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Socio-environmental determinants of tuberculosis in South Africa

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Abstract

Correlation analysis and trend analysis were employed to study the interaction of tuberculosis (TB) incidence with other socio-environmental variables in South Africa from 2000 to 2020. The data were obtained from the United Nations database and World Development Indicators. Malnutrition, air pollution (PM2.5), population density, and urbanization were vital variables under study. Findings showed population density and malnutrition to be strongly and positively correlated with case detection of TB, and both correlations were statistically significant. Urbanization was weakly negatively correlated, whereas air pollution was weakly, non-significantly positively correlated. Findings also showed overcrowding and undernutrition to be at the core of TB in South Africa. The study emphasized the need for specific interventions in food programs and shelter to check TB transmission and improve public health. The results highlighted the importance of integrating socio-environmental considerations into tuberculosis control policy to effectively manage the disease burden in high-risk environments *(Afr J Reprod Health 2025; 29 [11]: 204-211).*

Keywords: Life expectancy, Air Pollution, health, economic, non-economic, South Africa,

Résumé

Des analyses de corrélation et de tendance ont été utilisées pour étudier l'interaction de l'incidence de la tuberculose (TB) avec d'autres variables socio-environnementales en Afrique du Sud de 2000 à 2020. Les données proviennent de la base de données des Nations Unies et des Indicateurs du développement dans le monde. La malnutrition, la pollution atmosphérique (PM2,5), la densité de population et l'urbanisation étaient des variables clés étudiées. Les résultats ont montré une forte corrélation positive entre la densité de population et la malnutrition et la détection des cas de tuberculose, et les deux corrélations étaient statistiquement significatives. L'urbanisation présentait une faible corrélation négative, tandis que la pollution atmosphérique présentait une corrélation positive faible et non significative. Les résultats ont également montré que la surpopulation et la dénutrition étaient au cœur de la tuberculose en Afrique du Sud. L'étude a souligné la nécessité d'interventions spécifiques dans les programmes alimentaires et d'hébergement pour enrayer la transmission de la tuberculose et améliorer la santé publique. Les résultats ont souligné l'importance d'intégrer les considérations socio-environnementales dans les politiques de lutte contre la tuberculose afin de gérer efficacement la charge de morbidité dans les environnements à haut risque *(Afr J Reprod Health 2025; 29 [11]: 204-211).*

Mots-clés: Espérance de vie, pollution atmosphérique, santé, économique, non économique, Afrique du Sud, tuberculose

Introduction

Tuberculosis (TB) is one of the most persistent infectious diseases worldwide today and has attracted renewed attention due to its continued health and socioeconomic impact. TB is a communicable disease primarily affecting the lungs, as it is caused by the bacteria Mycobacterium tuberculosis. The spread is through airborne droplets, as they are formed when an infected person coughs, sneezes, or speaks[1]. The illness presents with continued cough with or without blood (hemoptysis), chest pains, fever, unexplained weight loss, and fatigue. According to Obeagu and Obeagu[2], TB causes infections in both human beings and animals, and pulmonary TB is the most dangerous and common TB because it is easily spread.

Tuberculosis is a preventable and curable illness but remains a major health issue globally. During 2020 alone, about 9.9 million people were infected with TB, the single biggest killer by a pathogen until it was overtaken by the COVID-19 pandemic[3,4,5]. Globally, TB remains the second deadliest infectious disease after HIV/AIDS. The World Health Organization approximates that 10.4 million individuals contracted TB in 2020, in addition to 558,000 drug-resistant TB new cases, which exacerbate the threat of antimicrobial resistance[6,7]. South Africa appears on the top 30 high-burden countries for TB list and accounts for 3.3% of the global burden. The country is under siege from a three-fold risk: TB, TB/HIV co-infection, and multi-drug or rifampicin-resistant TB[8,9]. The risks are compounded by rampant poverty, inequality, and population over-crowding in the country. Individuals from lower socioeconomic backgrounds are not just at greater risk of developing active TB but also stand to become poorer as a consequence of the disease[10].

TB infection and development determinants are multifaceted, ranging from genetic and biological to social, economic, and environmental. Exogenous factors such as the widespread prevalence of TB within communities, malnutrition, inadequate housing, population density, and occupational exposure play a major role toward heightened susceptibility[9]. Additionally, air pollution and malnutrition are established contributing factors that compromise respiratory and immune functions, allowing for the transmission and progression of TB[11,12].

