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Mapping Trends in Air Quality Research in South Africa: A Bibliometric Analysis, 1998-2024

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Abstract

The foundation of South Africa is the Constitution, which guarantees every citizen access to a safe and healthy environment. Despite a wealth of research on lower-income households, the effects of burning wood for cooking, heating, and comfort in South African homes are also affecting the air quality; even if the government is working very hard to put measures in place to improve air quality, it will be very difficult to accommodate every household in South Africa. South Africa's low-income urban settlements focus on air quality monitoring for policy formulation and strategy building and Lack of garbage removal services and systems is another characteristic of low-income communities that exacerbates ambient air pollution levels. Based on the quantity of South African publications and citations in air quality that are listed in the Scopus and Web of Science databases, the study used bibliometric analysis to look at the country's air quality and the factors that affect it. Data was collected from 1998 to 2024; the results show that air pollution, nitrogen dioxide and emissions are causing a risk to children, and also having a high impact in causing diseases like asthma, respiratory health and climate change is playing a critical role in increasing the risk. Moreover, the word cloud reflects a growing emphasis on certain air pollutants, including NO_2, PM2.5, black carbon, and SO_2. NO_2 has been linked to substantial health implications, including respiratory disorders, asthma aggravation, and cardiovascular issues.

Keywords: Analysis Air quality, South Africa and Air pollution

1. INTRODUCTION

Global climate and ecosystems are connected to air quality, and pollution sources are a major contributor to greenhouse gas emissions [1]. Seven (7) million premature deaths from respiratory and cardiovascular diseases are caused by poor air quality [1-2], mostly in low- and middle-income nations, and is mostly caused by urbanization and inefficient burning of fossil fuels. South Africa's air quality monitoring data show high levels of air pollution in cities, raising questions about

the potential health impacts. There is a restricted data set because only 24 of the 54 African countries can monitor air quality to any extent [2]. The research also notes that only 0.8 % of African cities met the PM2.5 air quality standards set by the World Health Organization [3]. The AI-powered air-quality monitor is a groundbreaking initiative showcasing leadership in pandemic preparedness and response [4]. The climate is protected by reducing pollutants. Given its carbon-intensive economy and more than 90% primary energy demand, South Africa, the 12th largest greenhouse gas polluter in the world, has a significant role to play in combating climate change [4]. On the other hand, another contributing factor to air quality in South Africa's fire culture is that it uses wood to heat homes at all income levels, with higher-income households employing enclosed or open fireplaces for coziness and atmosphere [4-5].

Despite a wealth of research on lower-income households, the effects of burning wood for cooking, heating, and comfort in South African homes are also affecting the air quality; even if the government is working very hard to put measures in place to improve air quality, it will be very difficult to accommodate every household in South Africa [6]. According to a settlement study, 60% of individuals are unemployed and 40% of households have low incomes, which affects indoor thermal comfort in homes with concrete roofs [7]. Low-quality materials and uncontrolled indoor-outdoor air exchange are two factors that contribute to indoor pollution in informal construction structures [8]. Higher PM10 concentrations than in formally constructed homes are caused by the release or re-suspension of particles from surfaces such as walls, roofs, and flooring [9].

The South African government has introduced a carbon tax to combat air pollution from industrial complexes and plants, imposing environmental fees on companies burning carbon-based fuels under the Carbon Tax Act No. 15 of 2019 and Customs and Excise Act No. 91 of 1964 [10-12]. The carbon tax aims to encourage major carbon companies like Eskom and Sasol to adopt renewable energy technologies to combat climate change and air quality [13]. It also acknowledges the polluter pays principle, requiring those responsible for harming the environment to bear the costs of pollution and environmental damage.

According to Pedro, South Africa's low-income urban settlements focus on air quality monitoring for policy formulation and strategy building and Lack of garbage removal services and systems is another characteristic of low-income communities that exacerbates ambient air pollution levels (Department of Environmental Affairs) [14-15]. In addition, other studies reviews past bibliometric analyses on air quality, identifying gaps in research patterns and methodologies[16]. Furthermore, the advancement in bibliometric analysis emphasizes the statistical models and interdisciplinary approaches, highlighting the need for comprehensive

data-driven analysis to address the complexities of air pollution and meteorological variables.

