



Bibliometric Mapping of Environmental Factors as Determinants of Tuberculosis Transmission in Developing Countries

La Ode Asrianto¹, Hamka¹, Erma Suryani Sahabuddin¹

¹Universitas Negeri Makassar, Indonesia

*Korespondensi: asriantostikes@gmail.com

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Abstrak

This study provides a comprehensive bibliometric mapping of research related to environmental factors that contribute to the transmission of tuberculosis (TB) in developing countries. By analyzing publications indexed in major scientific databases over the past decade, the study identifies key themes, research trends, and influential scholarly contributions within this field. Environmental determinants, such as household crowding, inadequate sanitation, poor air quality, limited ventilation, and socio-economic disparities persist as major drivers of TB incidence in resource-limited settings. The bibliometric approach enables researchers to visualize collaborative networks among authors, countries, and institutions, thereby revealing how scientific communities across regions address similar public health challenges. Keyword co-occurrence analyses highlight emerging areas of interest, including urban environmental health, climate-related risks, and community-level prevention strategies. Furthermore, the mapping illustrates shifts in research focus from purely biomedical perspectives toward more holistic environmental and social determinants of health. The findings of this bibliometric analysis provide valuable insights for policymakers, researchers, and public health practitioners to strengthen targeted interventions, promote interdisciplinary collaboration, and guide future research priorities aimed at reducing the burden of TB in developing countries.

1. Introduction

Tuberculosis (TB) remains one of the most significant infectious diseases worldwide, particularly in developing countries that face limited health care facilities, high population density, and complex socioeconomic challenges. Many studies show that environmental factors such as air quality, housing density, home ventilation, humidity, sanitation, and conditions in densely populated settlements play an

important role as determinants of TB transmission, in addition to individual factors such as nutritional status and immune status (Tiwari et al., 2025). However, research on TB in developing countries has often focused more on clinical and treatment aspects, while comprehensive scientific mapping that examines trends, research themes, researcher collaboration, and the connection between environmental factors and TB transmission remains limited (Abaynew et al., 2025). Bibliometric analysis therefore becomes a strategic approach for identifying publication patterns, dominant keywords, collaboration networks, and research gaps in the topic of environmental factors and TB, providing a comprehensive overview for researchers and policy makers in formulating evidence based interventions in developing countries (Cao et al., 2025).

A number of previous studies have emphasized the importance of environmental factors in the transmission of TB. (Deng et al., 2021) stated that crowded living conditions and poor ventilation increase the risk of TB transmission, particularly in urban areas of developing countries. (Leeka et al., 2025) reported that social and environmental determinants such as poverty, population density, and housing quality contribute significantly to TB incidence in low and middle income countries. (Liu et al., 2021) found that ambient air pollution is associated with a higher occurrence of TB, indicating that the quality of the physical environment cannot be separated from efforts to control the disease. Meanwhile, (Kumar and Jain, 2022) highlighted the relationship between household conditions, occupant density, and the risk of latent TB infection, reinforcing the argument that TB control interventions must incorporate improvements in environmental conditions as an integral component of public health strategies.

Bibliometric studies on TB have been conducted, but only a limited number have specifically focused on environmental factors in developing countries. (Dorjravdan et al., 2021) conducted a global bibliometric analysis on TB research and reported an increase in publication volume, although environmental themes remain dispersed across various subtopics. (Deng et al., 2021) mapped research on multidrug resistant TB and demonstrated that bibliometric approaches are effective for revealing research trends, international collaboration, and emerging keywords. (Zhang et al., 2021) also applied bibliometric methods to analyze the global landscape of TB research and found that contributions from developing countries are still not proportional to the burden of disease they experience. These findings indicate a research gap for conducting bibliometric mapping that specifically focuses on environmental factors as determinants of TB transmission in developing countries, enabling the proposed study to contribute new insights in the form of a structured overview of the scientific landscape, thematic trends, and opportunities for future research development.

Previous research findings indicate that environmental factors such as air quality, home ventilation, humidity, sanitation, and housing density play a significant role in the transmission of TB in developing countries. However, many of these studies remain focused on local case analyses or traditional epidemiological approaches, and therefore do not provide a comprehensive understanding of how research trends, patterns, and collaborations have evolved on a global scale (Wang et al., 2022). In addition, there is a gap in the integration of environmental data with TB prediction models, as most studies still position environmental factors as supporting variables rather than primary determinants. Existing bibliometric studies

have tended to emphasize medical aspects, multidrug resistant TB, or treatment patterns, while bibliometric mapping that specifically examines environmental factors as determinants of TB transmission in developing countries is still very limited (Jang et al., 2022). This situation has resulted in the absence of an integrated knowledge map that illustrates how environmental issues are discussed, who the key research actors are, and the extent to which the existing studies support evidence based health policy making (Mtetwa et al., 2023).

One of the major challenges in understanding the relationship between environmental factors and TB transmission is the limited availability of comprehensive data, particularly consistent and standardized environmental data in developing countries. Many countries with a high TB burden do not have adequate systems for monitoring air quality, sanitation, or housing conditions, which hinders in depth analysis. Another challenge is the limited level of international and regional collaboration in examining environmental factors, even though TB transmission is strongly influenced by the dynamics of urbanization, migration, and socioeconomic structure (Phadoongmai and Jariya, 2024). In addition, environmental issues are still not considered a primary priority in TB control policies, as the focus remains predominantly on treatment and case detection. This situation highlights the need for bibliometric mapping that can identify trends, reveal disparities in research among countries, and indicate areas that remain under investigated, thereby strengthening future research directions and public health policy formulation. This study has strategic relevance because it can provide a comprehensive picture of how environmental issues are addressed in global TB research. By mapping publication trends, dominant keywords, thematic clusters, and researcher collaboration, the study can reveal the development of scientific knowledge, emerging research directions, and the multidisciplinary connections between environmental health and TB epidemiology.

The main objective of this study is to identify the extent to which environmental factors such as air quality, housing density, sanitation, and settlement conditions have become the focus of international research, and to examine how developing countries contribute to the production of scientific knowledge on the determinants of TB transmission. The findings are expected to serve as a foundation for policy makers, health institutions, and researchers in formulating evidence based TB prevention strategies that take environmental contexts into account. This study is particularly compelling because it offers a new perspective that integrates public health approaches with bibliometric analysis, a method that has become increasingly relevant in the era of scientific big data. To date, research related to TB has largely concentrated on clinical aspects, drug resistance, and treatment effectiveness, while fundamental causes such as environmental factors have received less attention within the global knowledge landscape. By selecting this topic, the researcher has the opportunity to fill an important scientific gap, especially within developing countries that possess environmental and socioeconomic characteristics very different from those of high income nations. Moreover, this study provides added value by highlighting disparities in knowledge production between countries with high and low TB burdens, and by opening new avenues for collaboration aimed at environmentally based interventions. Therefore, the selected topic is not only academically relevant but also offers direct contributions to global health policy.

2. Methods

The method used in this study is a research trend analysis approach that focuses on Environmental Factors as Determinants of TB Transmission over the past ten years, employing bibliometric mapping techniques (Asemahagn et al., 2020). This study specifically examines publications released between 2015 and 2025 in order to capture significant developments in research methods and bibliometric analytical tools that have advanced during this period. The selected timeframe also reflects the consistent increase in coverage and the comprehensive scope provided by the Scopus database, which serves as the primary data source for this study. Bibliometric analysis is chosen as the main method due to its reliable ability to trace and examine large volumes of scientific data related to a specific topic (Manna et al., 2021).

This statistical approach enables the identification of trends, patterns, and relationships among various studies, thereby providing a comprehensive understanding of research developments in this field (Kumar and Jain, 2022). Through this approach, the present study aims to offer a clear overview of the dynamics and direction of research on Environmental Factors as Determinants of TB Transmission in Developing Countries over the past two decades, which is expected to serve as a foundation for future investigations in this area.

