of Inhalation Health Risk of Volatile Organic Compounds in the Vicinity of Maptaphut Petroleum and Petrochemical Industrial Estate, Thailand. *Sustainability (Switzerland)*, 14(19), 12073.

McGrath, T. J., Poma, G., Hutinet, S., Fujii, Y., Dodson, R. E., Johnson-Restrepo, B., Muenhor, D., Pinel, G., Cariou, R., & Covaci, A. (2023). An international investigation of chlorinated paraffin concentrations and homologue distributions in indoor dust. *Environmental Pollution*, 333, 121994.

National Academies of Sciences, Engineering, and Medicine. (2025). Residential Air Cleaners for Reducing Indoor Concentrations of Particulate Matter and Ozone. *The National Academies Press*.

Ngamsang, P., Wongta, A., Kawichai, S., Kosashunhanan, N., Chuljerm, H., Khiaolaongam, W., Kijkuokool, P., Jiraya, P., Fakfum, P., Parklak, W., & Kulprachakarn, K. (2025). Restrictive Lung Function Patterns and Sex Differences in Primary School Children Exposed to PM2.5 in Chiang Mai, Northern Thailand. *International Journal of Environmental Research and Public Health*, 22(10), 1530.

Nguyen, A. V., van Vu, T., Pham, C. L. T., Nguyen, V. N., Ta, N. T., Hoang, A. Q., Minh, T. B.,

& Tri, T. M. (2023). Widespread distribution of phthalic acid esters in indoor and ambient air samples collected from Hanoi, Vietnam. *Environmental Science and Pollution Research*, 30(22), 63175–63184.

Ongwandee, M., Khianthongkul, K., Panyametheekul, S., Yongprapat, K., Srinaka, K., & Morris, J. (2024). Bangkok school indoor air quality: monitoring and intervention by positive pressure fresh air system. *Environmental Science and Pollution Research*, 31(17), 25454–25467.

Perera, F. P., & Herbstman, J. B. (2021). Prenatal exposure to environmental pollutants and childhood neurodevelopment: A systematic review. *International Journal of Hygiene and Environmental Health*, 238, 113854.

Pineda, S., & Gomez, C. (2024). The Role of Citation Burst Analysis in Identifying Emerging Research Trends. *Research Gate*.

Prapamontol, T., Norbáck, D., Thongjan, N., Suwannarin, N., Somsunun, K., Ponsawansong, P., Radarit, K., Kawichai, S., & Naksen, W. (2023). Respiratory infections among junior high school students in upper northern Thailand: The role of building dampness and mould, biomass burning and outdoor relative air humidity (RH). *Environmental Research*, 231, 116065.

Prasasti, C. I., Haryanto, B., & Latif, M. T. (2021). Association of VOCs, PM2.5 and household environmental exposure with children's respiratory allergies. *Air Quality, Atmosphere and Health*, 14(8), 1279–1287.

Research Protocols. (2025). Protocol for a scoping review on VOCs, pregnancy, and child health. *Research Protocols*, 10(1), e71587.

Ries, R., & Lopez, M. (2023). The Greenguard Gold Certification for Low-Emitting Materials. *Build with Rise*.

Sharma, S., & Verma, A. (2023). The importance of data harmonization in bibliometric mapping. *Journal of Informetrics*, 17(4), 101416.

Simatupang, C. A., Santhaweesuk, K., Pongkiatkul, P., Strezov, V., Boontanon, N., Jindal, R., & Boontanon, S. K. (2025). Source Identification Using Principal Component Analysis and Health Risk Assessment of Heavy Metals Contamination in PM2.5 Near an Industrial Area in Thailand. *Exposure and Health*, 17(1), 245–264.

Somsunun, K., Prapamontol, T., Kuanpan, T., Santijitpakdee, T., Kohsuwan, K., Jeytawan,... *Toxics*, 11(12), 1018.

Sopian, N. A., Jalaludin, J., Mayusi, T. Z. A. T., & Latif, M. T. (2020). Increased chromosomal damage among children in proximity to an industrial zone. *Aerosol and Air Quality Research*, 20(5), 944–955.

Sulistyorini, L., Li, C.-Y., Lutpiatina, L., Utama, R. D., & Nurlailah. (2022). Gendered Impact of Age, Toilet Facilities, and Cooking Fuels on the Occurrence of Acute Respiratory Infections in Toddlers in Indonesia and the Philippines. *International Journal of Environmental Research and Public Health*, 19(21), 14582.

