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Bibliometric Analysis of Nitrogen Dioxide Exposure Research Using VOSviewer

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ABSTRACT

Background: Nitrogen dioxide (NO₂) is one of the most critical air pollutants, contributing to both environmental degradation and human health risks. In recent years, research on nitrogen dioxide and its environmental impacts has grown significantly, reflecting global concern over pollution control and sustainable energy development. **Object:** his study aims to examine the trends, patterns, and thematic evolution of international research on nitrogen dioxide through bibliometric analysis, identifying key topics, publication dynamics, and emerging research directions. **Methods:** A bibliometric approach was employed using data retrieved from the Scopus databases, covering the years 2010–2025. The analysis included document types, subject areas, and keyword co-occurrence mapping generated with VOSviewer software to visualize relationships, trends, and research intensity across thematic cluster. **Results:** A total of 434 publications were identified, showing a significant upward trend from 2010 to 2025, peaking in 2017 with 34 publications (7.83%). Most were research articles (372), followed by conference papers (27) and review articles (26). The leading subject areas were Environmental Science (211 publications) and Chemistry (122). Keyword analysis revealed 15 thematic clusters, demonstrating strong relationships among nitrate, nitrite, and nitrogen dioxide, with emerging themes such as nitrate reduction and electrocatalysis in recent years. **Conclusion:** Research on nitrogen dioxide has transitioned from conventional environmental and chemical studies toward innovative topics in electrocatalytic processes and sustainable energy.

Keywords: Nitrogen dioxide, Bibliometric, VOSviewer

BACKGROUND

The growing problem of air pollution in urban and industrial areas has become one of the most significant environmental and public health challenges worldwide. Human activities, such as transportation fueled by fossil fuels, electricity generation, and industrial operations, contribute to the release of harmful gases that contaminate the atmosphere. Air pollution is composed of various pollutants, including PM₁₀ and PM_{2.5} (25%), nitrogen oxides (NO_x, 30%), ozone (O₃, 10%), volatile organic compounds (VOC, 15%), carbon monoxide (CO, 15%), as well as other gases and particles such as sulfur dioxide (SO₂), heavy metals, and polychlorinated

biphenyls (PCB, 10%) (Abeydeera et al., 2019).

One of the pollutants with significant impacts on human health is nitrogen dioxide (NO₂). This gas is a key component of nitrogen oxides (NO_x), which are produced by the combustion of fuel at high temperatures, such as in motor vehicle engines, factories, and power plants. In addition to human activities, NO₂ can also be generated through natural processes such as volcanic activity, forest fires, and biological oxidation in the atmosphere (Riviwanto & Sani, 2017).

According to the Environmental Protection Agency (EPA), the safe concentration limit for NO₂ in ambient air

is 0.053 ppm (100 $\mu\text{g}/\text{m}^3$) for an annual average and 0.1 ppm (200 $\mu\text{g}/\text{m}^3$) for short-term exposure (1 hour). If concentrations exceed these thresholds, serious health problems can arise, particularly in the respiratory system. Chronic exposure to NO_2 has been shown to increase the risk of chronic obstructive pulmonary disease (COPD), asthma, pulmonary fibrosis, and cardiovascular diseases (Asmoay & Mabrouk, 2024).

Exposure to NO_2 begins at the port of entry, which includes the upper respiratory tract such as the nose, pharynx, and larynx, then progresses down to the trachea, bronchi, and eventually reaches the alveoli. In the alveoli, NO_2 diffuses across the alveolar membrane and enters the bloodstream. Once inside the body, NO_2 undergoes biotransformation into both active and inactive metabolites, namely nitrite (NO_2^-) and nitrate (NO_3^-). Nitrite is toxic and reactive, while nitrate is relatively more stable and is excreted through the kidneys as the primary route of exit (Isowa et al., 2023).

Biochemically, nitrogen dioxide (NO_2) is a potent oxidant and belongs to the group of reactive oxygen species (ROS). Oxidants are chemical compounds capable of pulling electrons from other molecules, while ROS are highly reactive molecules that target cellular components such as proteins, lipids, and DNA. When NO_2 enters the body through the respiratory system, it triggers the formation of free radicals, such as superoxide ($\text{O}_2^{\bullet-}$) and hydrogen peroxide (H_2O_2). The production of these free radicals can lead to oxidative stress, causing damage to cell membranes, protein dysfunction, and DNA mutations. This accelerates inflammation and the decline in the function of vital organs, such as the lungs (Jaszczur et al., 2023).