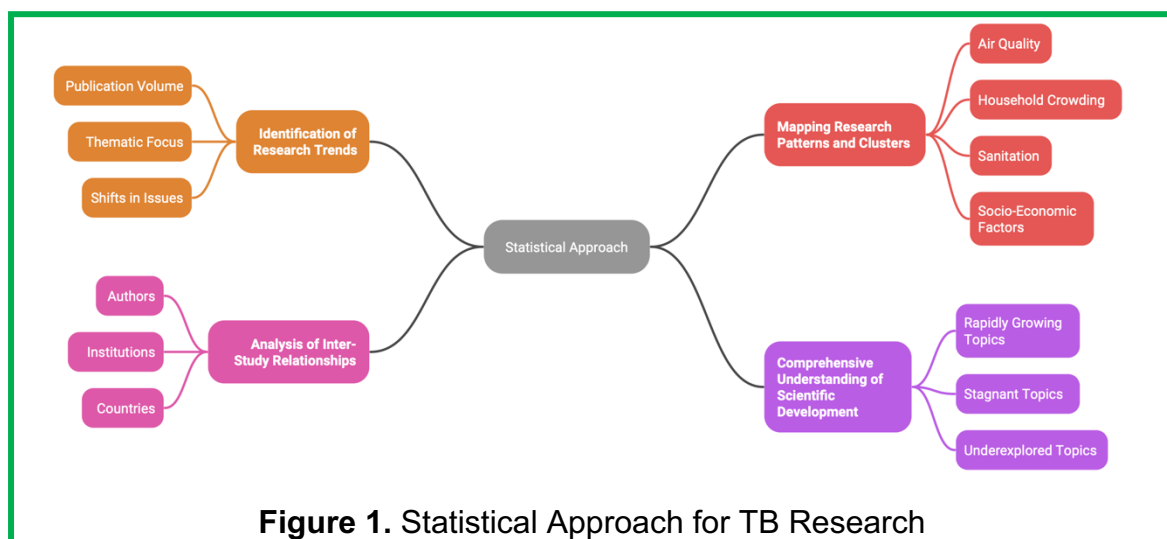


Figure 1. Statistical Approach for TB Research

The framework provides a comprehensive illustration of how statistical approaches are used to map the development of Tuberculosis (TB) research from multiple perspectives. The diagram presents the relationships among various dimensions such as publication trends, topic clusters, environmental factors, and networks of researchers, institutions, and countries. Key elements including rapidly growing topics, stagnant topics, and underexplored topics highlight the dynamic shifts in research focus, while socioeconomic factors, air quality, housing density, and sanitation are depicted as essential variables in examining TB transmission. Through the mapping of patterns and the analysis of relationships across studies, this approach generates a thorough understanding of scientific developments, research gaps, and future directions in TB research.

The data used in this study consist of primary, secondary, and tertiary journals published over more than ten years, providing a strong foundation for examining the development of Tuberculosis research. Through metric based bibliometric analysis,

this study traces publication trends, prominent themes, and the academic productivity of authors, institutions, and countries. To ensure a more focused search within indexes such as Scopus, relevant keywords were applied during the analytical process, including environmental factors and tuberculosis, determinants of TB transmission, TB research in developing countries, air quality and TB, and bibliometric analysis of TB. This diverse collection of data helps to provide a comprehensive overview of how TB related issues, particularly those associated with environmental conditions, have evolved within the scientific literature.

The findings of this study indicate a clear shift in TB research in developing countries toward analyses that position environmental factors as primary determinants of disease transmission. Variables such as air quality, sanitation conditions, housing density, and socioeconomic status appear to be the most frequently highlighted aspects across various studies. To strengthen the search process and clarify the characteristics of the research landscape, additional keywords were employed, including housing density and TB, sanitation and TB risk, socioeconomic status and TB prevalence, urban environmental health, and public health challenges in developing countries. Overall, the results of this study reaffirm that environmental factors play a crucial role in the dynamics of TB transmission and should be considered a central component in disease control strategies at both national and global levels.

This data collection framework is designed to provide a clear, systematic, and structured overview of the workflow for bibliometric research on environmental factors as determinants of tuberculosis (TB) transmission in developing countries. This roadmap serves as a guiding reference for tracing the literature, selecting keywords, conducting data screening, and extracting information from relevant publications (Laji and Asghar, 2024). With this roadmap in place, the data collection process can be carried out consistently, transparently, and in a reproducible manner, resulting in a valid and comprehensive dataset for further analysis.

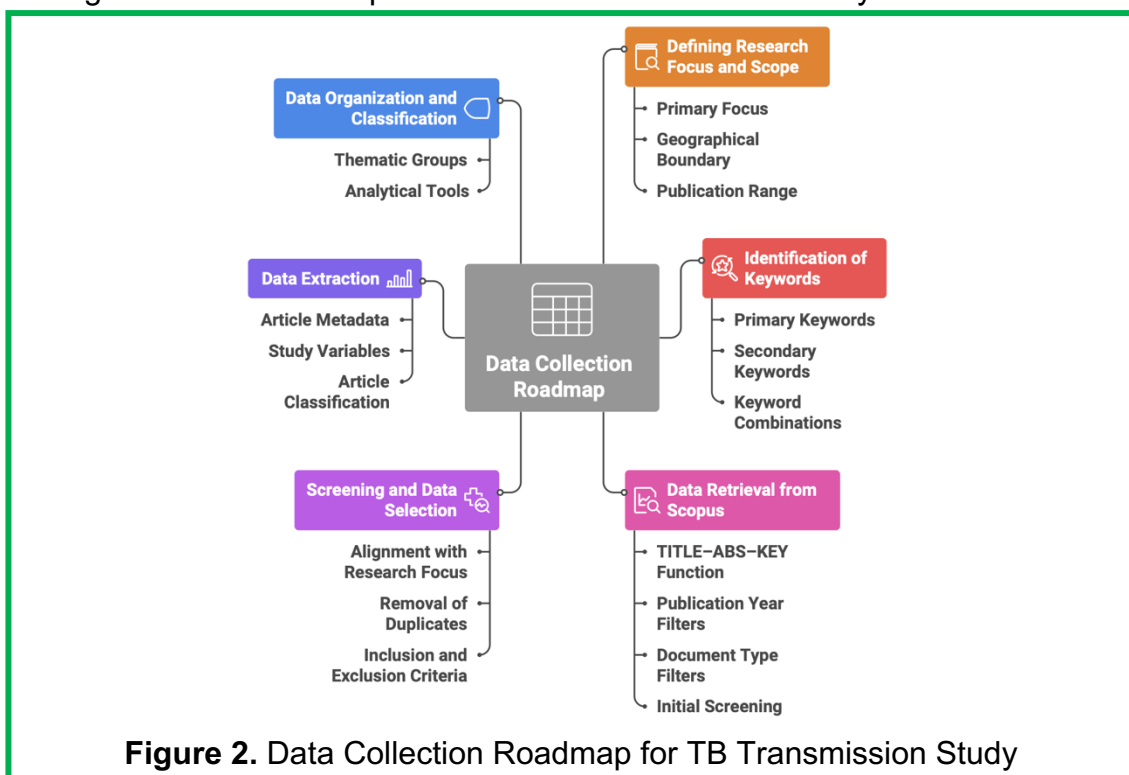


Figure 2. Data Collection Roadmap for TB Transmission Study

The figure illustrates a data collection framework consisting of six main components: defining the research focus, identifying keywords, conducting data searches in Scopus, performing the screening process, extracting data, and organizing and classifying the results. Each component is arranged in an interconnected sequence, demonstrating that all stages support one another to achieve optimal data quality. The initial stages, such as establishing the focus and scope of the research, serve as a critical foundation to ensure that subsequent processes do not expand beyond the context of environmental factors and TB transmission. In the keyword identification stage, the roadmap emphasizes the importance of incorporating both primary and secondary keywords to obtain broad and relevant search results within the Scopus database. The data search step is then carried out using the TITLE ABS KEY feature along with publication year filters and document type filters. This ensures that the retrieved publications are truly aligned with the topic and fall within a timeframe that supports the analysis of research development. The screening process is subsequently performed to filter out articles that do not meet the relevance or quality criteria.

The final stage in this roadmap is data extraction, organization, and classification. At this stage, article metadata, study variables, applied methods, and key findings are collected and then grouped into thematic categories such as air quality, sanitation, housing density, and socioeconomic conditions. The use of supporting software such as R Bibliometrix is also recommended to assist in visualizing keyword networks, publication trends, and research clusters (Syahrani and Palutturi, 2021). By following all the stages outlined in the roadmap, this study obtains a robust data structure that can be analyzed bibliometrically and provides an in depth understanding of the role of environmental factors in TB transmission.

