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# Improving performance of air quality monitoring: a qualitative data analysis

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**ABSTRACT**

This research aims to improve performance of air quality monitoring and understand the latest relevant technological developments. Employing the Kitchenham systematic literature review (SLR) method, the study examines 436 journal articles and conference proceedings published from 2019 to 2023, sourced from the Web of Science (WoS) and Scopus databases. The analysis was carried out using Leximancer 5.0 and identified research five themes; i) air quality, ii) artificial intelligence (AI), iii) pollution, iv) middleware, and v) smart environment. The results showed that only 48 journals had strict inclusion and exclusion criteria include relevance to the research theme, methodological quality, and contribution to the research field. In addition, this research integrates AI and middleware, which has significantly contributed to improving air quality. These findings can become the basis for the development of air quality monitoring technology that is more sophisticated and responsive to environmental needs. This research contributes to further understanding air quality monitoring technology trends and designing solutions to improve overall air quality.



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## 1. INTRODUCTION

Air quality monitoring has long been of primary importance in environmental health and public policy [1], [2]. In the era before the emergence of advanced technology, air quality monitoring and analysis approaches relied heavily on manual methods [3]. Initially, monitoring was carried out through direct observation and periodic collection of air samples, which were then analyzed in the laboratory to determine the concentration of various pollutants [4]. These classical methods are often limited in sampling frequency, which impacts the ability to understand and respond quickly to changes in air quality [5], [6]. At that time, fixed air quality monitoring stations, although providing accurate data, were only able to measure air conditions at specific locations. This creates difficulties in obtaining a comprehensive picture of the regional or global distribution of air pollutants [7], [8]. Additionally, the analytical tools available at that time often required complex and time-consuming procedures, limiting the ability of researchers and policymakers to make rapid, data-driven decisions [9]. This research challenge addresses the severe impacts caused by air pollution on a large scale, including complex phenomena such as smog and industrial air pollution. In this context, particular emphasis is needed on developing technology that can provide a rapid response and effective in responding to increasingly pressing air quality problems [10], [11]. The approach tends to be reactive rather than proactive, emphasizing mitigating impacts after an air pollution event occurs. Standards and guidelines from international organizations such as the World Health Organization (WHO) are a reference in measuring and controlling air pollution, especially in large cities, which is a significant concern because its negative impacts are limited to human health and environmental and economic stability [12], [13].

This traditional monitoring is also often limited in integrating air quality data with other variables, such as methodology and demographics, which are now crucial in understanding air quality dynamics and their impacts [14], [15]. As technology has developed and there has been a deeper understanding of the importance of air quality, monitoring methods and tools have evolved significantly [16]. The transition to an era of advanced technologies in air quality monitoring, such as internet of things (IoT) sensors, extensive data analysis, and machine learning algorithms, has opened new opportunities for more efficient, accurate and comprehensive monitoring [17]. In addition, this research will explore how transitioning from traditional methods to approaches based on advanced technology has changed how we monitor, analyze and respond to air quality issues. A key focus is understanding how technological advances can be further used to overcome existing challenges in monitoring air quality and protecting public health and the environment [18].

There is a gap in previous research investigating the use of technology in air quality monitoring. However, while these research findings have explored the effectiveness of current technologies, they have not explicitly addressed the integration of advanced technologies such as artificial intelligence (AI) and middleware in air quality monitoring [19]. Therefore, there is a gap in understanding of the extent to which such advanced technologies can improve monitoring and response to air pollution. Although previous findings have examined the technologies and methods used in air quality monitoring, they may not have specifically explored the qualitative aspects of the data collected. This includes how the data is used, understood, and interpreted by different stakeholders such as researchers, policy makers, and the general public. Therefore, there is a gap in the literature in depth in qualitative analysis of air quality monitoring data to improve monitoring system performance. This research shows that evaluating the effectiveness of current technologies in identifying and responding to air pollution events is important for better air quality management in the future. In comparison with other studies, this study emphasizes the role of more sensitive sensors and sophisticated data processing in improving responses to air pollution. In addition, it also highlights the need to take environmental and social factors into account in the evaluation of technology effectiveness, which can impact the sustainability of implemented solutions. The research design, as presented in Figure 1, was developed using specific three components: research problem (RP), research question (RQ), and research objectives (RO).

| RESEARCH COMPONENT | DESCRIPTION | |
|---|---|---|
| Research Problem (RP) | RP1 | How conventional air quality monitoring methods, which are often limited in geographic coverage and frequency, impact our ability to understand and respond to air quality dynamics in a timely manner. |
| | RP2 | The degree of negative impact of air pollutants on human health and the environment, especially in dense urban areas. |
| | RP3 | Challenges in responding quickly and effectively to large-scale air pollution events, such as smog and industrial disasters. |
| Research Question (RQ) | RO1 | How can the latest technologies, such as IoT sensors, big data analysis and AI, improve the air quality monitoring and analysis process. |
| | RO2 | How can technology be used to predict air pollution events and facilitate more effective prevention measures. |
| | RO3 | How can integration of data from various sources help in a more comprehensive understanding of air quality and its impact on human health and the environment. |
| Research Objectives (RO) | RQ1 | Developing technology-based solutions that can increase the accuracy, coverage and speed of air quality monitoring. |
| | RQ2 | Provides in-depth analysis of how air pollutants affect human health and the environment, with the aim of informing policy and mitigation strategies. |
| | RQ3 | Formulate recommendations for action strategies to overcome air quality problems. |