While a lot of studies have endeavored to address TB epidemiology in South Africa, there is a remarkable dearth of studies on patterns and associations of TB prevalence with some socio-environmental determinants such as urbanization, malnutrition, population density, and air pollution using visual and statistical approaches[13-15]. Most of the literature focusing on single variables or clinical determinants of TB says little about how broader determinants in the environment and social spaces shape TB prevalence trends over time.

Therefore, this study will attempt to close that gap by examining the relationship between tuberculosis incidence and some socio-environmental determinants in South Africa during the period 2000-2020. Applying trend analysis and correlation matrices, the research aims to provide a clearer comprehension of how urbanization, environmental health, and nutritional factors could determine TB trends in South Africa. The findings will be informative for the development of broad public health interventions and policies aiming at addressing the social determinants of TB.

Literature review

A quantitative descriptive study involving 207 TB patients in Limpopo Province, South Africa by Matakanye *et al*.[16] revealed that 93.25% of participants only became aware of their TB status upon diagnosis, highlighting low prior awareness. Cultural and religious beliefs significantly influenced health-seeking behaviour, with 75% visiting faith healers post-diagnosis and 76% expressing strong cultural or religious beliefs. These factors contributed to misconceptions and poor treatment adherence. The study concluded that despite ongoing TB control efforts, traditional beliefs remain a barrier to effective care. It recommended enhanced community-based health education to dispel myths and improve knowledge for better treatment outcomes.

Silva *et al*.[17] conducted a full-income analysis estimating the global economic impact of failing to meet the SDG target of reducing TB deaths by 90% by 2030. From 2020–2050, 31.8 million TB deaths could result in $17.5 trillion in losses. Meeting the target by 2030 could save 23.8 million lives and $13.1 trillion, while delaying until 2045 would save only 18.1 million lives and $10.2 trillion. The cost of delay is 5.7 million lives and $3 trillion. COVID-19 lockdowns may add $290.3 billion more. The study urged greater investment, especially in sub-Saharan Africa.

Zondo[18] investigated environmental determinants of TB incidence and mortality in Tshwane District, South Africa, using binary logistic regression. The study found that individuals aged 36–60, divorced, diabetic, smokers, or with other chronic illnesses had higher odds of TB. Occupations like mining, factory, and supermarket work were also positively associated with TB. Relapse and loss to follow-up cases showed increased TB incidence and mortality. Environmental exposures such as overcrowded households and silica dust significantly influenced TB outcomes. The study recommended coordinated efforts between environmental health and national TB programs to address these risk factors effectively.

Valencia-Aguirre *et al.*[13] analyzed TB mortality in

Colombia from 1999 to 2017, using national mortality data and census estimates to assess disparities by education, sex, and age. Of 19,720 TB-related deaths, 69% occurred in men, and nearly half were among those aged 65 and older. Mortality rates were consistently higher among individuals with the lowest education levels across all groups. The study revealed widening inequalities, with RII values of 9.7 for men and 13.4 for women, increasing annually by 8% and 1%. The authors recommended integrating social determinants and health education into national TB strategies.

Asefa *et al.*[19] conducted a case-control study among 373 HIV-positive adults on ART in Hawassa City, Ethiopia, to identify determinants of tuberculosis (TB). Using multivariable logistic regression, five key predictors were identified: older age (AOR = 2.7), rural residence (AOR = 6.4), advanced WHO clinical stage III/IV (AOR = 6.7), presence of other opportunistic infections (AOR = 3.6), and absence of 3HP prophylaxis (AOR = 0.5). The study concluded that advanced HIV stages, rural living, and co-infections increased TB risk, while 3HP prophylaxis reduced it. Strengthening TB screening and prevention among PLHIV was recommended.

Methods

This study applied the trend analysis and correlation matrix methodology to study the most dominant variables that contribute to tuberculosis in South Africa. The study used data seen from five-yearly trends between the years 2000 and 2020, gathered from the World Bank's World Development Indicators (WDI). Using the graphical trends and correlation matrix, how tuberculosis interacts with urbanization, rate of increase of population, overcrowding/population density, education, malnourishment, and air pollution, is investigated.

Estimation procedures

To explore the relationship between tuberculosis and a list of influencing factors namely, urbanization, population density, air pollution malnutrition in South Africa, a number of measures and proxies were utilized as given in Table 1. Due to the scope and objective of the study, a graphical analysis and correlation matrix analysis approach was pursued. Following health economic studies, this method offers a visually informative and comprehensive display, making it easy to identify patterns, trends, and potential relationships among the variables throughout the study [20-23].