The first step in enhancing research capacity on the effects of nitrogen dioxide exposure is to better understand the evolving trends in published studies within this field. Unfortunately, there has been limited publication on the historical

developments and scientific evidence in toxicology and public health related to this topic. Structured literature reviews utilizing various formal citation network analysis methods have been conducted, but the results remain quite limited, failing to demonstrate the evolution and spread of research on the health and environmental impacts of nitrogen dioxide exposure (Cunningham et al., 2022).

Given that nitrogen dioxide (NO_2) is classified as an oxidant with an oxygen atom that contains an unpaired electron (a free radical), it is highly reactive as it seeks to pair with the unpaired electron. This reactivity makes NO_2 a powerful compound that can damage other molecules in the body, such as cell membranes, proteins, and DNA, leading to oxidative stress. NO_2 is an unstable molecule that readily reacts with other substances to achieve stability. This reactivity contributes to various chemical reactions that can harm body tissues, particularly in the respiratory system. As a strong oxidant, NO_2 plays a role in generating reactive oxygen species (ROS) in the body, which damage cells and tissues. Prolonged exposure to NO_2 can lead to health issues such as inflammation, cell damage, and chronic respiratory diseases. In humans, oxidants are often in the form of ROS, including compounds like superoxide ($\text{O}_2^{\bullet-}$) and hydrogen peroxide (H_2O_2). Oxidants can have harmful effects on the body if produced in excess, such as through air pollution exposure or certain medical conditions (Zhao et al., 2020).

These factors can influence the characteristics and trends in research and publications in this area, creating a knowledge gap between understanding the literature and the practical conditions in the field of toxicology. This study aims to explore the development and evolution of research on the impact of nitrogen dioxide pollution based on bibliometric maps and research trends using Scopus data and VOSviewer software. Bibliometrics are essential for presenting data used by researchers, stakeholders, and

policymakers to improve the quality of research. It is a statistical method that analyzes quantitative research on specific topics through mathematical means (Zhang et al., 2022).

RESEARCH METHODS

Materials Method

In this study, articles were analyzed using the Scopus database, which contains 434 peerreviewed publications. Scopus is considered one of the most comprehensive and reliable databases for scholarly articles. The literature search was conducted online on November 5, 2025, using the keyword "Nitrogen Dioxide Exposure," with the search criteria set to include 'titles, keywords, and abstracts' related to the topic area. The time period for the sample selection covered articles published between 2010 and 2025.

The initial search resulted in a total of 1,536 terms associated with nitrogen dioxide exposure, including 141 terms related to nitrogen dioxide exposure literacy. From these 141 terms, 113 articles were identified as the most relevant to the topic of nitrogen dioxide exposure. The selected sample articles were then downloaded in *.csv format and processed using Microsoft Excel to examine the distribution of article citation data. Additionally, the articles were downloaded in *.ris format and processed with HistCite 12.3 software to facilitate further data analysis.

Subsequently, data analysis was carried out using VOSviewer, a software tool used for visualizing and analyzing trends through bibliometric mapping. VOSviewer allows the creation of publication maps, country maps, and journal maps based on co-citation networks. Additionally, it enables the construction of keyword maps based on shared networks and the creation of maps with multiple items. The number of keywords used in the analysis was adjusted to suit the study's requirements, and irrelevant keywords were excluded. Data

mining, mapping, and grouping of articles extracted from the database were carried out using VOSviewer software to ensure thorough analysis and visualization of the trends related to nitrogen dioxide exposure research.

Description of Materials or Research Subject

The articles analyzed were taken from the Scopus Database, which contains 434 publications; Scopus is one of the most comprehensive peer-reviewed journal databases. The literature search was conducted online on November 5, 2025, using the keyword "Nitrogen Dioxide Exposure" according to the criteria 'title, keywords, and abstract (topic area)'. The period used for sampling includes the topic of nitrogen dioxide exposure from 2020 to 2025.

In the initial search, the selected threshold resulted in 1,536 terms related to nitrogen dioxide exposure, with 141 terms concerning nitrogen dioxide exposure literacy. From the 141 nitrogen dioxide exposure terms, 113 articles most relevant to the topic of nitrogen dioxide exposure were selected. The sample articles were downloaded in *.csv format and processed using Microsoft Excel to view the distribution of article citation data. The articles were also downloaded in *.ris format and processed using HistCite 12.3 software to facilitate data analysis.

