REVIEW ARTICLE

Socio-Ecological Factors Associated with Tuberculosis Infection: A Systematic Review

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ABSTRACT

Introduction	Tuberculosis (TB) is a major public health issue and poses a threat to the community with high incidence and mortality, especially in the endemic countries. Social and ecological factors have been known to cause TB transmission. Hence, it is vital to synthesise evidence to adapt to the challenges caused by these factors. As such, this review aims to explore the relationship between TB prevalence and potential social and environmental factors.
Methods	We searched the electronic databases PubMed, Web of Science (WoS) and Scopus between 1st January 2013 and 31st 2024, for studies that met the following requirements: 1) original article investigating the social and environmental determinants associated with transmission of TB and; 2) the study was published in English. The Mixed Method Appraisal Tool (MMAT) assessed the study quality.
Results	We identified 484 potentially eligible published articles, of which 27 met our inclusion criteria. Findings from this systematic review showed that environmental and socioeconomic factors, mainly housing and living conditions, poverty, air quality and pollution, climate and weather, and water and sanitation infrastructure, influence the dynamics of TB transmission.
Conclusion	These findings can guide policymakers in improving and strengthening the TB control program.
Keywords	Social; environment; factors; tuberculosis; transmission

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INTRODUCTION

Tuberculosis (TB) is an airborne infectious disease which is the primary cause of mortality due to a single infectious agent.[1] Despite the fact that TB possesses a high cure rate when diagnosed promptly and treated with appropriate antibiotics, it remains one of the ten principal causes of mortality on a global scale.[2] Living or working in overcrowded or poorly ventilated environments, particularly where TB rates are high, increases exposure risk.[3]

Over 90% of TB patients worldwide reside in low and middle-income nations, and the disease continues to affect those who are economically and socially disadvantaged disproportionately.[4] Environmental factors such as air quality index, nitrogen dioxide, sulfur dioxide, carbon monoxide, particulate matter, and weather conditions like temperature, humidity and wind speed can promote *Mycobacterium tuberculosis* growth and reproduction.[5,6]

According to the World Health Organization (WHO), the elimination of TB requires a comprehensive strategy focusing on the underlying socioecological causes.[7] Growing research revealed that the primary causes of TB development were connected to environmental factors.[8] Thus, grasping the social and environmental factors contributing to TB transmission is essential. This review investigates how TB transmission relates to various social and environmental factors, including weather conditions. The information from this review can potentially inform policymakers on the future direction of TB prevention and management.

METHODS

Search Strategy, Study Selection, and Results Extraction for The Published Studies

While preparing the manuscript, we adhered to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[9] The search strategy focused on social and environmental factors that are involved in maintaining the transmission of TB. We systematically searched the literature using the PubMed, Web of Science and Scopus databases between January 1, 2013, and December 31, 2024. Without applying any restrictions, we used the terms “social factor*”, “social determinant*”, “environmental factor*”, “ecological factor*”, “environmental determinant*” and “ecological determinant*” for the exposure, and “Mycobacterium Tuberculosis”, “Tuberculosis” and “TB” for the outcomes. Social determinants of tuberculosis include key epidemiology social determinants such as poor socioeconomic background, underprivileged working conditions, and other social determinant factors, including inadequate housing, overcrowding, poor physical environment, health care needs and substance abuse (alcohol/smoking) as per WHO reports. The environment comprises the external factors and conditions surrounding, impacting and influencing TB transmission. The definition of the environment encompasses the physical surroundings, including nature, constructed spaces and pollution. DA and SAS independently did the literature search and article screening against the inclusive criteria. The process involved two steps: first, screening the titles and abstracts, followed by the full text. It is valuable to use two review authors to provide opportunities to explore the relevance and meaning of study findings.[10] Studies were included only if both authors could reach a consensus decision. There were no substantial disagreements over inclusion. We created a PRISMA flow diagram that outlines the number of studies accepted and rejected at each stage of the process.