The data analysis shows that collaboration among authors, highly cited articles, and the temporal patterns of keyword occurrence provide important insights into the development of research related to environmental factors as determinants of TB transmission in developing countries (Zavala et al., 2023). The most productive publishers and authors play an important role in facilitating global discussions on environmental challenges that influence TB transmission, such as poor air quality, inadequate sanitation, high housing density, and vulnerable socioeconomic conditions. The analysis of author collaboration also reveals cross national networks that strengthen the understanding of TB transmission dynamics from an environmental perspective at both local and global levels. In addition, the distribution of research contributions across countries helps identify regions with a strong focus on examining the role of environmental factors in TB transmission risk. Keyword trends such as air quality, sanitation, housing density, and socioeconomic conditions that appear over time reflect the growing attention to how environmental factors may accelerate or slow the spread of TB. Thus, this study provides a strong foundation for the development of public health policies that support more effective TB control through environmentally based approaches.

3. Findings and Discussions

3.1 Findings

The bibliometric mapping of research on Environmental Factors as Determinants of TB Transmission in Developing Countries shows a growing global attention over the past decade. Analysis of the Scopus CSV data reveals that

numerous publications focus on key issues such as housing density, inadequate sanitation, low socioeconomic status, urban environmental health conditions, and public health challenges in developing nations. Keywords such as overcrowding, poor sanitation, urban environmental health, socioeconomic inequalities, and public health challenges appear dominantly in both the Author Keywords and Indexed Keywords lists, reflecting the increasing body of research that links physical and social environmental conditions with TB epidemiology. Therefore, it is essential to examine the publication trends from 2015 to 2025 as an indicator of shifting research priorities toward a multidimensional approach in TB control.

Table 1. Trends in the Number of Articles Related to Environmental Factors as Determinants of TB Transmission in Developing Countries (2015–2025)

Year	Number of Articles Published	Focus of Environmental and TB Studies
2015	Fluctuation	Housing Density And TB Transmission Risks
2016	Fluctuation	Sanitation Conditions And Infection Vulnerability
2017	Increase	Socioeconomic Status And TB Prevalence
2018	Increase	Urban Environmental Health And Disease Transmission
2019	Increase	Settlement Pattern Changes And Air Quality
2020	Increase	Pandemic Impacts On TB And Environmental Conditions
2021	Increase	Poverty, Healthcare Access, And TB Spread
2022	Increase	Population Density And TB Clustering
2023	Increase	Environmental Sanitation And Health Service Equity
2024	Annual Growth	Regional Environmental Changes And TB Epidemiology
2025	Annual Growth	Rapid Urbanization And Public Health Challenges

The Scopus data show that since 2017, research on TB has increasingly been dominated by studies that link physical and social environmental conditions with rising TB cases, particularly in developing countries. Publications from this period highlight housing density or overcrowding as the most consistently reported factor contributing to TB transmission. Many articles emphasize that homes with poor ventilation, minimal space between individuals, and a high number of occupants within a single room significantly increase the risk of infection. In addition, environmental sanitation frequently appears as an important determinant, as areas with limited access to clean water, inadequate waste systems, and low hygiene standards tend to have higher TB prevalence. The rise in publications from 2018 to 2023 is closely associated with studies that integrate environmental epidemiology and public health perspectives.

In the years 2024 to 2025, publication trends show a shift toward broader issues such as socioeconomic status, urban environmental health, and increasingly complex public health challenges in developing countries. Many articles in the dataset discuss how poverty, limited access to health services, and social inequalities create conditions that exacerbate TB transmission, particularly in rapidly growing urban areas. In addition, several publications examine the effects of regional environmental changes, including declining air quality, extreme urbanization, and environmental degradation, which elevate the risk of respiratory diseases. Therefore, the patterns observed in both the table and the downloaded CSV data collectively demonstrate that modern TB research is moving toward a more comprehensive understanding, positioning environmental and social factors as integral components of global TB control efforts.

Statistical Analysis

Environmental factors as determinants of TB transmission in developing countries include air quality, housing density, sanitation, and overall settlement conditions. This study shows that more effective and innovative environmental management can significantly reduce the risk of TB transmission. In addition, access to adequate health care facilities and public health education programs are identified as important factors that contribute to a decrease in TB cases through more comprehensive prevention efforts.

The study also traces the chain of environmental determinants of TB transmission, from household environmental conditions to the distribution of risks at the community level. By examining the role of each factor such as air quality, humidity, sanitation, population density, health care access, and community awareness, the study identifies a range of challenges and opportunities that influence the transmission of TB. The findings indicate that strengthening community knowledge through education, training, and access to health information is essential for addressing structural weaknesses in environmental based TB control. Communities with better environmental health literacy are more capable of practicing clean and healthy living behaviors, improving housing conditions, and implementing sustainable preventive actions. These collective efforts contribute significantly to reducing the risk of TB transmission. Bibliometric evidence reinforces the importance of innovative environmental based approaches and community engagement as central elements in enhancing public health resilience in developing countries.

Table 2. The Top Ten Source Titles Contributing to Research on Environmental Factors Affecting TB in Developing Countries

Source titles	H-Index	Quartile
Agriculture, Ecosystems and Environment	212	Q1
Journal of the Science of Food and Agriculture	174	Q1
Computers and Electronics in Agriculture	168	Q1
Agriculture and Human Values	91	Q1
Culture, Agriculture, Food and Environment	17	Q1
International Journal of Agriculture and Biosciences	6	Q2
Basrah Journal of Agricultural Sciences	6	Q3
Journal of Library and Information Science in Agriculture	5	Q3
Journal of Agricultural Sciences (Belgrade)	4	Q4
Journal of Aridland Agriculture	3	Q4

Table 2 presents the top ten publication sources that contribute to research on environmental factors as determinants of TB transmission in developing countries. Q1 ranked journals such as *Agriculture, Ecosystems and Environment*, *Journal of the Science of Food and Agriculture*, and *Computers and Electronics in Agriculture* have high H Index values, reflecting strong scientific quality and influence in the fields of environmental studies, ecology, and public health, which are highly relevant for understanding the roles of air quality, sanitation, and housing density in TB risk. Meanwhile, Q2 to Q4 journals such as the *International Journal of Agriculture and Biosciences*, *Basrah Journal of Agricultural Sciences*, and the *Journal of Agricultural Sciences (Belgrade)* contribute through research that is more contextual and specific to local conditions in developing countries. The combination of journals across quartiles demonstrates that research on environmental factors and TB

encompasses a wide range of studies, from comprehensive global analyses to regional investigations that reflect real world situations. Altogether, this strengthens a holistic understanding of how environmental conditions influence TB transmission.

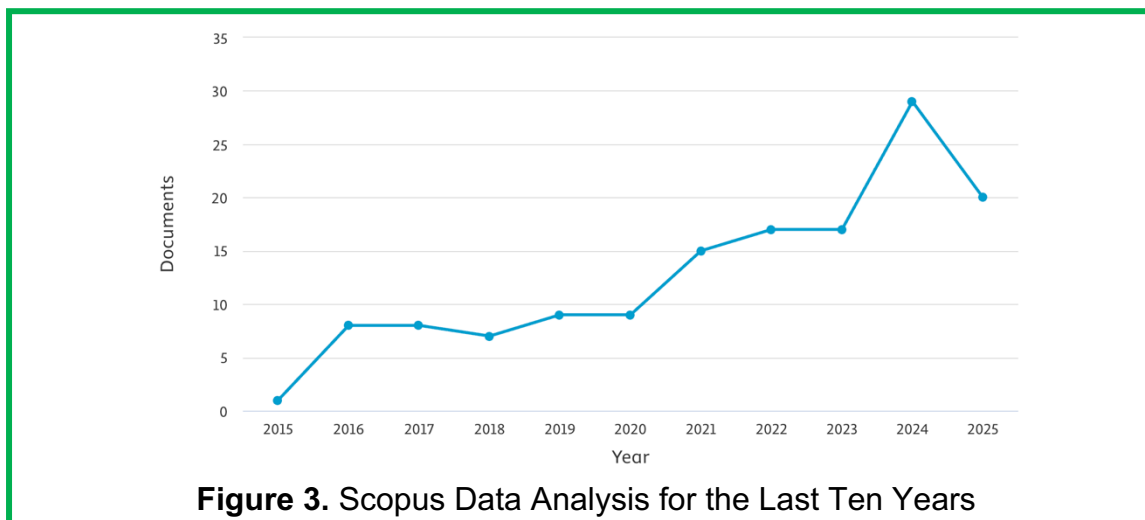


Figure 3. Scopus Data Analysis for the Last Ten Years

The publication trends related to environmental factors as determinants of TB transmission over the past ten years, based on Scopus data, show a significant increase from 2015 to 2024, with a sharp rise occurring between 2021 and 2024. In the early years, the number of publications was relatively low, but beginning in 2020 the trend continued to increase steadily as global attention toward environmental health and infectious diseases intensified. The peak number of publications occurred in 2024, reaching nearly thirty documents, reflecting the growing urgency of research on the relationship between environmental quality and TB transmission in developing countries. Although there is a slight decline in 2025, the number of publications remains higher than in the earlier years, indicating that this topic continues to receive considerable attention in global research and demonstrating consistent scientific progress in the field of environmental health.