2. METHODS

The bibliometric analysis in this study provides researchers with a structured approach to understanding air quality research trends in South Africa. The methodology follows a five-step process: data collection, data preparation, data analysis, results output, and conclusion [17-23], as illustrated in Figure 1. This structured workflow ensures a comprehensive approach to retrieving, processing, and interpreting bibliometric data, leading to meaningful insights.

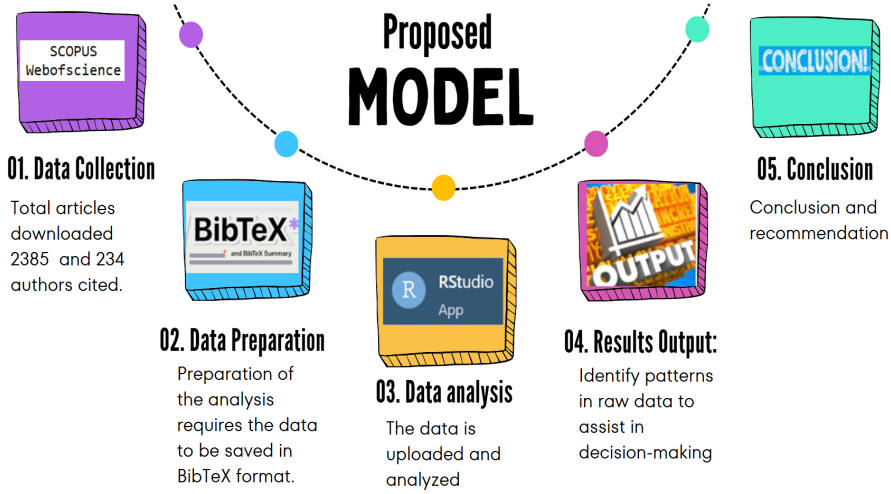

Figure 1. Bibliometric analysis of air quality research

1) Step 1: Data Collection

The first step involved collecting data from Scopus and Web of Science (WOS) using the search string "air quality in South Africa". A total of 2619 documents were identified, with 2358 publications retrieved from Scopus and 261 from WOS (Figure 1). These databases were chosen for their vast collections of peer-reviewed literature, covering over 25,000 indexed items across 7,000 high-impact journals. Their rigorous indexing and citation criteria enhance the reliability of bibliometric studies.

2) Step 2: Data Preparation

To ensure data consistency and accuracy, the Scopus BibTeX file and WOS CSV file were standardized by verifying that their tag fields matched correctly. This step

was critical for ensuring that both datasets could be merged without inconsistencies, facilitating a seamless bibliometric analysis.

3) Step 3: Data Analysis

Following data preparation, the datasets were merged in RStudio, and nine duplicate records were identified and removed. This ensured the dataset's accuracy and avoided overrepresentation of any study. Various bibliometric techniques were applied, including network visualization, co-occurrence mapping, and word cloud frequency analysis, to identify research trends and key focus areas. The screening and bibliometric analysis process is detailed in Figure 2, which illustrates how CSV data from both databases were imported into RStudio for trend analysis.

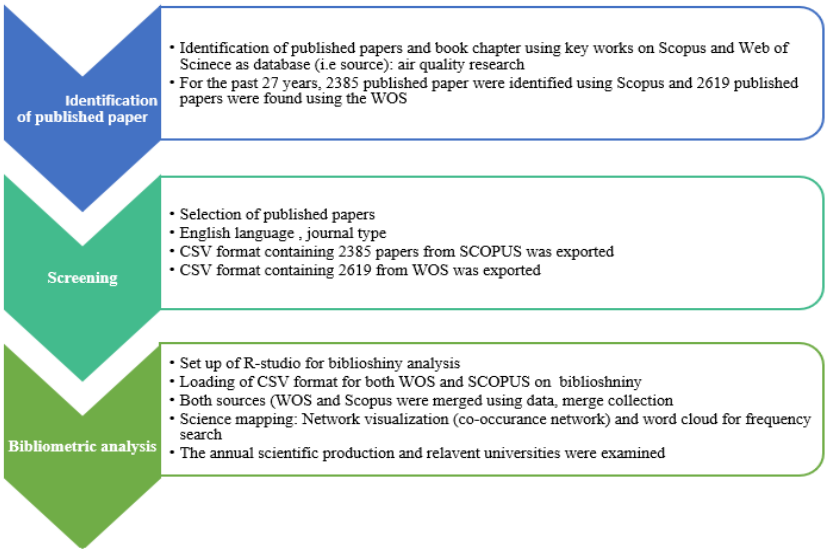

Figure 2. Step by step approach for Bibliometric analysis of air quality research