We incorporated a published paper if it met all the criteria: original research articles such as cohort, case–control, and cross-sectional studies, along with mixed methods and qualitative research that examine the social and environmental aspects related to TB transmission, and the publication was in English. All retrieved articles were added to the EndNoteX7 library, where duplicate entries were removed[11]. When accessible, we gathered and organised various characteristics from each paper we retrieved. This included the lead author's name, the publication year, the country of the sample population, the article title, and relevant social and environmental factors. Data quality was assessed using the Mixed Method Appraisal Tool (MMAT). The Mixed Method Appraisal Tool (MMAT) were used to assess the study quality as it caters for diverse study design and is efficient, comprehensive and reliable. All reviewers extracted study data from the included papers. This study was registered under PROSPERO (CRD42024576664).

RESULTS

Search Results

Our database search identified 484 published studies: 208 from Scopus; 154 from Web of Science (WoS); and 122 from PubMed. After excluding duplicate and non-English, 356 citations remained. After reviewing titles and abstracts, 30 papers were identified as potentially relevant and examined fully. 27 publications qualified for inclusion after a thorough screening process, as illustrated in the PRISMA flow diagram. (Figure 1).

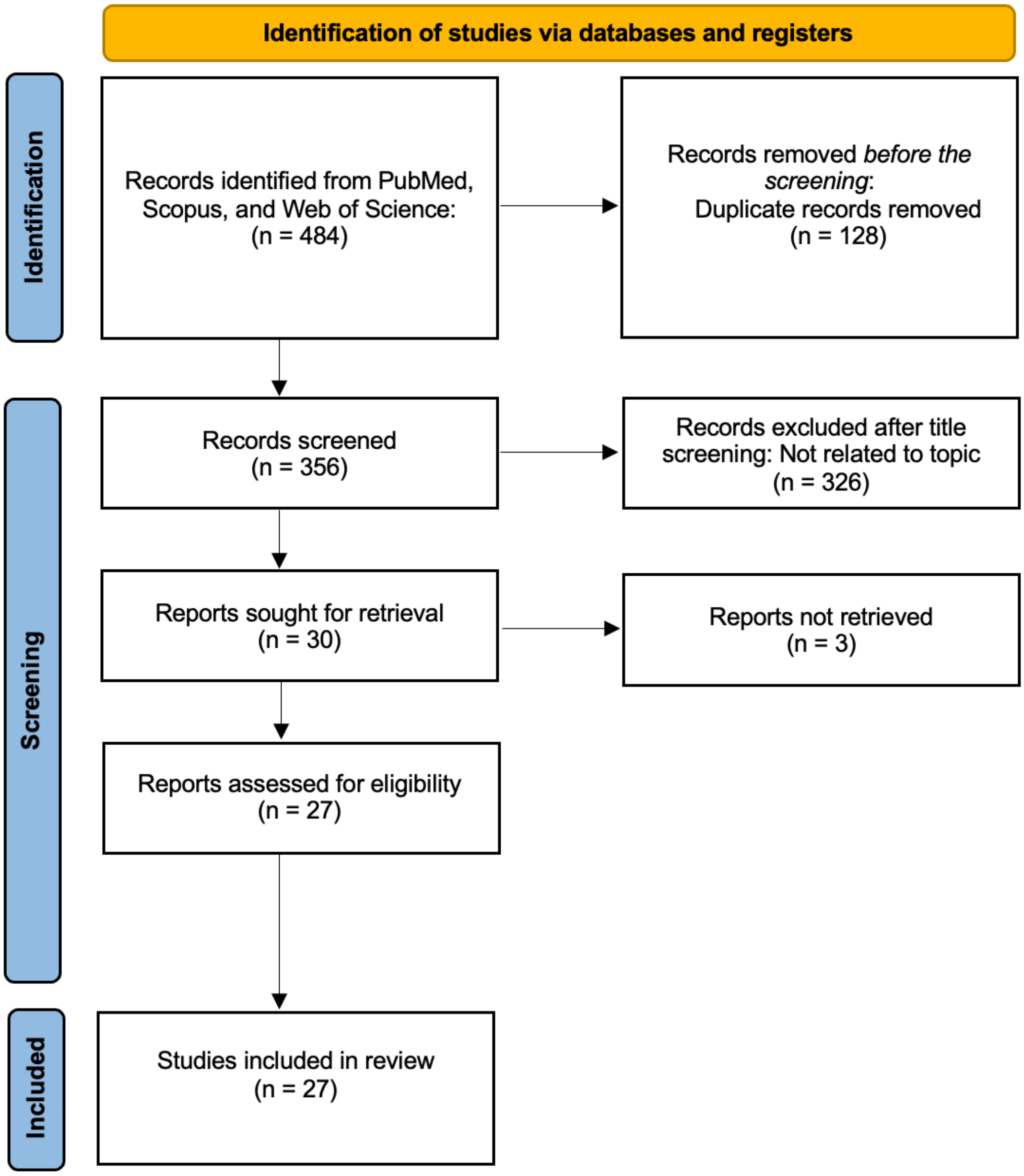

Figure 1 PRISMA flow diagram

Risk of Bias

We performed a quality assessment of all 27 studies utilising the MMAT. This tool can evaluate the methodological quality across four study categories: quantitative descriptive studies, qualitative studies, nonrandomized studies and mixed-methods studies. For each category, five criteria were employed to evaluate the quality of the study. The details of this assessment for the selected studies were presented in Table 1. DA evaluated the quality of each study included in the review, which was then assessed independently by SAS. There were no substantial disagreements over quality assessment. Table 1 presented the details of the assessment for the chosen studies.