Bibliometric Analysis

Bibliometric analysis provides a comprehensive overview of the research landscape through three main dimensions: country contributions, topic trends, and author productivity and collaboration networks. Country contributions reveal the extent to which each nation participates in producing scientific knowledge and how patterns of international collaboration are formed within a particular topic. Topic trends illustrate the evolution of research focus over time, including issues that are rising, stable, or declining based on the emergence and development of keywords. Meanwhile, author productivity and collaboration networks reflect the most active scientific actors, the level of connectivity among researchers, and the strength of the networks that drive the advancement of the field. Together, these three aspects help map the structure of scientific knowledge, the direction of research development, and the key actors who have significant influence within a given domain of study.

The analysis of country contributions is conducted to understand the extent to which each country plays a role in producing research related to environmental factors as determinants of TB transmission in developing countries. This measurement not only highlights the number of publications produced but also distinguishes forms of collaboration through Single Country Publications (SCP) and

Multiple Country Publications (MCP). Through this mapping, it becomes clear which countries serve as research hubs, which countries are actively engaged in international collaboration, and how global research dynamics are shaped based on the level of involvement of each country.

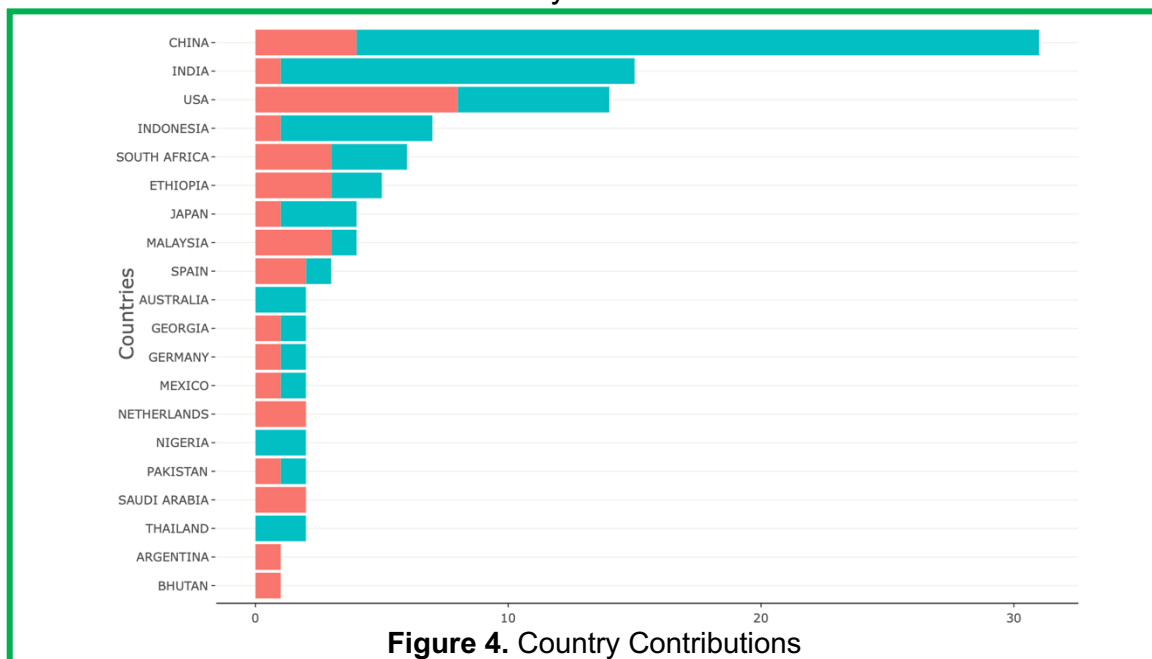


Figure 4. Country Contributions

The mapping results show that China occupies the top position with the highest number of publications, dominated by Single Country Publications, which indicates strong national research capacity and a high level of independence in studies related to environmental factors and TB. India and the United States follow in the next positions, with a relatively balanced combination of SCP and MCP, reflecting broader engagement in international collaboration. Indonesia also appears as a significant contributor within the top five, demonstrating growing scientific attention to environmental TB issues in the Southeast Asian region. This pattern suggests that countries with a high TB burden tend to be more active in producing research related to environmental determinants.

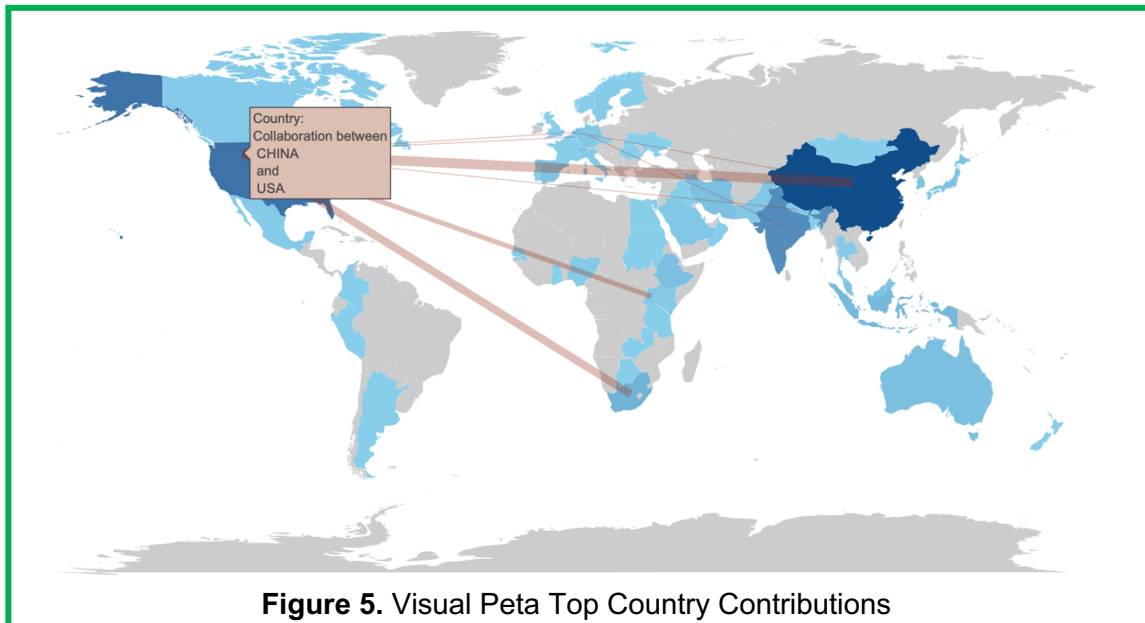
Other countries such as South Africa, Ethiopia, Japan, and Malaysia also show relatively stable research contributions, particularly through cross country collaborative publications (MCP). This collaboration pattern indicates that environmental TB research does not rely solely on national capacity but also requires the support of international networks, especially in issues related to sanitation, housing density, and socioeconomic determinants. Although countries such as the Netherlands, Nigeria, Pakistan, and Thailand have a smaller number of publications, their presence remains important in enriching the global perspective. Overall, these country contribution patterns demonstrate that environmental TB research is multiregional in nature and requires sustained collaboration to strengthen the scientific evidence base that is relevant in developing regions.