Figure 1. Research design

RP focuses on the challenges faced by traditional air quality monitoring methods. These methods, are often limited in geographic reach and need more data integration difficulties, impacting their effectiveness in responding to changes in air quality and large-scale air pollution events such as smog and industrial pollution. Then, identify the need to overcome approaches that tend to be reactive rather than proactive in dealing with air quality problems, including identifying primary pollutant sources. The RQ revolve around how using advanced technologie, such as IoT sensors, big data analytics, and machine learning, can improve air quality monitoring and analysis. How these technologies can help faster and more effectively respond to large-scale air pollution incidents and how they influence our approach to understanding and managing air quality in urban environments. RO develops a more profound understanding through systematic literature review (SLR) of how advanced technology can be used to improve air quality monitoring. The aims research to value the effectiveness of current technologies in identifying and responding to air pollution events and develop data-based policy recommendations for better air quality management in the future. The SLR approach seeks to identify knowledge gaps, build strong understanding, and formulate effective and efficient strategies for researchers, policymakers and practitioners facing the challenges of urbanization and globalization. This approach is expected to provide new insights and innovative solutions for handling air quality problems in the current era of advanced technology.

The focus on SLR aims to identify knowledge gaps, build solid understanding, and formulate recommendations for future research. Thus, the SLR approach is expected to provide a solid foundation for researchers, policymakers, and practitioners to plan, implement and understand air quality research more effectively and efficiently in facing the complex challenges large cities face in the era of globalization and continued urbanization. Beyond a conventional literature review, this research adopts a qualitative data analysis approach, delving into the intricate details of the selected publications. It seeks to discern not only the relevance and methodological quality of the existing research but also the contributions these studies make to the overarching field of air quality monitoring. As a distinctive feature, this study integrates qualitative data analysis with a focus on the identified research themes, emphasizing the role of AI and middleware in the improvement of air quality monitoring.

Underpinning this research is the comprehensive support for advancing air quality monitoring systems, encompassing environmental science, data analysis, and cutting-edge technology. At the heart of these advances is the integration of advanced technologies such as AI and middleware, which are poised to revolutionize the accuracy and responsiveness of air quality monitoring systems. This research underlines the importance of a qualitative analytical approach, which complements insight into air quality; it involves systematically identifying air quality problems and establishing questions and related objectives that guide structured exploration of the topic. A systematic research design is critical to this endeavour, as it outlines clear protocols for data collection, analysis, and interpretation, allowing for actionable insights to be derived. The integration of these technologies holds the promise of significant advancements, contributing to the development of more sophisticated and responsive monitoring systems. By merging a qualitative analytical approach with the latest technological insights, this research aims to provide a nuanced understanding of air quality monitoring trends. The research design systematically presents the identified problems, corresponding questions, and the set objectives, creating a structured foundation for comprehensively exploring air quality-related issues. This research is an initial step that has the potential to lead to innovative solutions to the complex challenges faced by large cities around the world in an era of rapid urbanization and industrialization [20].

The paper is structured as follows: section 2 details the criteria for database selection and the process of defining search keywords. Section 3 presents the research findings, offering a summary of insights, statistical information, and results from qualitative data analysis using Leximancer 5.0. The section also reviews any encountered limitations, ensuring transparency and context to the research. Section 4 concludes the paper by synthesizing findings, discussing implications, and suggesting future research directions.

## 2. METHOD

### 2.1. Research methods

Research used Kitchenham SLR method [21], a systematic approach that is relevant and comprehensive. The methodology shown in Figure 2, created by Alzami *et al.* [22], consists of three phases of literature reflection that can assist in planning, conducting, and reporting research [22]. This research combines a qualitative data analysis approach using Leximancer 5.0 tools with the aim of explaining insights in existing literature, contributing to a deeper understanding of the factors that influence air quality monitoring performance.

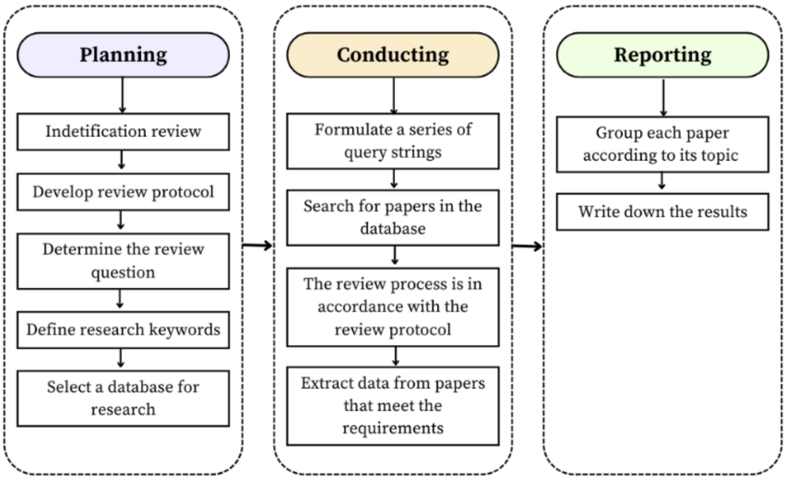


Figure 2. SLR protocol development

The first phase, “planning the review” emphasizes the importance of planning, starting with planning the review to gain a general understanding of the air quality domain. Then, a review protocol was developed to outline the literature selection process and criteria [23]. Air quality-specific RO and questions were determined, followed by the formulation of a review protocol that included inclusion and exclusion criteria [24]. Research keywords related to air quality were determined, and appropriate research databases were selected for the literature search. The second phase, “conducting the review”, concerns the execution of the review itself. A set of query strings is generated from predefined keywords, and papers are searched against relevant databases [25]. All review processes are conducted according to established protocols, ensuring consistency and accuracy. Data was then extracted from papers that met the criteria for further analysis. The third phase, “reporting the review”, focuses on presenting the results. Each paper is grouped by topic to facilitate analysis. The results of the review, including main findings and conclusions, are then documented. Overall, the Kitchenham method provides a systematic framework and structure.