Data analysis

To achieve the objective of this research, the methods of data analysis employed are graphs and correlation matrix. Graphs enable one to analyze and determine patterns, trends, and differences in data over time while the correlation matrix shows the direction and strength of the relationship. These techniques gives a comprehensive view of the area of study.

Ethical consideration

This study utilized publicly available statistical data from World Development Indicators (WDI). The data is anonymized and aggregated, with no risk to privacy for individuals or revelation of personally identifiable details. No sensitive or personal data was gathered or utilized in this study. Any analysis was conducted within the terms of use specified by the data providers. A definite and methodical process was adhered to throughout the research to uphold the integrity and transparency of the results. As the research did not involve human or animal participants, it did not need ethical clearance.

Results

Graphical trend

Figure 1 illustrates the pattern of tuberculosis case detection rates (TBC) against the growth of the urban population (URB) in South Africa from 2000 to 2020. Rates of tuberculosis between the two decades varied, increasing from 42% in 2000 to 56% in 2010, dropping a bit in 2015, and then increasing again to 58% in 2020. Urbanization, represented by the percentage annual growth in the urban population, was relatively small across the board, with the highest being in 2015 at 2.873% before decreasing somewhat in 2020.

Figure 2 illustrates the trend of tuberculosis case detection rate (TBC) against population density (POPD) from 2000 to 2020 in South Africa.

Table 1: Measurement of variables

Variable	Code	Measurement	Source	Expected sign
		Selected Determinants		
Urbanization	URB	Urban population growth (annual %)	WDI	+
Population Density	POPD	Population density (people per sq. km of land area)	WDI	+
Malnutrition	MNT	Prevalence of undernourishment (% of population)	WDI	+
Air pollution	AIRP	PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)	WDI	+
		Variable of Interest		
Tuberculosis	TBC	Tuberculosis case detection rate (%, all forms)	WDI	NA