Subsequently, data analysis was performed using VOSviewer for visualization and trend analysis in the form of bibliometric mapping. VOSviewer can create publication maps, country maps, and journal maps based on networks (co-citation), build keyword maps based on shared networks, and create maps with multiple items. The number of keywords used can be adjusted as needed, and less relevant keywords can be removed. Data mining, mapping, and grouping of articles taken from the database can be done using VOSviewer software.

Research Design

The research design for this study is bibliometric analysis, a method used to quantitatively analyze and visualize the trends, patterns, and development of research on nitrogen dioxide (NO₂) exposure. Bibliometric analysis is a non-experimental approach focused on studying the structure and dynamics of academic literature. The study involves reviewing published articles, focusing on trends in nitrogen dioxide exposure research from 2020 to 2025.

The research design incorporates data mining and visualization techniques to assess the distribution and citation of articles, trends in co-citations, and keyword mapping within this specific field. A database search methodology using Scopus will be employed, and the study will involve secondary data analysis of published articles rather than experimental or primary data collection.

Research Procedure

The research procedure involves several key steps, described as follows:

1. Literature Search: The first step involved conducting a thorough literature search using the Scopus database on November 5, 2025. The search was performed using the keyword "Nitrogen Dioxide Exposure," focusing on titles, keywords, and abstracts. The period for the search was restricted to publications from 2020 to 2025.
2. Data Collection: After the literature search, 1,536 terms related to nitrogen dioxide exposure were identified, and from these, 141 terms specifically related to nitrogen dioxide exposure literacy were selected. Among these, 113 articles were identified as most relevant to the research topic.
3. Article Download: The selected articles were downloaded in *.csv format for data distribution analysis using Microsoft Excel. Additionally, the articles were also downloaded in *.ris

format for further processing with HistCite 12.3 software, which helps in organizing and analyzing citation data

4. Data Analysis with VOSviewer: The downloaded articles were analyzed using VOSviewer software for bibliometric mapping and trend analysis. VOSviewer helps create maps of publication trends, co-citation networks, keyword networks, and country-specific research. The software provides a comprehensive visualization of how nitrogen dioxide exposure research has evolved over time, revealing key areas of study and collaborations.
5. Visualization: Finally, the data collected were visualized using VOSviewer to create detailed bibliometric maps, showing the relationships between different authors, journals, and keywords in nitrogen dioxide exposure research.

Instrumen and Equipment

The following instruments and equipment were used in the study:

1. Scopus Database: The primary tool used to gather academic articles and citation data. Scopus is a comprehensive peer-reviewed journal database that provides access to a wide range of publications related to various fields, including environmental science and health.
2. HistCite 12.3: This software was used to process and analyze citation data. HistCite is a bibliometric software that enables researchers to generate citation reports and analyze citation patterns, helping in understanding how research articles influence the development of scientific knowledge.
3. VOSviewer: A software tool used for bibliometric visualization and mapping. VOSviewer enables the creation of co-citation networks, keyword maps, and publication trends. The software also allows for the identification of clusters

of related research within a given topic, in this case, nitrogen dioxide exposure.

Data Collection Methods

Data collection for this study was based on the extraction and analysis of secondary data from Scopus, which is a reliable and comprehensive database for peer-reviewed articles. The data collection process involved:

1. **Keyword-Based Search:** A keyword search for "Nitrogen Dioxide Exposure" was conducted to identify relevant articles published between 2010 and 2025.
2. **Article Selection:** Articles were selected based on their relevance to the topic, with a focus on nitrogen dioxide exposure and its health effects.
3. **Data Extraction:** Citation data and metadata, including author names, publication years, journals, and keywords, were extracted from Scopus for further analysis.
4. **Validation:** The reliability of the data was ensured through the use of Scopus, a well-established and trusted database in the academic community. The search parameters were carefully defined to capture the most relevant literature on nitrogen dioxide exposure.

Data Analysis

Details of the data analysis methods should be included. Explain the statistical techniques or other analysis methods used to interpret the data. If specific software was used for data analysis, include the name and version of the software. The data analysis process involved several steps:

1. **Initial Data Sorting:** Using Microsoft Excel, the citation data were organized to examine the distribution of articles and citation trends.

2. **Bibliometric Mapping:** VOSviewer was used to create visual maps of the research trends, cocitations, and keyword relationships in the nitrogen dioxide exposure literature. The software helped to identify the most influential authors, journals, and research areas.
3. **Keyword and Co-Citation Analysis:** VOSviewer was used to map out keyword clusters based on co-occurrence, highlighting the major research topics within the nitrogen dioxide exposure field. This allowed for the identification of emerging research areas and the relationships between various terms and themes.
4. **Trend Analysis:** By visualizing the research trends and keyword evolution over time, the analysis provided insights into how the field has progressed from 2020 to 2025

RESULTS AND DISCUSSION

The result extracted from titles, keywords, and abstracts found 434 documents consisting of 45 documents in 2025, 40 documents in 2024, 41 documents in 2023, and 40 documents in 2022.