### 2.1. Search string and database selection

In attempting to perform automated searches in the air quality domain, this research was faced with the major challenge of identifying relevant studies. These challenges arise due to the breadth of literature available and the variety used by researchers. This strategy was to ensure the inclusion of as many relevant papers as possible, this study decided to adopt a more general approach using search strings. This approach aims to cover a wider spectrum of relevant literature in search results. The strategy used involved applying RQ and a gradual strategy to obtain appropriate search terms.

- Identify key concepts related to air quality, such as monitoring, analysis, management, pollution impacts, and the use of AI.
- Develop a search string using a combination of keywords related to the main concepts that have been identified, as well as adapting to variations and synonyms of terms used in the literature.
- Validate search strings to ensure coverage of important aspects of the research domain and refine based on feedback from other researchers or related domain experts.

The flow diagram in Figure 3, shown in the figure illustrates a careful and structured methodological approach in academic research. First, it determines the identification of the research topic, which is a critical step in determining the focus and scope of the research. With an explicit topic in mind, the researcher then selects the most appropriate database to search for relevant literature, ensuring that the topic is explored comprehensively and from multiple perspectives by choosing the trusted and extensive databases, web of science (WoS) and Scopus, both of which are known for their wealth of scientific literature.

Identify the WoS and Scopus databases as the main sources for collecting articles related to air quality. This study integrates both databases to ensure a comprehensive literature review covering a broad spectrum. The various digital libraries available are: i) WoS [clarivate.com]; ii) IEEExplore [ieeexplore.ieee.org]; iii) Emerald [emerald.com]; iv) SpringerLink [springerlink.com]; and v) Elsevier [elsevier.com]. The search string, (“improving performance” OR enhancement OR optimization) AND (“air quality monitoring” OR “air quality”) AND (“qualitative data analysis” OR qualitative research OR qualitative study) AND (“artificial intelligence” OR AI) AND (“pollution” OR pollutants OR contaminant)

AND (“middleware”) AND (“smart environment” OR “smart cities”). This search string was designed to search for articles that discuss improving air quality monitoring performance with qualitative data analysis and focus on the use of AI in the context of air quality monitoring, pollution, middleware technology, and smart environments. Through applying this detailed search strategy, it is hoped that the study will be able to identify and include as many relevant papers as possible for further analysis of the factors influencing air quality monitoring performance.

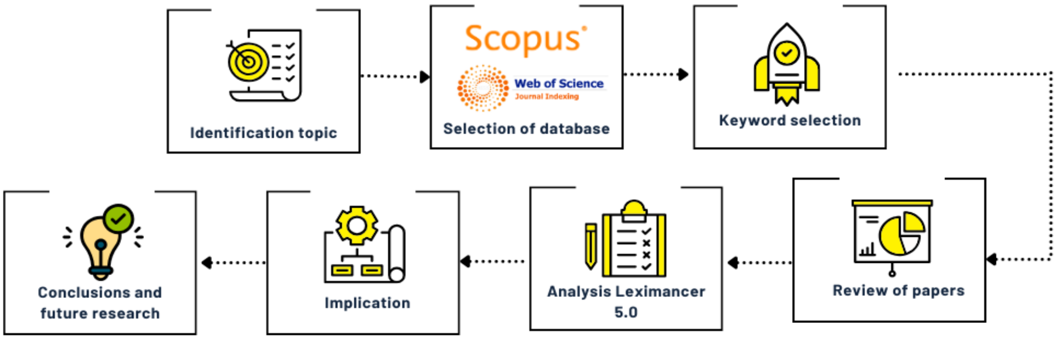


Figure 3. Research database selection

### 2.2. Review of selected article

Table 1 presents, the sample selection process which is divided based on two main criteria, namely inclusion criteria and exclusion criteria. Inclusion criteria ensure the relevance of the sample to the RQ and objectives, thereby significantly increasing the potential for research results to be applied in the context in question. On the other hand, exclusion criteria play a role in reducing bias by eliminating subjects who may have factors or conditions that could influence the research results. This stage is crucial in filtering out papers that do not fit the research focus or do not meet the specific criteria set for this review.

Table 1. Review protocol

| No | Inclusion criteria | Exclusion criteria |
|---|---|---|
| 1 | Research related to air quality monitoring | Research not related to monitoring or improving air quality |
| 2 | Qualitative data relevant to air quality monitoring | Qualitative data that is not relevant to air quality monitoring |
| 3 | Research with strategies or proposed improvements for air quality monitoring | Study without contributions or new solutions for air quality monitoring |

The approach described involves a series of detailed steps in the process of selecting relevant literature for a review of air quality. The initial broad and inclusive approach was designed to broaden the scope of the search and collect as many relevant literature sources as possible, with the aim of minimizing the risk of bias that might arise from overly restrictive search parameters. Inclusion criteria were then created to form the basis of a comprehensive literature review, which included studies of air quality modeling performance with a variety of methodologies and outcomes. Although research presented in various formats such as conferences and journals was considered, priority was given to current and complete versions to maintain data integrity. On the other hand, exclusion criteria act as a quality control mechanism by eliminating studies that do not have strong validation methods, thereby ensuring the credibility of the review. A refined screening process was carried out after the initial search to reduce order-induced bias, where the title and abstract of each study were carefully checked to ensure compliance with the research topic and review criteria. Studies that did not meet the initial criteria were then filtered out before full text assessment was carried out. This curated selection approach is key to building a focused and comprehensive literature review, thereby providing a valuable contribution to the understanding of air quality.