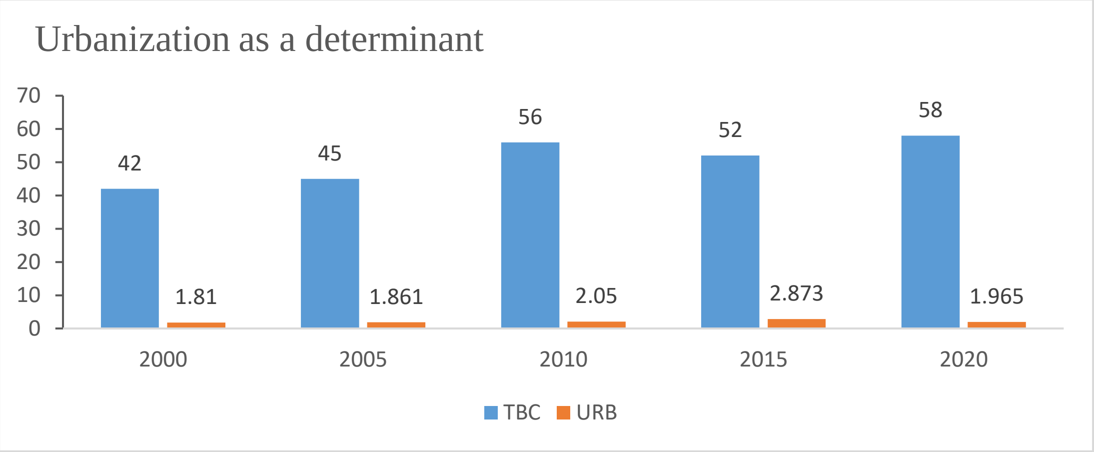

Figure 1: Urbanization and Tuberculosis in South Africa

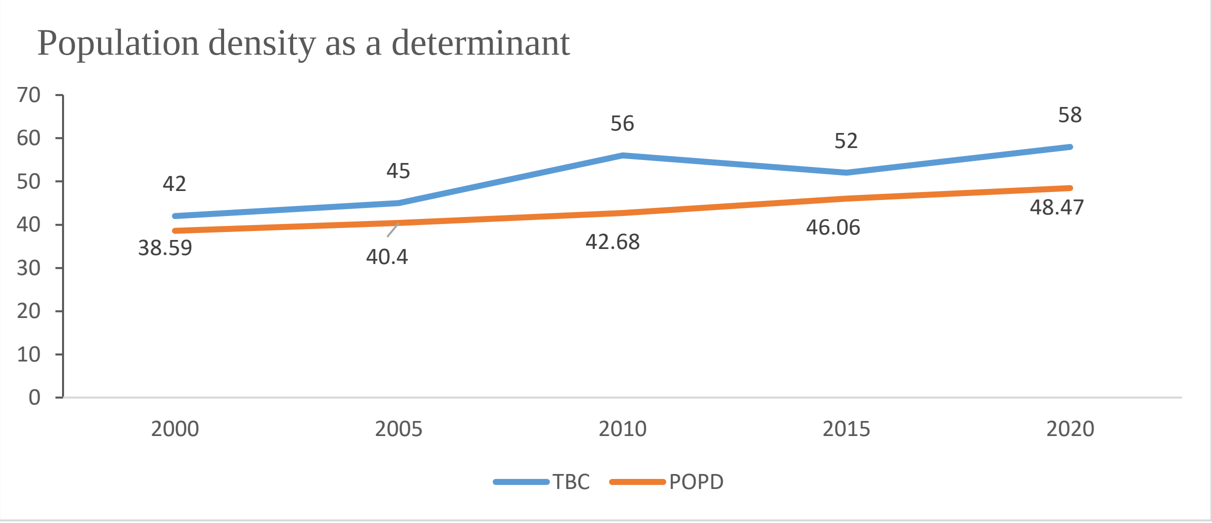

Figure 2: Population density and Tuberculosis in South Africa

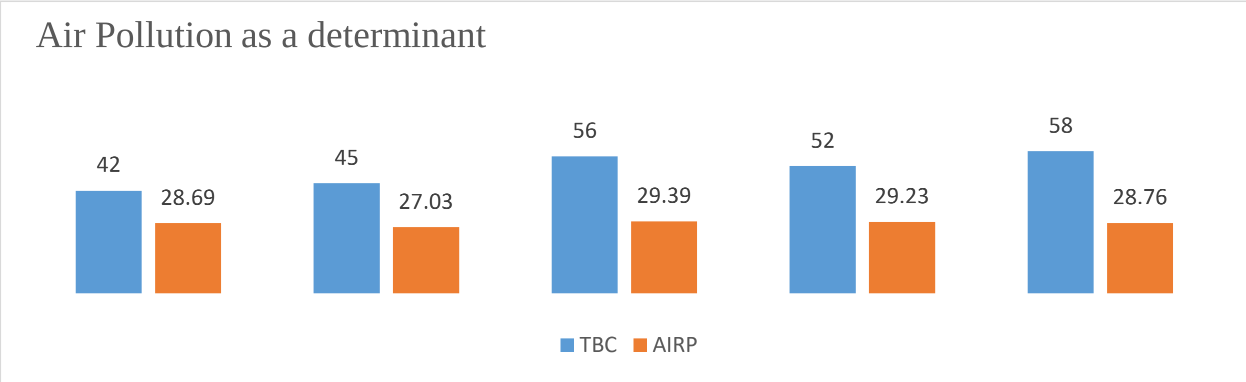

Figure 3: Air pollution and Tuberculosis in South Africa

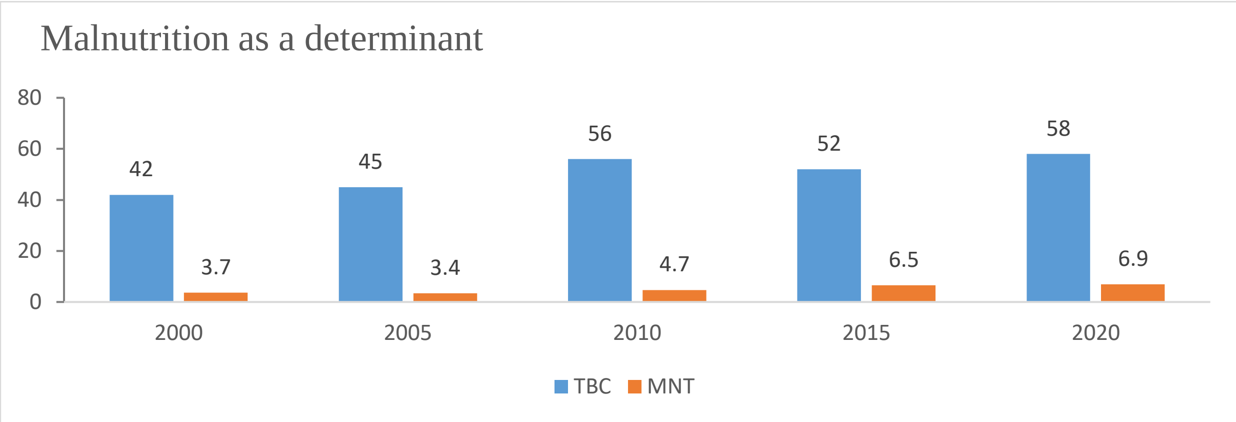

Figure 4: Malnutrition and Tuberculosis in South Africa

Both indicators have an upward trend over the two decades. Population density went up steadily from 38.59 people per square kilometer in 2000 to 48.47 in 2020, indicating growing overcrowd. Concurrently, the detection rate for TB also rose from 42% to 58%, with a drastic spike in 2010 and a slight drop in 2015 before rising again.

Figure 3 presents the trend between air pollution (AIRP in terms of PM2.5 exposure in µg/m³) and tuberculosis case detection rate (TBC) in South Africa between 2000 and 2020. The detection rate for tuberculosis (TBC) generally increased from 42% in 2000 to 58% in 2020. In contrast, levels of air pollution (AIRP) oscillated slightly but within a narrow range, falling slightly from 28.69 µg/m³ in 2000 to 27.03 in 2005, then increased to 29.39 in 2010, before remaining stable at about 29 µg/m³ through 2020.

Figure 4 demonstrates the trend relationship between tuberculosis case detection rate (TBC) and malnutrition (MNT), as measured by the prevalence of undernourishment (% of population), in South Africa for five-year intervals between 2000 and 2020. The graph displays a general positive relationship between rising malnutrition and tuberculosis rates over time. TBC stood at 42% in the year 2000, as malnutrition was at 3.7%. As malnutrition decreased slightly to 3.4% in the year 2005, TBC increased slightly to 45%. Both factors, however, began to drastically increase in subsequent years. In the year 2010, TBC had reached 56%, as malnutrition also increased to 4.7%. In 2015 and 2020, the rates continued their upward movements, with malnutrition increasing to 6.5% and 6.9% respectively, as TBC increased to 52% and 58%.

Table 2: Correlation matrix

	Tuberculosis Coefficient	Probability
URB	-0.200253	0.3372
POPD	0.809125	0.0000
AIRP	0.300655	0.1442
MNT	0.714434	0.0001

Correlation matrix

Table 2 shows the correlation coefficients and related probabilities between tuberculosis (TBC) and four potential determinants: urbanization (URB), population density (POPD), air pollution (AIRP), and malnutrition (MNT). These readings document the strength and directions of the linear associations between each of the variables and the rates of detecting tuberculosis cases in South Africa.