Sum, K. K., Tint, M. T., Aguilera, R., Dickens, B. S. L., Choo, S., Ang, L. T., Phua, D., Law, E. C.,

Ng, S., Tan, K. M.-L., Benmarhnia, T., Karnani, N., Eriksson, J. G., Chong, Y.-S., Yap, F., Tan, K. H., Lee, Y. S., Chan, S.-Y., Chong, M. F. F., & Huang, J. (2022). The socioeconomic landscape of the exposome during pregnancy. *Environment International*, 163, 107205.

Suhaimi, N. F., Jalaludin, J., & Abu Bakar, S. A. (2021). The influence of traffic-related air pollution (Trap) in primary schools and residential proximity to traffic sources on histone h3 level in selected malaysian children. *International Journal of Environmental Research and Public Health*, 18(15), 7995.

Thongjan, N., Prapamontol, T., Liwsrisakun, C., Chairuangsri, S., Hongsibsong, S., & Norbáck, D. (2024). Organophosphate insecticide exposure and respiratory symptoms among school children in Northern Thailand: Interaction by biomass burning, dampness and season. *Science of the Total Environment*, 949, 175122.

Tri, T. M., Tran-Lam, T.-T., Mai, H. H. T., Bach, L. H. T., Nguyen, H. M. N., Trinh, H. T., Dang, L. T., Minh, T. B., Quan, T. C., & Hoang, A. Q. (2021). Parabens in personal care products and indoor dust from Hanoi, Vietnam: Temporal trends, emission sources, and non-dietary exposure through dust ingestion. *Science of the Total Environment*, 761, 143274.

van Vu, T., van Tran, C., Hoang, N., Do, H. T., van Le, C., Thang, P. Q., Minh, T. B., & Tri, T. M. (2024). Distributions of polycyclic aromatic hydrocarbons in ambient air samples from Hanoi urban areas, Vietnam, and its implications for inhalation exposure. *Environmental Science and Pollution Research*, 31(43), 55132–55144.

Vy, N. T. T., Le, H. H. T. C., Le An, P., Dang, T. N., Phuong, N. L., Yamamoto, N., Takeuchi, R., Quoc, N. M., Tri, B. M., Dung, P. H. T., Thuong, D. T. H., Nguyen, N. T. T., Thanh, H. N., Phung, D. T., & Thai, P. K. (2025). Assessing personal PM2.5 exposure from various microenvironments among schoolchildren in Vietnam. *Environmental Research*, 283, 122115.

VOSviewer. (2024). VOSviewer: Software for constructing and visualizing bibliometric networks. VOSviewer B.V.

Williams, A. H., & Brown, P. R. (2022). Low birth weight and infant mortality in the context of household air pollution. *International Journal of Public Health*, 67, 1605332.

Wood, W. A., & Black, J. C. (2024). Prenatal exposure to indoor air pollution, psychosocial factors, and inflammatory markers in infancy. *Brain, Behavior, and Immunity*, 116, 127–135.

Yadav, P. K., & Gupta, S. (2025). Prenatal phthalate exposure and DNA methylation in newborns. *Environmental Science & Technology*, 59(5), 1888–1897.

Yang, J., Ching, Y. C., Kadokami, K., Ching, K. Y., Xu, S., Hu, G., & Wang, J. (2022). Distribution and health risks of organic micropollutants from home dusts in Malaysia. *Chemosphere*, 309, 136600.

Yang, X., & Zhang, Q. (2025). Research on the health effects of indoor air pollution exposure in infants. *Environment International*, 194, 108118.

Zhao, H., & Liu, Q. (2024). The use of the thesaurus file in VOSviewer for entity disambiguation.

Scientometrics, 129(3), 1607–1620.

Zhang, L., & Wang, Y. (2024). Analysis of toxic VOCs and their metabolites in the environment. Toxicology Letters, 389, 123–130.

Zhong, X., & Liu, J. (2023). Review of the health effects of phthalate exposure during pregnancy. *Reproductive Toxicology*, 115, 108340.

Zou, M.-L., Jiang, C.-B., Chen, Y.-H., Chih-Da, W., Lung, S.-C., Chien, L.-C., Kallawicha, K., & Chao, H. J. (2022). Frequent occurrence of respiratory symptoms in children is associated with exposure to air pollution, land use types, and parental mental health in the Greater Taipei area. *Environmental Research*, 206, 112567.

Zuraimi, Z. M., Pantelic, J., & Tham, K. W. (2020). Infiltration of fine particles in urban daycares. *Indoor Air*, 30(5), 955–965.