## 3. RESULTS AND DISCUSSION

### 3.1. Result of selected articles

The literature review process outlined in Table 2, transitioning from an initial pool of 436 articles, is a testament to the rigor and depth demanded in academic research, particularly in the fields of air quality and intelligent environmental monitoring. This process unfolds in several nuanced and carefully executed stages, ensuring that each selected article significantly contributes to the understanding and advancement of the topic. Table 3 presents, the extensive database search across multiple platforms, including the WoS and Scopus. These databases are known for their comprehensive coverage and include publications from leading publishers like IEEE, Emerald, Springer, and Elsevier. The aim at this stage is to cast a wide net, capturing a broad spectrum of academic discourse that touches upon various facets of air quality. This extensive search yields a considerable volume of potential articles, amounting to 436 papers. This large number reflects the breadth of the topic and the diverse range of research being conducted in this field.

Table 2. Summarizing selected papers

| Database initiation | Initiation | Title and abstract selection | Full paper selection |
|---|---|---|---|
| WoS | 59 | 14 | 6 |
| IEEE | 96 | 27 | 13 |
| Emerald | 47 | 19 | 4 |
| Springer | 172 | 36 | 14 |
| Elsevier | 62 | 32 | 11 |
| Total | 436 | 127 | 48 |

Table 3. Overviews of literature on air quality

| Author | Years | Method | Country |
|---|---|---|---|
| Jiang *et al*. [26] | 2023 | Deliberative dan choice experiment | China |
| Fu *et al*. [27] | 2023 | Weather Research and Forecasting | China |
| Kuang and Lin [28] | 2023 | Differences-in-differences (DID) | China |
| Wang *et al*. [29] | 2023 | Global random forest regression model | Australia |
| Zhang *et al*. [30] | 2023 | Urban development intensity-UDI | China |
| O’Regan and Nyhan [31] | 2023 | Narrative meta-review | Ireland |
| Arbilla *et al*. [32] | 2023 | Air sample collection | Brazil |
| Hama *et al*. [33] | 2023 | Perceived air quality (PAQ) | China |
| Storey *et al*. [34] | 2023 | Self-organizing maps (SOM | Australia |
| Kuiper *et al*. [35] | 2023 | Inverse treatment probability weights | USA |
| Li *et al*. [36] | 2023 | Emission process model | China |
| Munir *et al*. [37] | 2023 | Smart traffic interventions | United Kingdom |
| Pang *et al*. [38] | 2023 | Message-oriented middleware (MOM) | China |
| Yang *et al*. [39] | 2023 | Difference-in-difference (DID) | China |
| Jiang *et al*. [40] | 2022 | Fleet electrification | China |
| Cao *et al*. [41] | 2022 | Difference-in-differences strategy | China |
| Mangut *et al*. [42] | 2022 | Bluetooth low energy (BLE) | China |
| Majdi *et al*. [43] | 2022 | Proposed algorithm | China |
| Li *et al*. [44] | 2022 | Two-way fixed effects model) | China |
| Pei *et al*. [45] | 2023 | Perceived air quality (PAQ) | China |
| Meena *et al*. [46] | 2022 | Data collection | India |
| Helm *et al*. [47] | 2022 | Car scrappage scheme | Germany |
| Choi *et al*. [48] | 2022 | Natural experiment spatial difference | South Korea |
| Wang *et al*. [49] | 2022 | Regression discontinuity design (RDD) | China |
| Rao *et al*. [50] | 2022 | Geographically weighted regression (GWR) | China |
| Horn and Dasgupta [51] | 2022 | Remote procedure call (RPC) | USA |
| Mahmud *et al*. [52] | 2022 | Welch’s one-way ANOVA | Bangladesh |
| Gamboa *et al*. [53] | 2022 | Proposed algorithm | Brazil |
| Wang *et al*. [54] | 2022 | Convolutional neural network | China |
| Elbaz *et al*. [55] | 2022 | Residual network (ResNet) | China |
| Liu *et al*. [56] | 2022 | Model dubin spasial (SDM) | China |
| Pathak *et al*. [57] | 2022 | Spatial and temporal data analysis | India |
| Rios *et al*. [58] | 2022 | Data collection | Mexico |
| Zivelonghi and Giuseppi [59] | 2022 | AulaSicura platform | Italy |
| Pourkiaei and Romain [60] | 2022 | Literary analysis | Belgium |
| Beloconi and Vounatsou [61] | 2022 | Bayesian geostatistical regression models | Switzerland |
| Lee and Aghamohammadi [18] | 2022 | Cross-sectional | Malaysia |
| Tariq *et al*. [62] | 2022 | Aerosol optical depth (AOD) | Pakistan |
| Xie *et al*. [63] | 2022 | Urban surface transport index (USTI | China |
| Wan *et al*. [64] | 2022 | Weather Research and Forecasting | China |
| Liu *et al*. [65] | 2022 | Model spatial durbin | China |
| Mehmood *et al*. [66] | 2022 | Multi-pollutant profiling | India |
| Mehmood *et al*. [66] | 2022 | Bibliometric | China |
| Rowley and Karakuş [67] | 2022 | Long short-term memory (LSTM) | United Kingdom |
| Yogeswaran *et al*. [68] | 2022 | Settle plate | Malaysia |
| Cobbold *et al*. [69] | 2022 | Data survey | Australia |