Table 3. Country Contributions to Publications on Environmental Factors as Determinants of TB Transmission

Country	Articles	Articles %	SCP	MCP	MCP %
China	31	22.1	27	4	12.9
India	15	10.7	14	1	6.7

USA	14	10.0	6	8	57.1
Indonesia	7	5.0	6	1	14.3
South Africa	6	4.3	3	3	50.0
Ethiopia	5	3.6	2	3	60.0
Japan	4	2.9	3	1	25.0
Malaysia	4	2.9	1	3	75.0
Spain	3	2.1	1	2	66.7
Australia	2	1.4	2	0	0.0
Georgia	2	1.4	1	1	50.0
Germany	2	1.4	1	1	50.0
Mexico	2	1.4	1	1	50.0
Netherlands	2	1.4	0	2	100.0
Nigeria	2	1.4	2	0	0.0
Pakistan	2	1.4	1	1	50.0
Saudi Arabia	2	1.4	0	2	100.0
Thailand	2	1.4	2	0	0.0
Argentina	1	0.7	0	1	100.0
Bhutan	1	0.7	0	1	100.0

The distribution of country contributions to publications related to environmental factors as determinants of TB transmission in developing countries reveals clear disparities in scientific productivity and research engagement. China emerges as the largest contributor with 31 articles (22.1%), followed by India and the United States, each contributing more than ten percent of the total publications. These figures suggest that countries with substantial scientific infrastructure or high TB burdens tend to dominate research output in this field. A comparison between Single Country Publications (SCP) and Multiple Country Publications (MCP) further highlights distinct patterns of international collaboration. Countries such as the United States, Ethiopia, Malaysia, and Spain demonstrate strong collaborative behavior, with MCP percentages exceeding fifty percent, indicating their active participation in global knowledge exchange and cross national research initiatives. In contrast, countries including China, India, Indonesia, and Australia produce a higher proportion of SCP, reflecting solid domestic research capacity but a relatively lower level of international collaboration. Despite contributing fewer publications, nations such as Georgia, Mexico, the Netherlands, Saudi Arabia, and Bhutan play an important role in enriching the global research landscape through their meaningful involvement in collaborative studies. The presence of these countries, although smaller in volume, adds diversity to the scientific dialogue and supports the development of a more holistic understanding of how environmental factors influence TB transmission across different regions. Together, these patterns underscore the multiregional and interconnected nature of TB research, emphasizing the need for sustained international partnerships to strengthen the evidence base in developing countries.

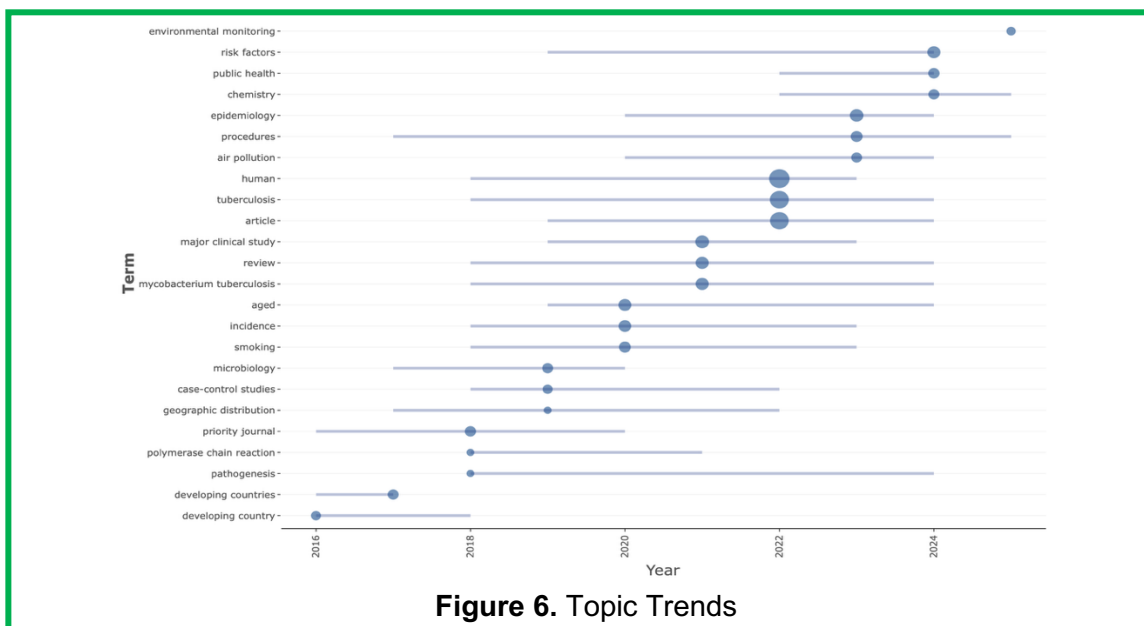


The visualization of the collaboration map shows that China holds a dominant role in the research landscape related to environmental factors as determinants of TB transmission in developing countries. This is reflected in the intensity of its scientific connections with countries such as the United States, South Africa, and several nations in Asia and Europe. The darker blue shading over China indicates a much larger volume of publications compared with other countries, consistent with the distribution of country contributions that identifies China as the largest contributor with 31 articles or 22.1 percent of the total publications. The collaborative lines on the map represent Multiple Country Publications (MCP), indicating that although most research from China is conducted independently through Single Country Publications (SCP), the country continues to build strategic scientific networks with influential partners such as the United States to strengthen the quality and scope of its research. This pattern highlights that China excels not only in the quantity of its publications but also plays an important role in shaping global collaboration flows in environmental based TB research.

Topic Trends

The analysis of topic trends is used to map the development of research themes over time, providing a comprehensive overview of how the scientific focus within studies on environmental factors as determinants of TB transmission in developing countries has evolved. Using bibliometric data, this visualization displays the emergence, intensity, and duration of the use of key terms in scientific publications. Each term that appears reflects an emerging research focus, a topic of growing interest, or an area that is gradually declining. Through this approach, researchers can understand how the field is moving and which environmental factors are receiving increasing attention in the context of TB transmission. In addition, topic trends help identify the relationship between the progression of scientific knowledge and global public health dynamics, including how new issues emerge as a result of environmental changes, urbanization, or increased exposure risks. This understanding is crucial for determining whether research is leaning more toward clinical, biological, social, or environmental aspects of TB transmission. Thus, topic trend analysis becomes a strategic tool for uncovering the evolutionary structure of the research domain, mapping research gaps, and indicating the directions that

future studies need to pursue, particularly in responding to the complexity of the relationship between environmental factors and TB epidemiology in developing countries.



The Topic Trends visualization illustrates the thematic evolution of research on environmental factors as determinants of TB transmission in developing countries over nearly a decade. During the early period (2016–2019), research was primarily centered on basic and foundational terms such as *developing country*, *pathogenesis*, *case control studies*, *geographic distribution*, and *polymerase chain reaction*. These themes reflect the initial foundations of TB research, which focused on biological mechanisms, population distribution, and clinical methodological approaches. At this stage, topics related to environmental exposure had not yet become dominant, indicating that scientific attention was still directed toward general epidemiological understanding and the characteristics of at-risk populations in developing countries.

Entering the period of 2020–2024, research trends shifted significantly toward more specific topics related to environmental factors and public health risks. Terms such as *air pollution*, *risk factors*, *environmental monitoring*, *epidemiology*, and *public health* began to dominate, with increasing intensity indicated by larger bubble sizes. The peak rise occurred between 2021 and 2023 when research attention increasingly focused on the links between air pollution, control procedures, and TB incidence influenced by environmental determinants. Meanwhile, clinical terms such as *tuberculosis*, *mycobacterium tuberculosis*, and *incidence* continued to appear consistently as core topics. This shift confirms that recent studies are more oriented toward understanding the complex interactions between environmental factors, social conditions, and TB epidemiology, resulting in a more comprehensive perspective to support health policy development in developing countries.