1. Number of Publications on Nitrogen Dioxide in the Scopus Database.

A total of 434 publications related to microplastics were identified in the Scopus database within the period 2010–2025. To provide a clearer depiction of the trend, Table 1 presents the growth pattern of international research publications concerning microplastics, titled “Number of Publications on Nitrogen Dioxide in the Scopus Database”.

Tabel.1

Number of publications on nitrogen dioxide in the Scopus database

Publication Years	Number of Publication	Percentage
2025	45	10,37
2024	40	9,22
2023	41	9,45
2022	40	9,22
2021	35	8,06
2020	36	8,29
2019	36	8,29
2018	35	8,06
2017	34	7,83
2016	13	3,00
2015	15	3,46
2014	18	4,15
2013	17	3,92
2012	12	2,76
2011	12	2,76
2010	5	1,15
Total	434	100

Table 1 shows that the growth of publications on microplastics in the Scopus database from 2010 to 2025 has increased significantly, with the peak occurring in 2017, reaching 34 publications (7.83%).

2. Types of Articles in International Publications on Nitrogen Dioxide

Based on the search results for international publications on microplastics in the scopus database from 2010 to 2025, it was found that

there were 372 research articles, 27 conference papers, and 26 review articles.

3. Types of Articles in International Publications on Nitrogen Dioxide by subjek/Area

Based on the search results for international research publications on nitrogen dioxide categorized by subject or field, a total of 24 subject areas were identified, as presented in Table 2.

Table 2.

Number of Core Journals Publishing Research on Nitrogen Dioxide in the Scopus Database by Subject/Field

Number	Core Journal Name	Pubished Journal
1	Environmental Science	211
2	Chemistry	122
3	Chemical Engineering	96
4	Engineering	64
5	Materials Science	58
6	Energy	45
7	Earth and Planetary Sciences	42
8	Biochemistry, Genetics and Molecular Biology	41

Number	Core Journal Name	Published Journal
9	Agricultural and Biological Sciences	41
10	Medicine	35
11	Physics and Astronomy	25
12	Pharmacology, Toxicology and Pharmaceutics	12
13	Immunology and Microbiology	12
14	Multidisciplinary	6
15	Veterinary	3
16	Computer Science	3
17	Business, Management and Accounting	3
18	Neuroscience	2
19	Mathematics	2
20	Economics, Econometrics and Finance	2
21	Social Sciences	1
22	Psychology	1
23	Nursing	1
24	Dentistry	1

Table 2 shows that research on nitrogen dioxide has been published most frequently in journals within the field of Environmental Science with 211 publications, followed by Chemistry with 122 publications, while other subject areas each have fewer than 100 publications.

4. Mapping The Development of International Research Publications on Nitrogen Dioxide Based on Keywords (co-word Analysis)

The minimum number of relationships with terms in the use of VOSviewer was set at 10 terms. After being analysed using VOSviewer there were 15 clusters (red, green, blue, yellow, purple, orange, cyan, pink, brown, gray, light green, dark blue, light pink, beige, turquoise) that showed the relationship between one topic to another. The thickness of the connecting line indicates the strength of the topic field or keyword pair. Regardless of groups and lines, node size indicates the frequency with which a keyword or topic occurs. In bibliometric analysis, VOSviewer can display 3 different mapping visualizations, namely Fig. 1 (network visualization), Fig. 2 (overlay

visualization), and Fig. 3 (density visualization). which are explained:

- a. Topic areas based on VOSviewer using Network Visualization
In bibliometric research, topic mapping is one of the important things. All topics regarding the keywords of nitrogen dioxide exposure, in general, can be seen in Fig. 1. Figure 1 shows that the topics or keywords of, nitrite, nitrate are in cluster 5 (purple are), and nitrogen dioxide is in cluster 1 (turquoise area). This indicates that there is a close relationship between these topics .
- b. Topic areas based on VOSviewer using Overlay Visualization
Visualization of topic areas based on VOSviewer using Overlay Visualization shows trends related to research topic areas or keywords from year to year. The colours in the keywords indicate the research period; research trends on the topic of Nitrogen dioxide are primarily carried out between 2010 and early 2025. Overlay Visualization on the subject of nitrogen dioxide exposure is shown in Fig. 2. The latest research trend in 2025 is on

keyword appears in publications. The connecting lines indicate co-occurrence relationships between keywords within the same research papers.