The next phase involves a critical evaluation of the titles and abstracts of these 436 papers. This title and abstract screening serves as the first layer of screening. It is during this stage that the articles are assessed for their direct relevance to the core aspects of the research topic. Keywords, thematic alignment, and preliminary alignment with the RO are crucial factors in this evaluation. The screening process is both selective and exhaustive, ensuring that each article's title and abstract align closely with the research's central themes. As a result, many papers that do not meet the specific preliminary criteria are excluded, significantly reducing the pool to 127 articles. This considerable reduction is indicative of the stringent criteria applied, ensuring that only articles with the most direct relevance and potential contribution to the RO proceed to the next stage.

The full paper selection stage is where the depth and precision of the review process truly come to the forefront. Each of the 127 articles that passed the initial screening is subjected to a comprehensive full-text review. This stage is meticulous and demands a high level of critical analysis. Researchers at this point evaluate the methodological robustness, the rigor of the findings, and the overall contribution of each study to the field. Predetermined inclusion and exclusion criteria play a pivotal role here. These criteria, while not explicitly detailed, are crucial in maintaining the integrity and relevance of the review. They likely encompass the methodological soundness of the studies, the contextual significance of the findings, the reputation and impact factor of the journals in which these studies are published, and citation metrics, which serve as indicators of the influence and recognition of the research within the academic community. This thorough evaluation is also mindful of avoiding biases, such as the order effect, where the sequence of paper review might inadvertently influence selection. The process is rigorous and objective, ensuring that each paper is evaluated on it is merits. After this in-depth analysis, only 48 of the 436 articles meet the stringent standards set for inclusion. This final selection represents a collection of relevant, high-quality research with a series of carefully structured filters and this process not only ensures selection of the most relevant and high-quality articles, but also reflects rigorous academic research standards and contributes significantly to the understanding of air quality and intelligent environmental monitoring.

The results a comprehensive compilation of studies that collectively offer a deep and diverse understanding of the current state of air quality research, highlighting the breadth of the research field and the specific advances and insights that have been achieved in recent years. The findings show that several studies on air quality use middleware or AI as part of the research methodology. The use of message-oriented middleware (MOM), remote procedure call (RPC), convolutional neural network (CNN), and long short-term memory (LSTM) is seen in several studies. The application of middleware and AI reflects the diversity of technologies used to improve the performance and effectiveness of air quality analysis. Additionally, the findings show that using MOM, RPC, and deep learning algorithms such as CNN and LSTM reflects research efforts to leverage advanced technologies to overcome the complexity of air quality data and gain deep insights.

### 3.2. Description statistic

The diagram presented in Figure 4, provides a visual representation of the distribution of 48 literature articles related to a specific topic based on year of publication and country of origin between 2019 and 2023. In 2023, China showed many publications reflecting the country's particular urgency or priority concerning air quality issues. Although China stands out in the graph, other countries also show growth in their publications, although less intensively than China [70], [71]. This shows that air quality problems are not only limited to one area but are also a focus in various parts of the world. Overall, the diagram offers an in-depth look at air quality related publications' geographic and temporal distribution. Meanwhile, other countries such as Italy, Switzerland, Belgium, Arabia, Ireland, USA, South Korea, Bangladesh, Mexico, and Pakistan, each with one article recorded, reflect a stable condition in their research output. Furthermore, Brazil, Malaysia, and Australia, which each produced two articles, showed a moderate upward trend in scientific publications, which may indicate that there has been an expansion of research activities or perhaps a growing awareness and need to understand and address air quality problems in these countries. On the other hand, countries such as Spain, the UK, Germany and India, with three articles, show more intensive and consistent research, reflecting a more structured research strategy or a stronger commitment to broader and more diverse environmental issues. In addition, research shows that countries such as Italy, Switzerland, Belgium, Arabia, Ireland, the United States, South Korea, Bangladesh, Mexico, and Pakistan only have one article, which reflects the consistency of their research output. This indicates a phenomenon where there is a limitation in the number of published studies from these countries regarding air quality problems.

This research explores the impact of air pollution in several countries with a comprehensive approach involving systematic analysis. Through collecting and integrating data from various sources, including air sensor data, public health surveys, and environmental predictive models, this research was able to identify complex air pollution patterns and their impacts on human health and the environment. However, further and in-depth studies may be needed to confirm the validity of these findings. Advanced analyzes that look at larger geographies and demographics could provide more detailed insight into the health risks associated with air pollution in different populations. To overcome these limitations and their potential impact on the results, this study comprehensively explores the topic by considering various aspects. However, to ensure the validity of the findings and the accuracy of the analysis, further and more in-depth research may be needed. This is especially important in identifying concrete solutions related to air quality problems, as well as in understanding their full impact. Overall, the information presented provides a valuable perspective on how interest and focus in air quality research have developed and transformed over the observed period. This diagram also helps identify and highlight that more focused interventions and more profound research may be required to address various air quality-related challenges currently facing or emerging in the future, thereby helping policymakers, researchers, and petitioners.