Table 1 The details of the quality assessment

Author	Type of study	1.1	1.2	1.3	1.4	1.5
		Is the sampling strategy relevant to address the research question?	Is the sample representative of the target population?	Are the measurements appropriate?	Is the risk of nonresponse bias low?	Is the statistical analysis appropriate to answer the research question?
Luo et al[8]	Ecological	Yes	Yes	Yes	Yes	Yes
Amoori et al[21]	Quantitative	Yes	Yes	Yes	Yes	Yes
Giacomet et al[20]	Quantitative	Yes	Yes	Yes	Yes	Yes
Chen et al[25]	Quantitative	Yes	Yes	Yes	Yes	Yes
Panaiotov et al[12]	Quantitative	Yes	Yes	Yes	Yes	Yes
Zhang et al[17]	Ecological	Yes	Yes	Yes	Yes	Yes
Ren et al[22]	Quantitative	Yes	Yes	Yes	Yes	Yes
Mohidem et al[13]	Quantitative	Yes	Yes	Yes	Yes	Yes
Sujatmiko et al[19]	Quantitative	Yes	Yes	Yes	Yes	Yes
Monteiro De Castro Fernandes et al[53]	Quantitative	Yes	Yes	Yes	Yes	Yes
Alene et al[54]	Quantitative	Yes	Yes	Yes	Yes	Yes
Im & Kim [23]	Quantitative	Yes	Yes	Yes	Yes	Yes
Luo et al[8]	Quantitative	Yes	Yes	Yes	Yes	Yes
Miandad et al[14]	Quantitative	Yes	Yes	Yes	Yes	Yes
Huang et al[15]	Quantitative	Yes	Yes	Yes	Yes	Yes
Singh et al[55]	Quantitative	Yes	Yes	Yes	Yes	Yes
Cardoso et al[56]	Quantitative	Yes	Yes	Yes	Yes	Yes
Rao et al[26]	Quantitative	Yes	Yes	Yes	Yes	Yes
Taher-Ghasemi et al[27]	Quantitative	Yes	Yes	Yes	Yes	Yes
Sun et al[61]	Quantitative	Yes	Yes	Yes	Yes	Yes
Tesema et al[18]	Quantitative	Yes	Yes	Yes	Yes	Yes
Li et al[57]	Quantitative	Yes	Yes	Yes	Yes	Yes
Lin & Liao[58]	Quantitative	Yes	Yes	Yes	Yes	Yes
Smith et al[24]	Quantitative	Yes	Yes	Yes	Yes	Yes
Wood et al[59]	Quantitative	Yes	Yes	Yes	Yes	Yes
Lai et al[60]	Quantitative	Yes	Yes	Yes	Yes	Yes
De Oliveira & Gonçalves [16]	Quantitative	Yes	Yes	Yes	Yes	Yes

Description of Included Studies

All included studies were quantitative descriptive studies. Countries where published research was conducted included: (in order from most to least frequent): China (10), Brazil (4), USA (2), Iran (2), Bulgaria (1), Ethiopia (1), Hong Kong (1), India (1), Indonesia (1), Malaysia (1), Pakistan (1), South Korea (1) and Taiwan (1). Table 2 summarized all the included studies: name of the lead author, publication year, title of the study, social and environmental factors associated with transmission of TB and result.