4) Step 4: Results Output

The results phase focused on identifying patterns in research output, key contributors, prominent research institutions, and thematic areas within air quality studies in South Africa. This step facilitated a deeper understanding of how the field has evolved over time, as depicted in Figure 2, which highlights the bibliometric mapping techniques used to visualize research trends.

5) Step 5: Conclusion

The final step synthesized the findings, drawing conclusions on air quality research patterns and offering recommendations for future studies. As outlined in Figure 1,

this structured workflow ensures an efficient and data-driven bibliometric analysis process, making it replicable for future research. By integrating Scopus and WOS data, standardizing formats, and applying advanced bibliometric techniques, this methodology offers a systematic, accurate, and scalable approach to analysing research landscapes. The use of RStudio enhances computational efficiency, ensuring a robust evaluation of air quality research trends in South Africa.

3. RESULTS AND DISCUSSION

Understanding air quality research trends in South Africa is crucial in addressing the growing concerns over pollution and its associated health risks. This bibliometric analysis covers studies published between 1998 and 2024, providing insights into publication trends, key research themes, collaboration networks, and institutional contributions. The findings highlight the increasing academic interest in air quality, the interdisciplinary nature of the research, and the role of universities and international collaborations in advancing knowledge in this field.

3.1. Publication Trends and Growth Rate

The analysis indicates a steady increase in air quality research output, with an annual growth rate of 6.39% (Figure 3). This reflects a rising global and regional awareness of environmental challenges and the urgency of mitigating air pollution. Furthermore, 50% of these publications involve international co-authorship, emphasizing global scientific collaboration in tackling air quality concerns. A total of 234 sources were extracted from the Scopus and Web of Science (WOS) databases, highlighting the diversity of academic contributions. The document average citation per paper is 17.78, indicating a strong academic impact and engagement with air quality research. 165 author keywords were identified, underscoring the breadth of topics covered in this research domain.

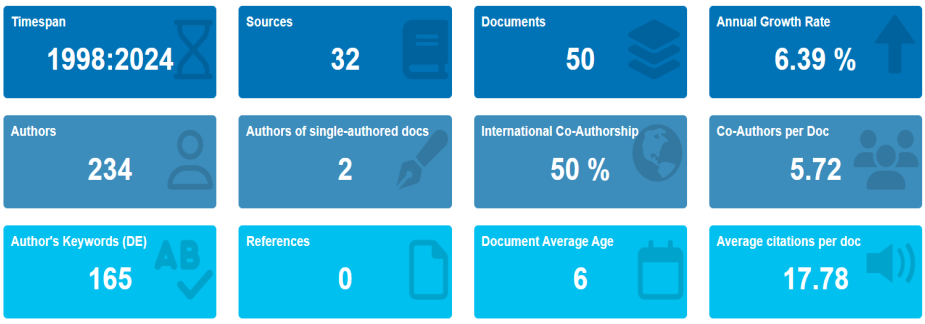

Figure 3. Summary of the results

3.2. Keyword Analysis and Research Focus Areas

A keyword co-occurrence analysis (Figure 4) reveals the most frequently explored themes in air quality research. "Pollution," "exposure," "air pollution," "particulate matter," "mortality," and "climate change" are among the most dominant terms, suggesting that health and environmental impacts of air pollution are key areas of focus. The presence of terms such as "respiratory health," "PM2.5," "black carbon," and "nitrogen dioxide" further confirms that research is strongly centered on pollutants linked to human health risks.