Urbanization (URB) also bears a negligible negative relationship with tuberculosis (coefficient = -0.200253), although the regression is not statistically significant (p = 0.3372). Population Density (POPD) is also very highly and statistically significantly correlated with TB (coefficient = 0.809125, p = 0.0000). Air Pollution (AIRP) is positively but weakly correlated with TB (coefficient = 0.300655) but is not significant (p = 0.1442). Malnutrition (MNT) exhibits high, positive, and statistically significant correlation with TB (coefficient = 0.714434, p = 0.0001)

Discussion

Outcome of the 2000-2020 analysis of tuberculosis (TB) in South Africa presents varying degrees of correlation between TB incidence and selected socio-environmental determinants, namely urbanization, population density, air pollution, and malnutrition. Correlations were ascertained through trend analysis and correlation coefficients, which give an insight into potential drivers of TB prevalence in the country for the study period.

Urbanization, as represented by the rate of growth in urban population per annum, was weakly negatively correlated with TB case detection rates. Although the relationship was not statistically significant, the trend graph (Figure 1) reveals a roughly inverse relationship that is TB rates increased modestly over the years whereas urban growth had only trivial fluctuations. This finding implies that urbanization itself may not have a major relationship with TB incidence in South Africa. One explanation for this weak association may be improved health infrastructure and access to health care in urban settings that may counterbalance the risks typically associated with urban population concentration. Through urbanization, targeted investment in health and sanitation may reduce TB risks, which would explain the lack of a strong positive correlation in line with the A-priori expectation.

Population density, on the other hand, showed a strong and statistically significant positive correlation with TB. This is supported by the pattern in Figure 2, which shows that TB detection rates increased steadily with population density between 2000 and 2020. Densely populated areas are typically susceptible to close human proximity, overcrowding of living areas, and poor ventilation- all factors that facilitate airborne transmission of TB bacteria. This connection may be particularly pronounced in slums and low-income residential areas, whose inhabitants are likely to experience poor access to health and overcrowding. This finding is in line with the A-priori expectation of this study.