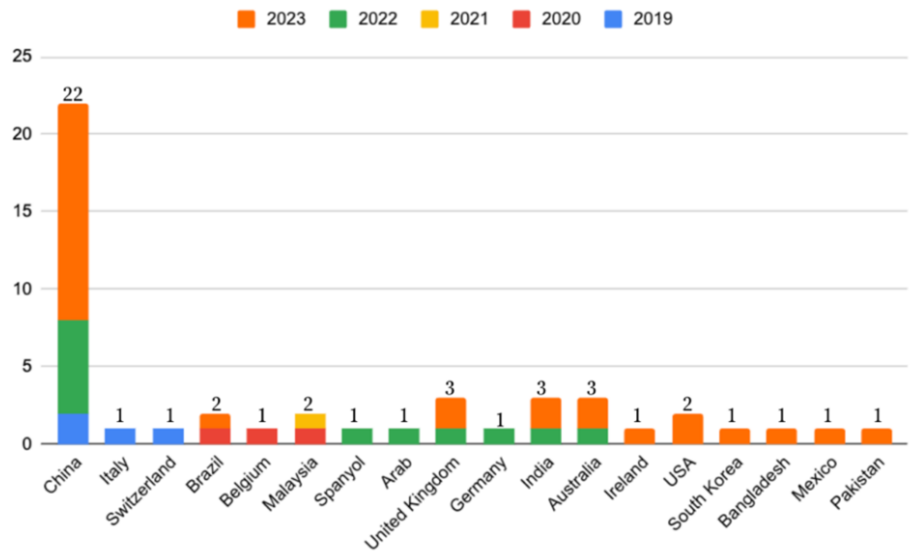


Figure 4. Number of publications per year and country

### 3.3. Leximancer results

The analysis carried out using Leximancer 5.0 aims to provide in-depth and comprehensive insight into the main themes, patterns and trends that exist in the literature related to air quality. The results of this analysis will be a strong basis for researchers in formulating conclusions, recommendations and implications for future research, as well as for policy making and practical implementation in the fields of environment and public health. Thus, the use of Leximancer 5.0 in the context of this research is key in gaining a deep and sustainable understanding of important aspects related to air quality.

In qualitative research, data analysis is often categorized into three distinct but interconnected methods: conceptual analysis, relational approach, and temporal analysis. This method systematically categorizes and quantifies specific words or phrases to understand their significance and frequency in the study context. Relational analysis, on the other hand, delves deeper by exploring the relationships and connections between these identified concepts. It seeks to uncover patterns that reveal how different themes are interrelated, often shedding light on cause-and-effect dynamics within the data. Finally, temporal analysis adds the dimension of time, focusing on how concepts, themes, or relationships evolve or are influenced over time. This approach is crucial in understanding trends, changes, and the timing of events, providing insights into how historical contexts or chronological factors impact the subject of study. Together, these three methods offer a comprehensive framework for analyzing qualitative data, each contributing a unique perspective that enriches the overall understanding of the research findings.

#### 3.3.1. Conceptual analysis

Conceptual analysis of the concept map in in Figure 5, highlights five main themes: air quality, AI, middleware, pollution, and smart environment. Through the Leximancer analysis technique, where color interpretation is used to provide conceptual meaning to each theme, there are color gradations from red which indicates urgency, to purple which may appear less frequently but is still relevant. In this analysis, the links between these themes become clear. AI and middleware play an important role in optimizing systems to monitor and reduce pollution. It illustrates how technology can help in monitoring air quality and identifying pollution sources effectively. Furthermore, the smart environment theme describes how the integration of innovative technologies can improve overall air quality, creating a healthier and more sustainable environment.

This analysis also shows how integration between AI, middleware, and environmental technologies forms the foundation for the development of intelligent environments. In this context, a smart environment not only includes technological aspects, but also focuses on sustainability and adaptation to environmental challenges. Technology, in this case, plays a key role in improving air quality and facing existing environmental challenges.