Table 2 Characteristics of included studies

Author & Country	Title	Social Factors	Environment Factors
Luo et al[8]	Spatial spillover effect of environmental factors on the tuberculosis occurrence among the elderly: a surveillance analysis for nearly a dozen years in eastern China	-	• Air quality ($PM_{2.5}$) • Annual mean temperature • Precipitation
Amoori et al[21]	Identification of Risk Factors Associated with Tuberculosis in Southwest Iran: A Machine Learning Method	• History of imprisonment	-
Giacomet et al[20]	A distributional regression approach to modelling the impact of structural and intermediary social determinants on communities burdened by tuberculosis in Eastern Amazonia – Brazil	-	• Inadequate sewage treatment systems
Chen et al [25]	A Spatio-temporal Bayesian model to estimate risk and influencing factors related to tuberculosis in Chongqing, China, 2014–2020	-	• SO_2 level
Panaiotov et al[12]	Biodiversity of Mycobacterium tuberculosis in Bulgaria Related to Human Migrations or Ecological Adaptation	• Human migration to Bulgaria	-
Zhang et al[17]	An Ecological Study of Tuberculosis Incidence in China, From 2002 to 2018	• Unemployment rate • Population density	• Sunshine duration
Ren et al[22]	Specific urban units identified in tuberculosis epidemic using a geographical detector in Guangzhou, China	-	• Monthly average of the fine particulate matter concentration ($PM_{2.5}$)
Mohidem et al[13]	Association of sociodemographic and environmental factors	• Urban area • Smoking status	• Air quality index (AQI) • Carbon monoxide (CO) • Nitrogen dioxide (NO_2)

	with spatial distribution of tuberculosis cases in Gombak, Selangor, Malaysia		• Sulphur dioxide (SO_2) • PM_{10} • Heavy rainfall • High humidity • High temperature • Wind speed • High atmospheric pressure
Sujatmiko et al[19]	Role of Environment and Contact-Pattern Factors in Pulmonary Tuberculosis Patients from Bandung City, Indonesia	• Household density • Time spent inside the house	• Absence of cross-ventilation
Monteiro De Castro Fernandes et al[53]	Environmental and social effects on the incidence of tuberculosis in three alian municipalities and in Federal District	• Access to drinking water • Sewage treatment (lack off) • Lack of garbage collection • Poor basic sanitation	• Wind speed • Radiation • Precipitation • Vapor pressure
Alene et al[54]	Spatiotemporal patterns of tuberculosis in Hunan province, China	-	• Low sunshine exposure
Im & Kim[23]	Spatial pattern of tuberculosis (TB) and related socio-environmental factors in South Korea, 2008-2016	• Population growth rate Population composition ratio	• SO_2 • Temperature
Luo et al[8]	Spatiotemporal epidemiology of, and factors associated with, the tuberculosis prevalence in northern China, 2010-2014	• Rural residence • Birth prevalence • Population density	• Air pressure • Sunshine duration • Number of beds
Miandad et al[14]	Assessment of risk factors associated with spread of tuberculosis in Gujrat city Pakistan	• Malnutrition • Poverty • Smoking • Housing Congestion • Accessibility to healthcare	-
Huang et al [15]	Space-time clustering and associated risk factors of pulmonary tuberculosis in southwest China	• Smoking • Urban residence	• Coal used for cooking/heating
Singh et al[55]	Potential effect of household environment on prevalence of tuberculosis in India: evidence from the recent round of a cross-sectional survey	• Daily exposure to smoke (second-hand smoke) • Toilet sharing among household	-
Cardoso et al[56]	Environmental aspects related to tuberculosis and intestinal parasites in a low-income community of the Brazilian Amazon	-	• Inadequate sanitation structure • Water supply (Well water)
Rao et al[26]	Spatial transmission and meteorological determinants of tuberculosis incidence in	-	• Temperature • Precipitation • Wind speed