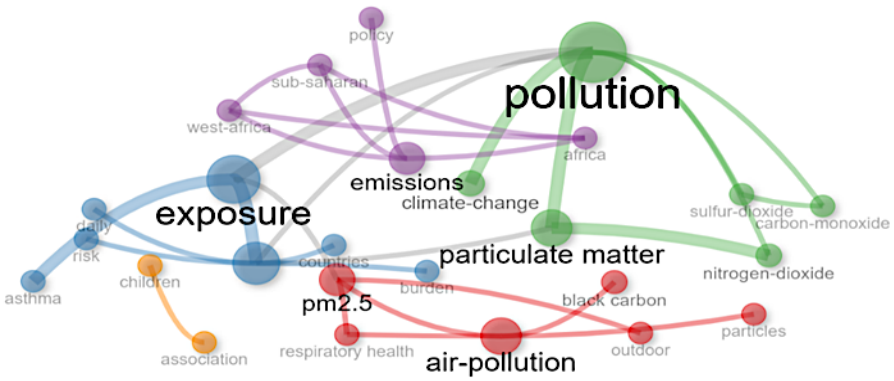

Figure 4. Co-network air quality

The network visualization in Figure 4 illustrates how these keywords are interconnected. Each node represents a distinct keyword, while lines between nodes indicate their association in the literature. The larger the node, the higher the frequency of the keyword in the dataset. The close clustering of terms such as "emissions," "climate change," and "health effects" reflects the interdisciplinary nature of air quality research, linking environmental science, public health, and urban policy.

3.3. Frequently Discussed Topics in Air Quality Research

A word cloud analysis as shown in Figure 5 further highlights frequently used terms in air quality discussions. The dominant presence of words like "pollution," "exposure," "particulate matter," "mortality," "emissions," and "climate change" reinforces the research emphasis on the health implications of air pollution. This finding aligns with global concerns that air pollution contributes significantly to respiratory diseases, cardiovascular conditions, and premature mortality. Additionally, terms such as "renewable energy" and "electrification" suggest that researchers are exploring potential solutions for mitigating pollution through clean energy technologies.

Figure 5. Frequently used word

3.4. Sustainable Solutions for Air Quality Improvement

Figure 6 presents a co-occurrence network analysis focusing on strategies to improve air quality. The terms "renewable energy," "sustainable construction," and "electrification" appear prominently, indicating that researchers are investigating alternative energy sources and urban development strategies to combat pollution. These approaches are essential in South Africa, where reliance on fossil fuels and industrial emissions contributes significantly to air pollution levels.

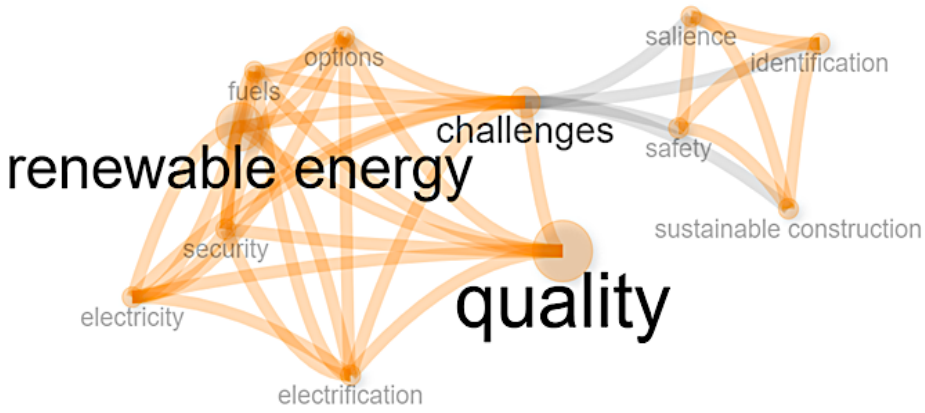

Figure 6. Co-network to sustain air quality

The presence of terms like "challenges" and "safety" in the network suggests that while these solutions hold promise, their implementation may face economic, technical, and policy-related obstacles. Thus, further research and investment in green technologies and sustainable urban planning are crucial for improving air quality in South Africa.

3.5. Top Institutions Leading Air Quality Research

An analysis of institutional contributions (Figure 7) reveals that several South African universities and research organizations are actively engaged in air quality studies. North-West University leads with 80% of published articles, followed by the University of Pretoria (73%) and the University of KwaZulu-Natal (70%). The University of Cape Town and the University of Johannesburg contribute between 60% and 70%, while the University of the Witwatersrand accounts for 55% of publications in this field.