Air pollution, as indicated by PM2.5 exposure (micrograms per cubic meter), was weakly positively correlated with TB prevalence but was not significant statistically. Figure 3 shows that there were some fluctuations in PM2.5 during the period of study, with small increases and decreases but no extreme deviations. While air pollution is known to worsen respiratory health and also render one more susceptible to TB and other infections, fairly stable PM2.5 levels in South Africa over the time period examined may have masked a more significant impact. Ambient air pollution may also not be indicative of indoor air quality, which is more relevant in settings where individuals spend significant periods in poorly ventilated spaces. Thus while air pollution is an environmental factor, its independent contribution to TB incidence in this case appears minimal and warrants investigation using more specific environmental and health data.

Malnutrition was a highly significant predictor of TB, with a statistically significant positive correlation. Figure 4's trend graph confirms this finding, with a clear increasing trend in undernourishment levels as well as TB case detection. Malnutrition weakens the immune system, lowering the body's resistance to TB bacteria and increasing the risk of disease in infected individuals. The relationship between TB and malnutrition highlights the critical role of nutritional support in TB care. Undernutrition and hunger prevail in the majority of impoverished populations across South Africa and often occur alongside other risk factors, such as HIV infection and inadequate sanitation.

These findings reflect broader global patterns in infectious disease vulnerability. Wang et al.[22] highlight disparities in healthcare-seeking behaviour among impoverished populations, mirroring the inequalities observed in South Africa. Diagnostic challenges raised by McAuliffe and Renton[23] further emphasize the need for early detection.

Evidence from vaccine-related immune responses by Jia et al.[24] and Xu et al.[25] shows how underlying immune dysregulation can influence disease outcomes. Additionally, Chen et al.[26] demonstrate genetic susceptibility factors relevant to TB risk.

Strength and weakness

Strength of this study is that it is a comprehensive approach, taking two decades' worth of data to analyze tuberculosis trends versus important socio-environmental variables in South Africa. Use of widely accepted global sources such as World Bank's WDI datasets brings credibility and comparability across results. Graphical and statistical methods also provide an effective visualization and measurable relationships. However, the study is far from ideal. Its reliance on secondary, aggregated data makes it impossible to measure household or individual-level variation in exposure or vulnerability to TB. Additionally, correlations are reported but causation cannot be definitively established without multivariate regression or time-series analysis. Finally, air pollution was only measured by way of PM2.5 averages and potentially overlooked other toxic emissions or local environmental factors contributing to TB incidence. Despite the aforementioned constraints, the study offers good data regarding macro-level TB determinants and offers a solid foundation for future research.

Policy implications

Based on the study findings, policy intervention would need to address overcrowding and malnutrition, which were strongly correlated with tuberculosis. Policies for decongesting the cities by subsidizing housing as well as improving slum infrastructure through government initiatives are the need of the hour. Concurrently, comprehensive nutrition programs targeting vulnerable groups such as the poor, children, and the elderly should be incorporated in TB control efforts. These can be in the form of maternal nutrition schemes, food subsidy schemes, and school feeding schemes. Additionally, increased TB early diagnosis and surveillance in crowded conditions are needed, supplemented with community outreach and mobile clinics. Increased public health interventions providing awareness on crowding and nutrition's contribution to TB should also be implemented. Cross-sectored collaboration between health, social protection, and housing sectors is critical for sustained TB reduction. These interventions, if properly implemented, can reverse the tide of TB prevalence while promoting overall social health and justice.

Conclusions

Lastly, in this study, the interlinkage between tuberculosis (TB) incidence and basic socio-environmental determinants namely urbanization, population density, air pollution, and malnutrition, were explored in South Africa between 2000 and 2020. The study employed graphical method to compare the trend of each selected determinant with that of prevalence of TB in South Africa. It also employed a simple econometric tool of correlation to measure the relationship between the chosen determinants and TB incidence in South Africa. The findings are such that the evidence demonstrates population density and malnutrition to be statistically significant and strongly associated with TB prevalence, which means poor nutritional condition and crowding are basic causes of TB persistence. In contrast, urbanization was weakly and statistically insignificant negatively correlated, possibly reflecting improvements in urban health access that can counteract risk. Air pollution was weakly positively but non-statistically significant correlated, implying the need for more precise data to assess its long-term impact on trends of TB.

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