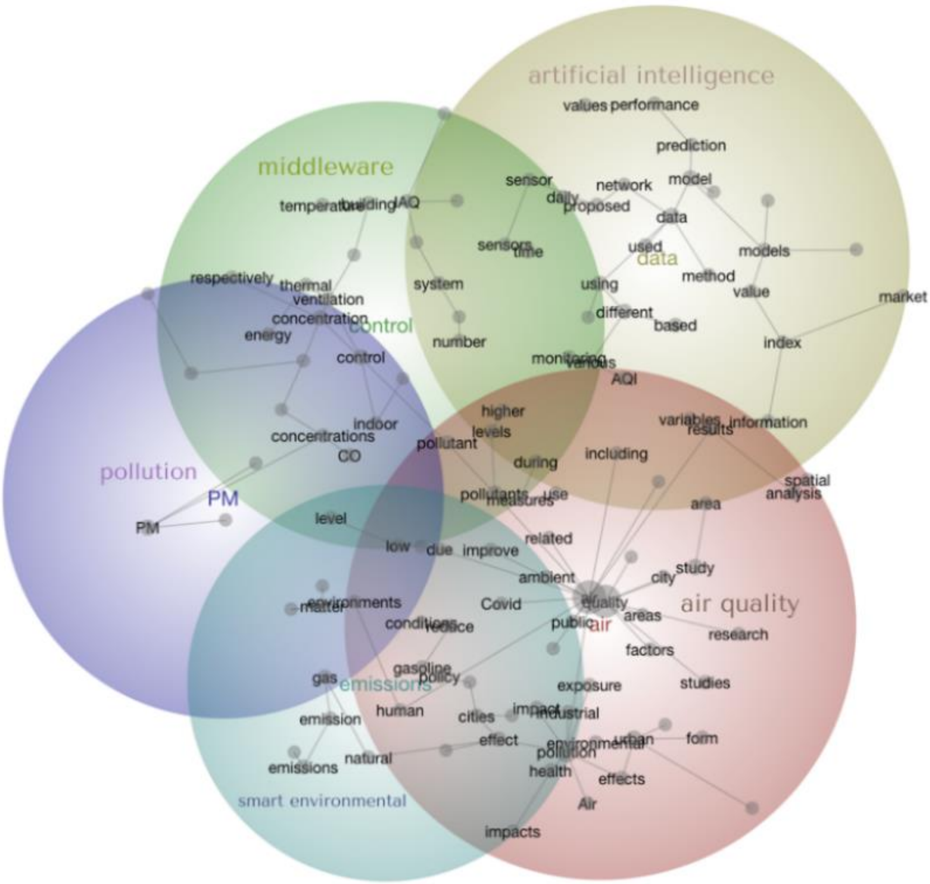


Figure 5. Concept map generated using Leximancer 5.0 software

This integration is a step towards creating smarter, more sustainable environments, where technology plays a key role in enhancing air quality and addressing environmental challenges. The conceptual analysis thus provides a comprehensive view of how various themes interlink and contribute to the broader understanding of environmental technology and sustainability. Overall, this conceptual analysis provides a comprehensive picture of the interaction and contribution of various themes to a broader understanding of technology, sustainability and environmental management. This highlights the importance of an integrated approach in addressing environmental problems, where technology, innovation and sustainability are key aspects.

### 3.3.2. Relational approach

Using Leximancer 5.0 for analysis Figure 6, offers a nuanced visualization of the frequency and relevance of the five primary themes extracted from the dataset. This visualization elucidates the prevalence of each theme within the dataset and underscores their significance in relation to the comprehensive scope of the study. The figure accentuates the most prominent themes while also delineating the interconnections between them, demonstrating that themes appearing less frequently nonetheless hold considerable importance within the broader context of the research.

The theme "air quality" dominated the analysis with 2,797 appearances, reaching the highest relevance of 100%. This shows that "air quality" is the main focus of the data set and forms the basis for other themes. This theme may include various sub-themes, such as air quality measurements, health effects, pollutant sources, and mitigation strategies. In the context of technology, "artificial intelligence" appeared 1,159 times with a relevance of 41%. This signals the importance of AI technology in understanding, monitoring, and possibly predicting air quality. The "middleware" theme, which was present 703 times with a relevance of 25%, highlights the technical and infrastructure aspects that support the processing and analysis of data related to air quality. Meanwhile, the theme "population" which appeared 525 times with a relevance of 19%, likely highlights how air quality affects human populations or how population activity can affect air quality. Finally, "smart environmental" with 521 occurrences and a relevance of 19%, denotes innovative approaches or technology-based solutions to address air quality challenges, reflecting the interaction between technology and the environment in creating sustainable solutions. The analysis results based on Figure 7, provide an in-depth overview of the research focus areas and how these themes are related to each other in the context of air quality and potential solutions to these problems.

| | Count | Relevance |
|---|---|---|
| air quality | 2797 | 100% |
| artificial intelligence | 1159 | 41% |
| middleware | 703 | 25% |
| popullation | 525 | 19% |
| smart environmental | 521 | 19% |

Figure 6. Relevance of concepts relative to each other

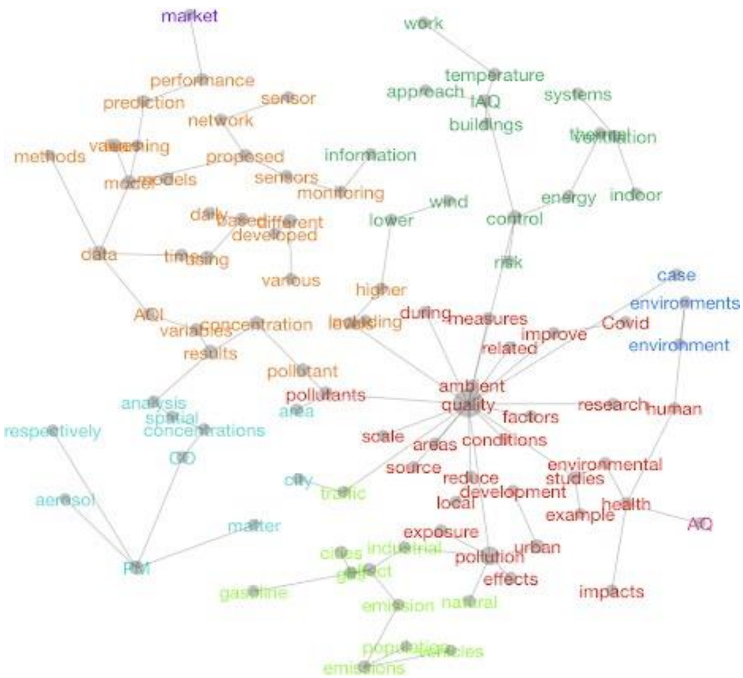


Figure 7. Visual mind map representation

The detailed Leximancer 5.0 analysis provides a justified representation of the most pertinent themes within the field of air quality research. Despite varying frequencies, each theme contributes essential insights into the collective understanding of the domain, signifying the interrelated nature of technological advances, environmental challenges, and societal impacts. The data substantiates the need for continued exploration and integration of these themes to develop comprehensive air quality management and improvement strategies.