	Qinghai Province, China: a spatial clustering panel analysis		
Taher-Ghasemi et al[27]	Associations between socio-environmental determinants and the risk of pulmonary tuberculosis in Guilan, Iran	• Poor house hygiene • Inadequate garbage disposal	• UV irradiation (inadequate) • Building materials (brick vs cement vs wooden-clay)
Sun et al[61]	A spatial, social and environmental study of tuberculosis in China using statistical and GIS technology	• Population density	• Altitude • Climate • Air quality
Tesema et al[18]	Environmental and host-related determinants of tuberculosis in Metema district, north-west Ethiopia	• Household density	• Availability of windows • Availability of ceiling
Li et al[57]	Exploration of ecological factors related to the spatial heterogeneity of tuberculosis prevalence in P. R. China	-	• Air quality (NO_2, PM_{10}, SO_2) • Climatic factor • Geographic factor
Lin & Liao[58]	Seasonal dynamics of tuberculosis epidemics and implications for multidrug-resistant infection risk assessment	-	• Seasonality • Temperature
Smith et al [24]	Particulate air pollution and susceptibility to the development of pulmonary tuberculosis disease in North Carolina: an ecological study	-	• Exposure to particulate matter PM_{10} and $PM_{2.5}$
Wood et al[59]	Quantification of Shared Air: A Social and Environmental Determinant of Airborne Disease Transmission	• Increase occupants in sleep space / household	• Winter month
de Oliveira & Gonçalves[16]	Social and environmental factors associated with the hospitalization of tuberculosis patients	• Alcohol use & addiction	• Housing type • Lack of daily garbage collection
Lai et al[60]	Risk of tuberculosis in high-rise and high density dwellings: an exploratory spatial analysis	• House location (lower floors)	• Air quality

Social Factors Associated with TB Transmission

A study in Bulgaria found that human migration might have contributed to the high rate of TB in the country. It was well documented that human migration to Bulgaria from other parts of the world has occurred since the 12th century, which could have caused the genetic biodiversity of MTB in Bulgaria, which could have made the bacilli more virulent.[12]

Three studies have identified smoking as a social risk factor for TB transmission. A study in Malaysia concludes that smoking status is linked to

TB infection, showing that smokers have a higher risk of developing TB transmission.[13] A study in Pakistan discovered that smokers who smoke more than 5 cigarettes per day are also at risk of contracting TB.[14] Meanwhile, a study in China found that non-smoker is a protective factor from developing TB.[15]

A study in Brazil found that alcohol use and dependency have been shown to be an important risk factor in contracting TB, as alcoholism could cause malnutrition and reduce immunity.[16]A study in Malaysia found that TB cases are higher in more developed and urban areas.[13] A study in Pakistan also found that there was a high TB incidence in the urbanised part of Gujrat City, where housing congestion coupled with high household numbers could have contributed to the high number of TB cases.[14] A study in Zhaotong, China discovered that urban residency is one of the main factors for TB transmission due to overcrowding and frequent movement of people.[15] Another study in China concludes that increased urban population density contributes to the increased burden of TB.[17] 2 studies from Ethiopia and Indonesia, respectively, confirmed that increased household density will increase the risk of developing TB.[18,19] From their findings, households with more than 4 family members have three times higher chances of contracting TB.

A study in Brazil showed a direct correlation between TB cases and localities with nonexistent or insufficient sewage treatment facilities.[20] It also demonstrated that providing basic sanitation correlates with the conditions promoting TB spread. A study in Iran confirmed that a history of imprisonment is an important factor for TB transmission among the community, aside from other sociodemographic and socioeconomic factors.[21]