Table 4. Distribution of Topic Trends Based on Term Frequency and Time Span of Occurrence

Term	Frequency	Year (Q1)	Year (Median)	Year (Q3)
Developing Country	7	2016	2016	2018
Developing Countries	9	2016	2017	2017

Priority Journal	10	2016	2018	2020
Pathogenesis	5	2018	2018	2024
Polymerase Chain Reaction	5	2018	2018	2021
Microbiology	9	2017	2019	2020
Case-Control Studies	7	2018	2019	2022
Geographic Distribution	5	2017	2019	2022
Aged	16	2019	2020	2024
Incidence	15	2018	2020	2023
Smoking	12	2018	2020	2023
Major Clinical Study	20	2019	2021	2023
Mycobacterium Tuberculosis	17	2018	2021	2024
Review	17	2018	2021	2024
Human	71	2018	2022	2023
Tuberculosis	57	2018	2022	2024
Article	54	2019	2022	2024
Epidemiology	19	2020	2023	2024
Procedures	12	2017	2023	2025
Air Pollution	9	2020	2023	2024

The development of key terms in research related to environmental factors as determinants of TB transmission in developing countries is reflected through their frequency of occurrence and the span of time in which they appear. In the early period, topics such as *developing country*, *priority journal*, and *microbiology* emerged around 2016-2017 as foundational concepts in contextual and methodological studies. Between 2018 and 2020, clinically oriented terms such as *incidence*, *aged*, *case control studies*, and *mycobacterium tuberculosis* became dominant, indicating a shift in research focus toward population characteristics and disease attributes. Meanwhile, during the 2021-2024 period, topics such as *epidemiology*, *procedures*, and *air pollution* gained prominence, reflecting growing interest in the analysis of environmental determinants, exposure risks, and public health approaches. These trends confirm the evolution of research from basic epidemiological issues to more complex studies examining environmental factors that influence TB transmission.

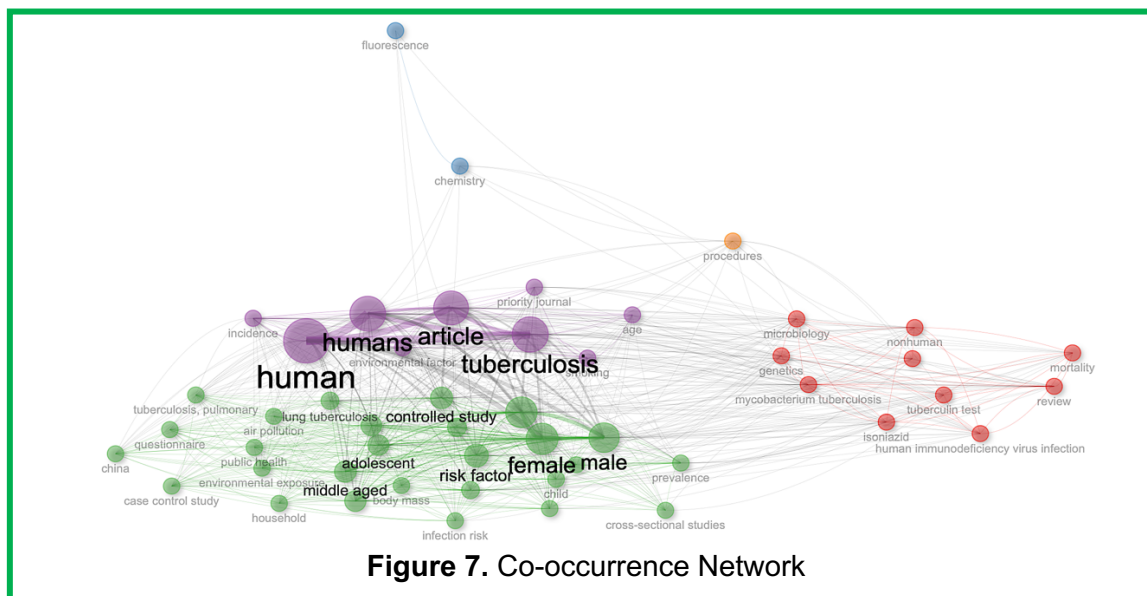


Figure 7. Co-occurrence Network

The co-occurrence network illustrates the relationships among terms that frequently appear together in research on environmental factors as determinants of TB transmission in developing countries. The purple cluster displays core terms such as *human*, *humans*, *tuberculosis*, *article*, and *controlled study*, which represent the primary research focus on human populations and clinically structured study designs. This cluster forms the foundation of general TB research and serves as a central connecting point among the other clusters. Terms with larger node sizes indicate higher frequency and greater significance in shaping the conceptual map of the research domain.

The green cluster represents themes related to environmental factors and socio-demographic characteristics, including terms such as *air pollution*, *environmental exposure*, *risk factor*, *middle aged*, *adolescent*, and *household*. This cluster reflects the growing scientific attention toward environmental determinants and household contexts that influence TB risk. Meanwhile, the red cluster contains clinical and laboratory terms such as *microbiology*, *tuberculin test*, *review*, *mortality*, and *mycobacterium tuberculosis*, which form the basis for pathogen analysis and health outcomes. The smaller blue and orange clusters highlight more specialized topics such as *fluorescence*, *chemistry*, and *procedures*, which are commonly associated with method oriented or diagnostic technique research. Together, these diverse clusters demonstrate that TB research is multidisciplinary and involves an integration of clinical, environmental, social, and laboratory approaches.

This co-occurrence network shows that the structure of research on environmental factors and TB is firmly rooted in studies of human populations and basic epidemiology, while also demonstrating significant development toward environmental issues and exposure risks. The strong connections among environmental terms, risk factors, and social characteristics indicate that a multidimensional perspective is increasingly recognized as essential for understanding TB transmission in developing countries. Therefore, this co-occurrence network not only maps the current research focus but also provides a clear direction toward integrating environmental, social, and biomedical research in future TB control efforts.

Factorial Analysis

Factorial analysis is employed to map the conceptual relationships among terms that frequently appear in publications related to environmental factors as determinants of TB transmission in developing countries. By projecting keywords into two principal dimensions, this method uncovers the underlying structure that shapes the overall research landscape. The visual representation allows researchers to identify how closely related concepts cluster together, revealing thematic groupings that reflect dominant areas of inquiry. Terms associated with environmental determinants, for example, often cluster in proximity, highlighting the growing emphasis on factors such as air quality, sanitation, population density, and exposure risks. Likewise, clinical and demographic terms form distinct groups, illustrating the interconnected yet differentiated nature of TB research across multiple scientific domains.

Through this analytical approach, factorial analysis provides a deeper understanding of the direction, emphasis, and concentration of scientific studies within the field. It enables researchers to observe not only which themes are most

prominent but also how these themes evolve and interact over time. The identification of these conceptual clusters helps to pinpoint areas where research is well established and areas where significant gaps remain. Consequently, factorial analysis serves as a valuable tool for guiding future research priorities and promoting a more integrated approach to understanding TB transmission, particularly in developing countries where environmental and social determinants play critical roles.