Each color cluster represents a group of interrelated topics. For instance, the blue cluster corresponds to themes such as *carbon dioxide*, *adsorption*, and *photocatalyst*, which are mostly related to environmental chemical reactions and catalysis. The light green cluster includes *nitrogen*, *groundwater*, *climate change*, and *hydrochemistry*, focusing on environmental impacts and water quality. The purple cluster emphasizes studies on *nitrate*, *nitrite*, *oxidation*, and *ammonia*, which highlight nitrogen compound conversion processes. The red cluster is centered around *biogas*, *seawater*, and *CO₂ capture*, reflecting renewable energy and carbon management research.

Finally, the yellow cluster represents emerging themes such as *nitrate reduction* and *hydrogen evolution reaction*, which have become the latest focus in electrocatalysis studies.

Overall, this visualization shows that *nitrate*, *nitrite*, and *oxidation* have been central topics in previous studies, while recent trends are shifting toward *nitrate reduction* and *hydrogen evolution reaction*, reflecting a growing interest in clean energy conversion technologies.

2. Density Visualization (Figure 2.)

The density visualization illustrates the level of research intensity or concentration on certain topics. The color scale indicates density levels: bright yellow areas denote topics that

receive the most attention, while green or blue areas indicate lower research frequency.

From the figure 2., the brightest yellow zones are concentrated around *nitrate*, *nitrite*, *carbon dioxide*, *oxidation*, and *photocatalysis*, suggesting that these have been dominant research themes over the past decade. Light yellow also appears around *nitrate reduction* and *hydrogen evolution reaction*, indicating these are emerging and increasingly popular research directions. Meanwhile, bluish-green areas such as *biogas*, *climate change*, and *groundwater* represent supporting topics that connect across disciplines.

This pattern suggests that between 2010 and 2025, studies have largely focused on nitrogen compound conversion, oxidation reactions, and carbon emission control. The recent trend, however, shows a growing emphasis on *nitrate reduction* and *hydrogen evolution reaction* as part of efforts to advance green and sustainable energy technologies.

3. Overlay Visualization (Figure 3.)

The overlay visualization provides insight into how research trends have evolved over time. The color of each keyword represents the average year of publication — from dark blue (earlier research around 2010–2015) to green (2015–2020) and yellow (recent studies from 2020–2025).

The results indicate that early research (2010–2015) was dominated by themes such as *carbon dioxide*, *adsorption*, *photocatalyst*, and *climate change*. During 2015–2020, the focus gradually shifted toward

oxidation, ammonia, nitrogen, and pH. Interestingly, from 2020 to 2025, new emerging themes—highlighted in yellow—include *nitrate reduction, hydrogen evolution reaction, and electrocatalysis*. These topics signify a new research direction focusing on energy conversion technologies through electrocatalytic processes.

This visualization clearly demonstrates a shift in scientific focus—from climate change and carbon capture studies toward the development of electrocatalytic reactions supporting clean energy transition and carbon-neutral sustainability.

CONCLUSION

This bibliometric study provides a comprehensive overview of the characteristics, development, and research trends on nitrogen dioxide exposure from 2010 to 2025 based on data from the *Scopus* database. The findings demonstrate that research in this field has undergone dynamic changes, with notable fluctuations in publication output and thematic focus. Although the number of publications declined between 2021 and 2025, the overall trend reflects growing scientific attention to nitrogen dioxide and its environmental and health impacts.

Most publications were original research articles (approximately 70%), while the remainder consisted of non-research documents such as reviews and conference papers. Earlier studies around 2010 were dominated by topics on nitrate, whereas from 2015 to 2020, research began to emphasize nitrogen dioxide, nitrogen, and urea, showing a thematic evolution in environmental chemistry. The bibliometric approach successfully identified research clusters, collaboration patterns, and emerging keywords, offering valuable insights into the scientific landscape.

However, this study is limited by the lack of systematic analysis concerning the contributing countries, subject categories, and income levels of participating nations. Despite this limitation, the visualization and mapping results effectively illustrate the structure and interaction of major research themes. Overall, the study contributes to a better understanding of current and emerging research directions related to nitrogen dioxide exposure. It emphasizes the importance of maintaining research relevance to environmental health and public well-being, encouraging future studies to align with global sustainability and pollution reduction efforts.

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