Environmental Factors Associated with TB Transmission

Six studies examine air quality as a factor in TB transmission. A study in China conclude that a higher monthly average of $PM_{2.5}$ correlates with increased TB cases in the urban area of Guangzhou.[22] A study in Malaysia discovered a strong link between two primary pollutants, smoke (NO_2, CO, SO_2) and PM_{10}, and instances of TB cases.[13] Meanwhile, a study in Korea discovers that environmental variables such as SO_2 only have minor effects on TB incidence.[23] A study conducted in the USA discovered that prolonged exposure to PM_{10} and $PM_{2.5}$ may contribute to an increased risk of TB transmission.[24] Additionally, recent research in China suggests that rising levels of $PM_{2.5}$ correspond to a higher notification rate for TB and may have a spatial spillover effect on TB incidence among older adults.[8] Another study done in Chongqing, China found that 1 $\mu g/m^3$ rise in SO_2 will increase the risk of TB infection.[25]

A study in China found that farmers living in a cold environment and at high altitude were at a higher risk for TB infection, since during cold weather, people tend to stay more indoors and are exposed to more infections that could be due to poor ventilation.[26] This was also echoed by another study in China that that the annual mean temperature is related to increased TB cases.[8]

Mohidem et al discovered that heavy rainfall and high humidity were significant risk factors for developing TB in Malaysia.[13] A study in China also concludes that precipitation directly affected TB spread.[8] Zhang et al proposed that greater exposure to sunlight may lower TB incidence, likely due to vitamin D production, which is crucial for the host's response to MTB.[17] A separate study from Iran found that insufficient UV exposure significantly increases the risk of TB infection, indicating that individuals residing in homes with limited sunlight face a higher likelihood of contracting TB.[27]

Research conducted in Taiwan revealed a significant connection between seasonality and TB incidence, with new cases peaking in late spring to early summer.[2] Conversely, Wood et al. identified that TB rates are most elevated during winter, likely due to increased indoor activities that promote overcrowding.[28]

A study conducted in China found that individuals who primarily used coal for cooking and heating had nine times greater odds of developing TB infection than those who relied on electricity.[15]
A study in Ethiopia discovered that not having windows and ceilings in a home significantly increases the likelihood of occupants contracting TB.[18] Those living in a house without a ceiling face 1.46 times greater odds of developing TB. This might due to rooms with ceilings can reflect radiation more effectively than those without, potentially reducing the survival rate of airborne mycobacteria.

DISCUSSION

Demographic Dynamics

Our study discovered that migration is one of the social factors mentioned to have caused TB transmission. Migration and the permanent relocation of significant populations in new geographic areas are thought to be the key drivers of the global spread of illnesses. Emerging infections in certain geographic locations can be attributed to these events.[12] Although the risk of TB infection and disease in migrants is correlated with the incidence of TB in their home country, the migration process itself may raise the risk of contracting an infection or getting TB disease.[29] Increased exposure risk during migratory routes and different social and behavioural factors upon arrival in the host nation might also contribute to this.[30-32]

Climate and Weather

It is unclear what causes seasonality in TB cases. According to several research, spending more time in crowded, poorly ventilated areas and increasing the frequency of viral infection in the winter may contribute to spreading TB.[33] It's important to note that the increase in TB cases during spring can be partially linked to a delay in diagnosing the illness from winter.[34] Symptoms like coughs and fever can disguise the onset of a TB infection, leading to potential delays in early diagnosis, especially during the winter season.[35]

A study in the UK found that seasonality may impact vitamin D levels and the likelihood of contracting TB.[36] Vitamin D is generated by sunlight exposure. The active metabolite of vitamin D (25-(OH) D) can inhibit the growth of *M. tuberculosis* [37] by stimulating macrophages to produce more nitric oxide. Based on a study in Australia, the highest frequency of TB has been discovered in regions with decreased ultraviolet exposure and higher rates of vitamin D insufficiency.[38]

Our findings indicate that lower temperatures significantly increased the likelihood of TB transmission. A congested and poorly ventilated environment during the winter may increase TB transmission.[39] Respiratory illnesses such as influenza and respiratory syncytial virus may weaken a person's immune system, resulting in the springtime emergence or recurrence of TB illness.[40] Furthermore, there is evidence that the temperature fluctuations that occur during the winter may have an effect on the respiratory epithelium by impeding phagocytosis and decreasing mucociliary clearance, both of which increase susceptibility to infection.[41]