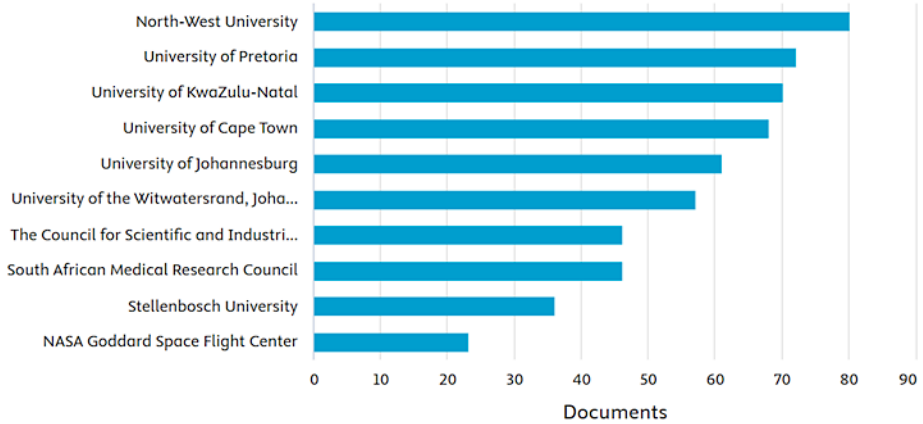

Figure 7. Top university doing research air quality

Beyond universities, research institutions such as the Council for Scientific and Industrial Research (CSIR) and the South African Medical Research Council (SAMRC) also play a crucial role, contributing 45% of research output. Additionally, international institutions such as NASA Goddard Space Flight Center and Stellenbosch University are actively involved, contributing over 20% of studies on air quality in South Africa.

The strong academic involvement in air quality research suggests that South African institutions are at the forefront of addressing environmental health challenges. However, continued funding, interdisciplinary collaboration, and policy integration are needed to translate research findings into actionable solutions for improving air quality.

This bibliometric analysis highlights the growing interest and collaboration in air quality research, with a particular focus on pollution sources, climate change impacts, and health risks. The findings reveal that academic institutions and international partnerships play a significant role in advancing scientific knowledge in this domain. The emphasis on renewable energy and sustainable urban planning suggests that researchers are actively seeking long-term solutions to mitigate air pollution.

To build on this momentum, further studies should explore the effectiveness of existing air quality policies, the socio-economic impacts of pollution, and innovative mitigation technologies. Strengthening government-academic partnerships and increasing public awareness can enhance efforts to reduce pollution and improve public health outcomes. By leveraging the insights gained from this analysis, policymakers, scientists, and environmental organizations can work together to develop evidence-based strategies that address South Africa's air quality challenges and contribute to global sustainability goals.

3.6. Discussion

The bibliometric analysis conducted in this study provides a comprehensive overview of air quality research in South Africa, revealing key trends, thematic focus areas, institutional contributions, and collaborative efforts. The findings highlight the growing significance of air quality research, particularly its intersection with public health, environmental sustainability, and climate change adaptation strategies.

The steady increase in air quality research output, as reflected by the 6.39% annual growth rate, indicates a rising awareness of pollution-related issues and a greater emphasis on environmental research in South Africa. The fact that 50% of publications involve international co-authorship suggests that air pollution is a global challenge requiring cross-border collaboration. The increasing number of peer-reviewed publications in high-impact journals demonstrates that research on air quality is gaining prominence, reinforcing the need for evidence-based policies to address pollution concerns.

A critical observation from this study is the strong presence of South African universities and research institutions in air quality research. Institutions such as North-West University, the University of Pretoria, and the University of KwaZulu-Natal lead in publication volume, highlighting their role in advancing knowledge in this field. Additionally, the participation of international institutions such as NASA Goddard Space Flight Centre suggests cross-institutional research efforts that leverage advanced technologies such as satellite monitoring and remote sensing to study air pollution trends.