The Leximancer 5.0 concept map resulting from qualitative data analysis in the study offers in-depth insight into the interrelationships between various factors that influence air quality [72]. The central theme of "air quality" includes concepts such as "PM" and "CO", indicating the primary focus of this research is assessing and improving the way we monitor pollutants in the atmosphere. In a technological context, the emergence of "AI" and "models" substantially indicates that there is great potential in the use of machine learning algorithms to predict and analyze air quality patterns, which can help in making data-based decisions to address pollution problems [73]. Additionally, the "middleware" that emerged in the analysis underscores the critical role of technological infrastructure in managing and processing data collected from air quality sensors. This proves the importance of systematic integration between monitoring hardware and data analysis software. Factors such as "energy" and "temperature" are recognized as variables that in- fluence air quality, both indoors and in the external environment, emphasizing the importance of monitoring conditions that influence pollutant levels [74]. The concepts of "work", "system", and "building" provide further context for how air quality monitoring is integrated into various aspects of life and infrastructure. "Traffic" and "city" in particular highlight how population concentration and urban mobility play a role in air pollution, reflecting the importance of urban environmental management solutions [75]. Then, "COVID" and "health" mark the influence of the pandemic on air quality dynamics and its public health consequences, while "environmental studies" and "sustainable development" indicate how air quality monitoring is integrated into broader initiatives to maintain ecological balance and health man. By exploring the connections between these themes, researchers can develop more informed and effective strategies for better air quality monitoring, which not only meet technical challenges but also take into account health and environmental aspects. These concept maps are an important tool in identifying unexplored areas of research and potential for innovation, which could ultimately lead to significant changes in the way we understand and address air pollution problems.

### 3.4. Discussion on limitations

The discussion section delves deeper into the limitations of this study, aiming to offer a thorough understanding of the constraints and possible biases inherent in the methodology. While selecting keywords was meticulously done, it is essential to acknowledge that this approach might introduce bias. The analysis conducted in this study brings to light a critical revelation among various factors influencing air quality. AI and middleware's role in air quality management is multifaceted and profound, from predictive analytics to real-time monitoring and control strategies. It is important to emphasize that this research highlights the major impact AI will have on air quality monitoring. AI emerged as an important theme in the research, with 1,159 accurrences and 41% relevance in the data set. This underscores the important role AI technology plays in understanding, monitoring and potentially predicting air quality. AI-based approaches, including machine learning algorithms, have revolutionized air quality management by enabling more accurate and real-time data analysis.

AI models can predict the concentration of pollutants like PM2.5, nitrogen oxides, and sulfur dioxide, allowing cities to implement preemptive measures to curb air quality deterioration. AI enhances real-time monitoring of air quality. Advanced sensors, integrated with AI algorithms, provide real-time data on pollutant levels. This constant data stream is crucial for immediate responses to air quality crises. Moreover, AI contributes to air quality research by enabling the analysis of large and complex environmental datasets. This capability facilitates the understanding of air pollution dynamics and the interaction between various pollutants and meteorological factors. Such insights are crucial in developing more effective air quality management strategies.

While discussing the impact of AI on air quality, it is essential to acknowledge the limitations in current research methodologies. The reliance on predefined keywords and subjective assessments in literature reviews, as well as potential biases in data used for AI models, can influence the conclusions drawn. However, the consistent and significant findings across multiple studies reinforce the argument that AI role in improving air quality is substantial and cannot be overlooked. AI is a new breakthrough in managing air quality, with its ability to predict, monitor, and control air pollution changing the way we understand and overcome the challenges of this environment. By continuing to perfect the AI system and overcome the bias methodology, the potential for significant global air quality improvement is increasingly achieved.

## 4. CONCLUSION

The present study conducted a SLR on air quality articles to identify research gaps and future directions. Analyzing 48 articles published from 2019 to 2023 using Leximancer, the study identified five main themes: air quality, AI, middleware, pollution, and smart environments. The theme of air quality dominated the dataset with 2,797 occurrences, emphasizing its central role in the research analyzed. Themes AI appeared 1,159 times and was highlighted as crucial for understanding and predicting air quality, while middleware, with 703 occurrences, underscored the importance of technical infrastructure in processing air quality data. Population activity, represented by 525 occurrences, indicated a significant relationship between human activities, air quality, and smart environments, with 521 occurrences showcasing the importance of innovative technologies in addressing air quality challenges. The findings stress the urgency of addressing air quality issues through collaborative and innovative solutions. They emphasize the need for developing sophisticated AI models for better predictions, optimizing middleware to ensure efficient data flow, and increasing public awareness about the impact of air quality on health and the environment. This research highlights the broad and varied implications of air quality, necessitating a multidisciplinary approach that combines expertise from data science, technology, and environmental science. Such an approach promises innovative solutions by integrating diverse perspectives and expertise. Future research should focus on developing AI models to improve the accuracy and timeliness of air quality predictions, exploring middleware optimization to ensure efficient data flow between various platforms in air quality management systems, and investigating the integration of climate change and air pollution to understand their mutual impacts and develop mitigation strategies. Additionally, research should explore policy implications of integrating technological advances with environmental science and evaluate the effectiveness of multidisciplinary approaches in shaping sustainable air quality management policies. Long-term strategies at both global and local levels, with a focus on international cooperation in air quality research and policy, are essential. By detailing and exploring these aspects, future research is expected to make a significant contribution to the understanding and management of air quality globally.

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