Additionally, environmental factors such as humidity may influence the spread of TB, altering the population's risk of infection. The incidence rate of TB in a province of Iran was discovered to be inversely correlated with the average annual rainfall, which serves as another direct indicator of humidity.[42] One possible explanation is that extended exposure to dry air could reduce the respiratory tract's capacity to generate protective mucus, subsequently impeding the growth of *Mycobacterium tuberculosis.*[43]

Air Quality and Pollution

Current studies indicated a correlation between the reporting rate of TB and atmospheric pollutants such as SO_2, NO_2 and $PM_{2.5}$.[44] Air pollution might plausibly affect a person's susceptibility to TB by damaging the tracheobronchial mucosa and triggering systemic immune responses, which could hinder the production and release of inflammatory mediators.[44]

Behavioral Factors

A study by Lönnroth et al stated that high alcohol consumption or a diagnosis of an alcohol use disorder corresponds to a three-fold increase in risk of TB.[29] Alcohol consumption may also increase mycobacteria's survival inside macrophages and reduce the generation of cytokines, which are vital for healing processes and thus increase TB transmission.[45] Research conducted in South Korea found that smoking raises the rate of TB cases, mortality rates, and the likelihood of TB recurrence.[46] Smoking alters host defense mechanisms, impacting lung function and structure, and changes pathogen clearance pathways, resulting in lung damage.[46]

Socioeconomic Status

Socioeconomic elements also play a crucial role in TB incidence; for example, poverty restricts access to healthcare, resulting in delayed diagnosis and treatment, which facilitates the disease's spread.[47] Poverty, close community interaction, and the poor quality of water supply and sanitation contribute to the increase in TB cases in rural areas.[48] According to a study conducted in Egypt, patients with TB in rural areas are more likely to experience treatment failure due to a lack of awareness regarding treatment adherence and the long distance between their homes and the treatment facility.[48] Malnutrition, frequently linked to poverty, weakens the immune system, therefore increasing vulnerability to active TB.[47]

Institutional Exposure

It has long been known that prisons present a significant risk of TB, with contact between susceptible and infectious inmates serving as the primary mode of transmission.[49] A study in South Africa showed that the annual risks of TB transmission were 90% due to excessive crowding in shared cells and inadequate active case detection of TB cases.[49]

The complex interplay of elements, including environmental variables and socioeconomic factors, creates a web of interconnected influences that shape the dynamics of TB transmission. Tuberculosis is often more prevalent among those who are economically disadvantaged, underscoring the connection between socioeconomic status and disease prevalence.[50] This suggests that TB is not solely a medical issue but is also deeply intertwined with socioeconomic and environmental factors.[51,52]

This systematic review identifies few limitations. Though TB is prevalent in various regions globally, only 27 articles meeting our search criteria were included. It's important to recognise the potential impact of publication bias, as grey literature was omitted from this analysis. Additionally, since we only considered articles published in English, there is a risk of language bias. Nevertheless, our search strategy yielded literature from multiple countries where English isn't the primary language. Despite these limitations, this review effectively synthesises research evidence concerning the social and environmental factors influencing TB transmission.

CONCLUSION

TB infection results from many factors working in tandem to increase mycobacteria infectivity and provide the necessary conditions for transmitting the disease. Although previous studies highlighted that social determinants factors as the main reason for TB transmission, environmental factors could also play a vital role in TB dissemination. Findings from this systematic review showed that environmental and socioeconomic factors, mainly housing and living conditions, poverty, air quality and pollution, climate and weather, and water and sanitation infrastructure, influence the dynamics of TB transmission. These findings can guide policymakers in improving and strengthening the TB control program.

Declarations

Conflict of interest
The authors state that they have no conflicting interests.

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Ethical Approval statement
Not applicable

Availability of data and materials
The datasets used in this study are available from the corresponding author on reasonable request

Author's contributions
SAS conceptualised the study, while DA contributed to the methodology. DA analysed the data, interpreted the results, and wrote the original manuscript draft, with SAS serving as adviser. SAS read the manuscript and provided substantial edits. All authors reviewed and approved the final manuscript. The authors alone are responsible for the views expressed in this article, which do not necessarily represent the views, decisions, or policies of the institutions with which they are affiliated. All authors reviewed and approved the final manuscript.

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