The keyword co-occurrence analysis reveals that air pollution, exposure, particulate matter, and emissions are the most frequently researched topics. The prominence of "climate change" within the keyword network suggests that researchers recognize the strong correlation between air pollution and global warming, particularly in urban areas where carbon emissions and industrial pollution are significant.

Health-related terms such as "respiratory health," "asthma," "mortality," and "PM2.5" indicate that air pollution's adverse effects on human health are a major research focus. This aligns with global trends emphasizing the link between poor air quality and chronic diseases. The presence of "black carbon" and "nitrogen dioxide" in the dataset further underscores the interest in specific pollutants and their long-term environmental and health impacts.

The co-occurrence network analysis of solutions and mitigation strategies (Figure 6) highlights renewable energy, sustainable construction, and electrification fuels as potential methods for reducing pollution levels in South Africa. These strategies align with global recommendations advocating for transitioning away from fossil fuels and adopting clean energy alternatives to lower emissions. However, the presence of keywords such as "challenges" and "safety" suggests that policy implementation and infrastructure limitations may hinder the widespread adoption of these solutions. Economic constraints, energy security concerns, and regulatory barriers continue to be significant obstacles that policymakers must address to ensure the successful deployment of sustainable air quality improvement initiatives.

The institutional analysis (Figure 7) indicates that South African universities and research centres are making substantial contributions to air quality studies. However, collaboration with government agencies and industries remains essential to bridge the gap between scientific research and policy implementation. While universities are at the forefront of publishing high-impact studies, the translation of research findings into regulatory actions and enforcement mechanisms remains a challenge. Moreover, the need for improved public awareness and education on air quality issues is evident. Strengthening environmental education programs, promoting citizen engagement in air monitoring, and enhancing community resilience to air pollution can help create a more informed society capable of advocating for cleaner air policies. While this study provides valuable insights into air quality research trends, several gaps remain that require further exploration:

1) Policy Effectiveness Studies: More research is needed on the effectiveness of air quality regulations and interventions in South Africa to assess their real-world impact.
2) Technological Innovations: Studies on smart air pollution monitoring systems, AI-driven predictive modelling, and IoT-based air quality sensors could enhance data collection and pollution forecasting.

3) Socio-Economic Impacts: Understanding the economic burden of pollution-related diseases and the social disparities in air pollution exposure is crucial for developing equitable environmental policies.
4) Climate Adaptation Strategies: Research should focus on how urban planning, green infrastructure, and nature-based solutions can mitigate pollution in highly industrialized areas.

4. CONCLUSION

Air quality monitoring data in South Africa reveals high levels of pollution in urban areas, raising serious concerns about its potential health impacts. This study employed bibliometric analysis to examine South Africa's air quality research trends, focusing on publication output, key research themes, and contributing institutions based on Scopus and Web of Science (WOS) data from 1998 to 2024. The findings indicate that North-West University leads in air quality research, contributing 80% of published articles, followed by the University of Pretoria (73%), the University of KwaZulu-Natal (70%), and the University of Cape Town and the University of Johannesburg (60%–70%). Additionally, the University of the Witwatersrand (55%), along with research institutions such as the Council for Scientific and Industrial Research (CSIR) and the South African Medical Research Council (SAMRC) (45%), play a significant role. Stellenbosch University and NASA Goddard Space Flight Center also contribute over 20% of research on air quality.

In terms of thematic focus, the results highlight that air pollution, nitrogen dioxide emissions, and particulate matter are significant risk factors, particularly for children's health. Exposure to these pollutants has been linked to asthma, respiratory diseases, and broader climate change impacts, which further exacerbate health risks. Given the strong correlation between pollution and adverse health outcomes, urgent policy interventions, sustainable energy solutions, and enhanced public awareness are needed to mitigate these effects. These findings emphasize the critical role of academic and research institutions in advancing knowledge on air quality. Future efforts should focus on strengthening interdisciplinary collaboration, enhancing policy implementation, and promoting innovative air quality monitoring and mitigation strategies to ensure a healthier and more sustainable environment in South Africa.

CONFLICT OF INTEREST DECLARATION

The authors further assert that conflicting financial or personal interests may not have affected any of their findings.

DATA AVAILABILITY

If requested, data will be provided

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