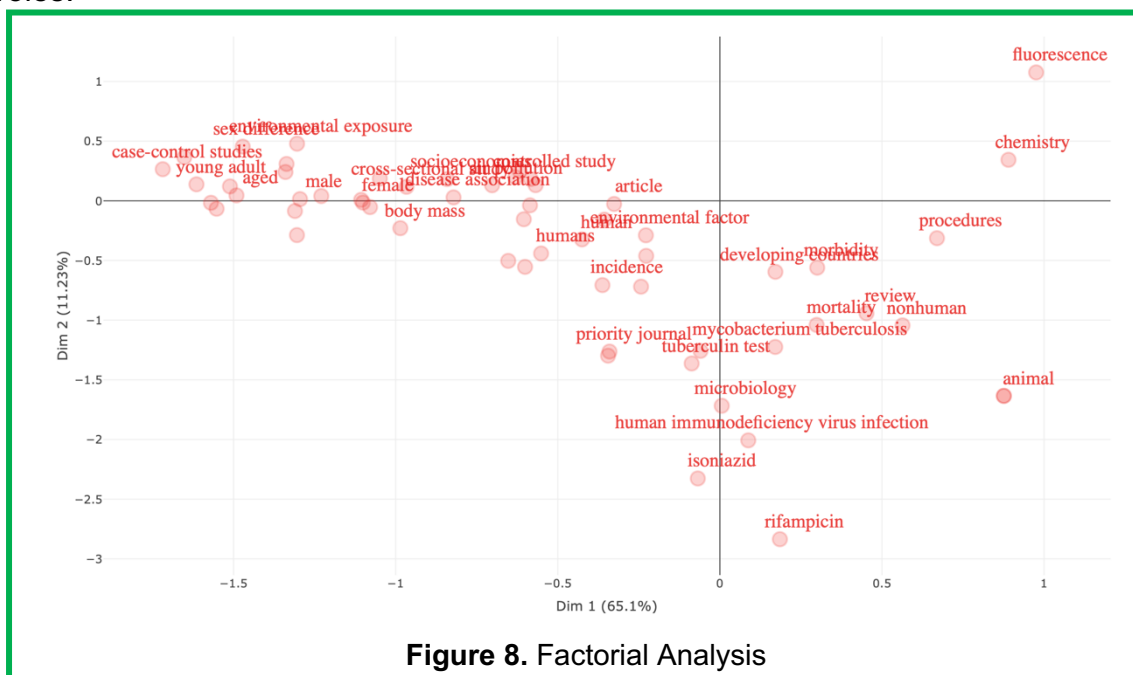
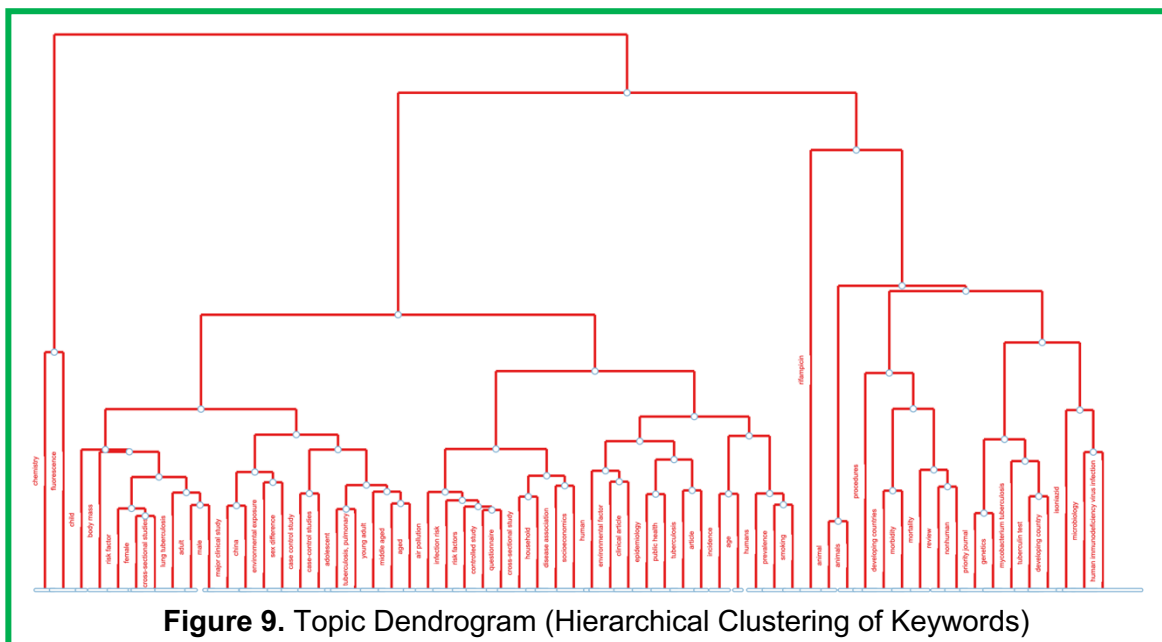


Figure 8. Factorial Analysis

The Factorial Analysis visualization shows the distribution of keywords across two principal axes, with Dimension 1 (65.1 percent) contributing the largest explanation of thematic variability and Dimension 2 (11.3 percent) serving as a secondary component. On the left side of the plot, terms such as *case control studies*, *environmental exposure*, *cross sectional studies*, *young adult*, *aged*, and *risk factor* form a strong cluster associated with environmental factors and population characteristics. This indicates that a substantial portion of the research emphasizes environmental exposure, socio-demographic conditions, and epidemiological study designs to explain the relationship between environmental determinants and TB risk. The right side of the plot is dominated by clinical and laboratory terms such as *microbiology*, *tuberculin test*, *mycobacterium tuberculosis*, *isoniazid*, *rifampicin*, *procedures*, and technical topics such as *chemistry* and *fluorescence*. This cluster highlights research focused on diagnosis, pathogenesis, laboratory testing, and the pharmacological dimensions of TB. The presence of these two major poles, environmental factors and biomedical determinants, demonstrates that TB research in developing countries is inherently multidimensional. This analysis reinforces that both aspects complement one another in building a comprehensive understanding of TB transmission, underscoring the importance of integrating environmental and clinical approaches in the development of disease control strategies.



The topic dendrogram illustrates the results of hierarchical clustering of keywords that appear in publications related to environmental factors as determinants of TB transmission in developing countries. The dendrogram uses a similarity-based clustering approach, placing terms with thematic relationships or frequent co-occurrence within the same branch. The tree-like structure, organized in successive levels, reflects the conceptual distance among terms: branches that lie close together indicate strong relationships, whereas higher-level branches represent broader groupings or thematic generalizations. The dendrogram reveals several major clusters of terms forming thematic groups, such as a cluster containing environmental risk-related keywords including *air pollution*, *environmental exposure*, *household*, and *risk factor*. Another cluster represents clinical and laboratory themes such as *mycobacterium tuberculosis*, *tuberculin test*, *incidence*, and *microbiology*. Meanwhile, a cluster that includes keywords such as *aged*, *adolescent*, *male*, and *female* reflects a focus on demographic characteristics. These groupings demonstrate how TB research in developing countries integrates environmental, biomedical, and social dimensions within a complex and interconnected research landscape.

This topic dendrogram presents the conceptual structure of environmental-based TB research, showing that the field does not stand on a single dimension but is distributed across multiple interconnected thematic clusters. The dendrogram reinforces the integrative pattern embedded within TB studies, where environmental factors, biological conditions, and socio-population characteristics form a unified framework for scientific explanation. This visualization helps researchers understand the thematic landscape comprehensively and identify dominant research areas, emerging topics, and clusters that require further exploration.

3.2 Discussions

Country Contributions

The analysis of country contributions shows that the production of research related to environmental factors as determinants of TB transmission in developing countries is strongly influenced by national research capacity and the level of

international collaboration. China emerges as the largest research hub, with a dominance of Single Country Publications (SCP), indicating strong internal capacity to generate knowledge without substantial dependence on global networks. Other countries such as India, the United States, and Indonesia also demonstrate significant contributions, suggesting that nations with a high TB burden tend to be more active in producing relevant research that supports disease control efforts. Findings from the comparison of SCP and MCP reveal considerable variation in international collaboration patterns across countries. The United States, Ethiopia, Malaysia, and Spain display strong international engagement, with MCP percentages exceeding fifty percent, reflecting their role in building global research networks and enriching cross-national perspectives. In contrast, countries such as China, India, Indonesia, and Australia continue to rely more heavily on national capacity in scientific publication, which, while indicating research independence, also highlights opportunities to expand collaboration to enhance the impact and quality of research.

The visualization of the collaboration map further reinforces the distribution of country contributions, particularly the strategic position of China within the landscape of environmental TB research. Although China's publications are dominated by SCP, the international networks established through MCP with key countries such as the United States demonstrate that collaboration remains an essential component in broadening the scope of research. Overall, these country contribution patterns emphasize that research on environmental determinants of TB is multiregional and requires synergy between strong national research capacity and global collaboration to generate comprehensive scientific evidence that can have meaningful impact in developing countries.

The findings on country contributions in research on environmental factors as determinants of TB transmission align with recent studies stressing the increasing importance of international scientific collaboration in understanding the relationship between environmental conditions and the spread of infectious diseases. The study by (Hu and Yan, 2023) shows that TB analysis in developing countries is shifting toward a multidisciplinary approach that integrates air quality data, housing density, and socioeconomic factors to provide a more comprehensive understanding. Kumar's emphasis on the importance of global research networks reinforces the finding that countries such as China and the United States play major roles in knowledge production, while developing countries expand their contributions through international collaboration to strengthen scientific evidence related to TB epidemiology.

Topic Trends

The Topic Trends analysis is used to map the development of research themes over time, providing a comprehensive overview of how scholarly focus in studies on environmental factors as determinants of TB transmission in developing countries has evolved. Using bibliometric data, this visualization displays the emergence, intensity, and duration of key terms in scientific publications. Each term reflects an emerging area of interest, a topic gaining traction, or a theme that is gradually declining. This approach helps researchers trace the evolution of scientific knowledge and identify environmental factors that are receiving increasing attention in the context of TB transmission from clinical, social, and environmental perspectives. The Topic Trends illustrate thematic evolution over nearly a decade.

In the early phase (2016–2019), research focused on foundational terms such as *developing country*, *pathogenesis*, *case control studies*, and *geographic distribution*, which represent the initial basis of TB research rooted in biology and traditional epidemiology. However, entering the 2020–2024 period, the research landscape experienced a significant shift toward themes that emphasize environmental determinants and public health risks. Terms such as *air pollution*, *risk factors*, *environmental monitoring*, and *public health* began to dominate, indicating growing scientific concern regarding the influence of environmental quality, air pollution exposure, and social behavior on increasing TB incidence. This shift reflects a transformation from basic clinical inquiry to more complex multidimensional issues.

Findings from the graphs further illustrate the frequency and time span of key term emergence. During 2016–2017, terms such as *developing country*, *priority journal*, and *microbiology* dominated as indicators of early-stage research. From 2018 to 2020, the focus shifted toward clinical and population-based topics such as *incidence*, *aged*, *case control studies*, and *mycobacterium tuberculosis*, indicating strengthened clinical epidemiology research. In the most recent period, 2021–2024, terms such as *epidemiology*, *procedures*, and *air pollution* became more prominent, reflecting heightened urgency in studying environmental determinants and exposure risks in relation to TB transmission. The development of these terms highlights a clear evolution from foundational epidemiological issues to more complex discussions regarding the role of environmental factors.

The Co-occurrence Network analysis enriches the understanding of topic trends by visualizing the interconnections among terms that frequently appear together. The purple cluster represents the foundational components of TB research, focusing on human populations and clinical study designs, while the green cluster highlights environmental factors such as *air pollution*, *environmental exposure*, and *household*, which are increasingly recognized as critical determinants of TB risk. The red, blue, and orange clusters represent pathogen-related themes, diagnostic methods, and laboratory techniques, complementing the environmental perspective. This network demonstrates that TB research in developing countries is inherently multidisciplinary, integrating clinical, environmental, and social approaches. The integration of these findings reinforces that contemporary research is moving toward a holistic understanding of the complex relationship between environmental determinants and TB epidemiology.

The Topic Trends analysis shows that research developments related to environmental factors as determinants of TB transmission have undergone a significant shift from basic epidemiological inquiry toward a multidisciplinary focus integrating environmental, social, and public health dimensions. In the early period, research emphasized conventional topics such as *pathogenesis*, *geographic distribution*, and *case control studies*, but since 2020 there has been a notable rise in themes such as *air pollution*, *environmental exposure*, and *risk factors*, reflecting global concern over the impact of environmental change and urbanization on TB risk. This shift aligns with findings by (Mtetwa et al., 2023), which reveal that variables such as air quality, housing density, and socioeconomic conditions have become central in explaining TB transmission dynamics in developing countries. Thus, the analysis of topic trends not only maps scientific evolution but also underscores the

urgent need for interdisciplinary approaches in understanding and addressing environmentally driven TB transmission.

Factorial Analysis

Factorial analysis is used to map the conceptual relationships among terms that frequently appear in publications related to environmental factors as determinants of TB transmission in developing countries. Through this approach, keywords are projected onto two principal dimensions that illustrate the latent structure of the overall research themes. The visualization shows how particular terms form thematic groups representing environmental determinants, clinical factors, and demographic characteristics. In this way, factorial analysis provides an initial overview of how research focuses are distributed, whether they lean more toward environmental exposure or biomedical aspects thus helping researchers understand the concentration and direction of scientific inquiry in this field.

The Factorial Analysis output displays two main axes, with Dimension 1 explaining 65.1 percent of data variability and Dimension 2 explaining 11.3 percent. On the left side of the plot, terms such as *case control studies*, *environmental exposure*, *cross sectional studies*, *young adult*, *aged*, and *risk factor* cluster tightly together, reflecting the close relationship among environmental exposure, socio-demographic conditions, and TB epidemiology. In contrast, the right side of the plot is dominated by clinical and laboratory-related terms such as *microbiology*, *tuberculin test*, *mycobacterium tuberculosis*, *isoniazid*, *rifampicin*, and technical terms such as *chemistry* and *fluorescence*, which represent the biomedical and diagnostic framework of TB research. The presence of these two thematic poles underscores that TB research in developing countries is multidimensional, involving an interplay between biological factors and environmental exposures in understanding disease transmission.

The Topic Dendrogram illustrates the results of hierarchical clustering of keywords, forming thematic clusters based on similarity among terms. Branches that lie closer together indicate strong conceptual relationships, whereas higher-level branches represent broader thematic groupings. Major clusters include environmental risk-related terms such as *air pollution*, *environmental exposure*, *household*, and *risk factor*, as well as clinical and laboratory-related groups such as *mycobacterium tuberculosis*, *tuberculin test*, *incidence*, and *microbiology*. Another cluster consists of demographic terms such as *aged*, *adolescent*, *male*, and *female*, highlighting the role of population characteristics in understanding TB risk. These patterns demonstrate that TB research integrates environmental, social, and biomedical approaches simultaneously within a broader conceptual landscape.

When analyzed together, Factorial Analysis and the Topic Dendrogram provide a deeper understanding of the conceptual structure of environmental-based TB research. Both visualizations show that the research does not concentrate within a single domain but is distributed across interconnected thematic clusters. This integrative approach highlights that TB transmission is influenced not only by pathogens or clinical factors but also by environmental exposures, socioeconomic conditions, and demographic characteristics of populations. As such, thematic mapping helps researchers identify dominant themes, emerging research areas, and potential spaces for exploration that can support the development of more comprehensive and evidence-based TB control strategies.

The findings from the factorial analysis and topic dendrogram reveal that research on environmental factors as determinants of TB transmission in developing countries exhibits an interconnected thematic structure reflecting a multidimensional approach. The factorial analysis differentiates terms into two major groups: one related to environmental exposure and population characteristics, and the other related to clinical and laboratory aspects. The topic dendrogram reinforces these relationships through hierarchical clustering that groups terms such as *environmental exposure*, *risk factor*, *air pollution*, *household*, *mycobacterium tuberculosis*, and *incidence*. Together, these approaches illustrate that TB transmission is shaped by interactions between environmental conditions, public health quality, and biological factors. These findings align with (Molemans et al., 2022), who emphasize that TB transmission cannot be understood solely from medical aspects but must also account for the influence of social and economic environments that shape population vulnerability patterns.

4. Conclusion

The conclusions drawn from the analysis of country contributions, topic trends, and factorial analysis indicate that research on environmental factors as determinants of TB transmission in developing countries has developed significantly and is driven by diverse national contributions. Countries with strong research capacity such as China, India, the United States, and Indonesia serve as key drivers of knowledge production, each exhibiting variations in collaboration patterns between single-country and multi-country publications. This mapping of contributions reinforces that TB research is not concentrated in specific regions but constitutes a global effort that requires synergy among countries to generate more comprehensive findings. In terms of topic trends, there has been a notable shift from basic epidemiological issues toward more complex discussions involving environmental determinants, air pollution, exposure risks, and social characteristics of communities. This shift demonstrates growing scientific awareness of the increasing influence of environmental factors in explaining TB transmission dynamics.

The factorial analysis provides deeper insight into the conceptual structure of TB research by separating themes into environmental, clinical, and demographic clusters. The visualizations show that environmental factors such as *environmental exposure* and *risk factor* are interconnected with clinical terms such as *mycobacterium tuberculosis* and *tuberculin test*, as well as population-related variables such as age and household conditions. These findings confirm that TB research is multidimensional and requires an integrated approach that combines environmental, social, and biomedical perspectives. Overall, the three analyses collectively show that TB research is moving toward a more interdisciplinary framework to achieve a comprehensive understanding of disease transmission and to support the development of more effective TB control strategies in developing countries.

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