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Global Trends, Regional Disparities, and the Role of Case Detection in Tuberculosis Mortality

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Abstract:

Tuberculosis (TB) is a significant health issue in the whole world, as it can be prevented and treated, and there are still regional inequalities, late diagnosis, and differences in case detection that prevent the achievement of effective control. This study examined global trends in TB incidence, mortality, and case detection from 2000 to 2024, assessed regional disparities, and evaluated the association between case detection ratio (CDR) and TB mortality. An ecological longitudinal design was employed using country-level panel data from the World Health Organization global TB database, comprising 5,322 country–year observations across 217 countries. Descriptive statistics, log-linear regression, and correlation analyses were conducted to assess trends and relationships. Findings showed that TB incidence declined by 3.15% annually and mortality by 5.59% annually, while CDR increased by 1.32% per year. High-burden regions, particularly Africa and South-East Asia, exhibited lower detection rates and higher disease burden. A significant inverse association was observed between CDR and TB mortality ($r = -0.436$; $p < 0.001$), indicating that improved detection is associated with reduced mortality. Although global TB outcomes have improved, substantial inequalities persist, highlighting the need for strengthened early detection, particularly in high-burden regions. Achieving TB elimination will require integrated, context-specific strategies addressing both health system performance and broader social determinants.

Keywords: tuberculosis, case detection ratio, mortality, regional disparities, global trends

1. Introduction

Tuberculosis (TB) has remained a significant international health issue of concern, being one of the top causes of death as a result of infectious diseases. Although preventable and curable, TB still poses a major problem, especially in low and middle-income nations where socioeconomic factors like poverty, malnutrition, and overcrowding increase the rate of transmission (Khan et al., 2019). Mycobacterium tuberculosis causes the disease and is mostly associated with the lungs, but extrapulmonary manifestations cause significant morbidity. Persistence of TB is an indicator of biomedical problems, as well as structural constraints in medical services. TB diagnosis and treatment are complicated and resource-demanding procedures. The timeliness in diagnosing the infection is important in minimizing the transmission and enhancing patient outcomes, yet there is a tendency to delay the diagnosis because of insufficient availability of diagnostic services and poor screening procedures (Suárez et al., 2019). The usual treatment programs involve a long-term use of many antibiotics, usually six months or more, which may cause adherence issues and drug reactions (Peloquin & Davies, 2021). These problems are also enhanced by the fact that TB has become drug-resistant, and it poses an obstacle to the global control efforts and requires more complex and expensive treatment mechanisms.

In addition to clinical management, TB is also a major factor that influences the quality of life of patients. The TB patients tend to have physical debilitation, mental stress, and social stigma, which can adversely affect the treatment adherence and recovery rates (Aggarwal, 2019). Also, TB is often comorbid with other issues, especially HIV infection, which suppresses the immune system, making one more vulnerable to active disease. TB/HIV co-infection is another clinically complex situation that needs combined healthcare (Torpey et al., 2020). Recent trends in the world show that the progress towards TB elimination is also decelerating, which leads to doubts regarding the possibility of achieving the international targets. WHO Global Tuberculosis Report 2021 also pointed to the failure in case detection and treatment, and also indicated that the global TB response is not on track (Chakaya et al., 2022). The COVID-19 pandemic has been one of the most prominent influencing factors and has interfered with healthcare services, diminished access to diagnostic facilities, and diverted resources toward TB programs. This has led to the lack of diagnosis and treatment of numerous cases, which could result in further transmission and burden of disease (Souza et al., 2022).

Early diagnosis has been a pillar of good TB control measures. The development of new technologies in diagnostics and screening methods has increased the number of cases detected; there are still gaps to serve the high-risk and underserved groups (Yayan et al., 2024). Case Detection Rate (CDR) and Case Notification Rate (CNR) are the epidemiological indicators that are necessary to monitor the TB control program performance. Regional differences in these indicators indicate differences in access to health care and programs (Mahmudah & Setiyabudi, 2023). Enhancing community engagement, as well as the strengthening of local health systems, are therefore important in the effective control of TB. The community-based interventions have become more and more popular as a way to improve the detection and management of TB. Engagement of trained community health workers or TB cadres has been demonstrated to enhance awareness, early diagnosis and treatment adherence at the grassroots (Paryanto et al., 2023). They are especially relevant in environments with a low degree of formal healthcare infrastructure. Also, it is still challenging to treat serious and rare forms of TB, including central nervous system TB, as it is complicated to diagnose and it is often fatal (Navarro-Flores et al., 2022). These aspects explain the necessity of context-specific and holistic strategies of TB control.

The current literature offers a general knowledge on TB epidemic, clinical treatment and community health interventions. The inequitable distribution of the TB burden has always been revealed in epidemiological investigations as a social determinant of the disease transmission (Khan et al., 2019). Clinical research has enhanced the knowledge on diagnostic methods and treatment protocols, emphasizing the need to intervene early and comply with the treatment (Suarez et al., 2019; Peloquin and Davies, 2021). Research has also examined the overall consequences of TB on patients, such as poor quality of life and psychosocial difficulties (Aggarwal, 2019). Research on public health has paid attention to assessing TB control programs with the help of such indicators as CDR and the success rate of treatment, and gaps in the system of detection and reports (Mahmudah & Setiyabudi, 2023). The development of TB cadres has been identified as a community-based approach that can be useful in enhancing the detection of cases and patient care (Paryanto et al., 2023). Moreover, the most recent research has investigated how co-infections and global upheavals, including the COVID-19 pandemic, affect the control of TB (Torpey et al., 2020; Souza et al., 2022). The systematic reviews have also brought to the fore the severity and outcomes of certain TB manifestations, such as CNS TB (Navarro-Flores et al., 2022). Observations in high-burden countries like India over several years have shown that there have been

consistent but disproportionate declines in the incidence and death rate of tuberculosis over the past decades, which pointed at persistent problems with the consistent control of tuberculosis in all populations (Dhamnetiya et al., 2021).

Although there is a lot of literature on the field of epidemiological indicators, there is a great disparity between the research on epidemiological indicators and the interventions in practice at the community level. There are numerous studies that focus on clinical or programmatic issues, and very little has been done in integrating the impact of local strategies on the detection rates and treatment outcomes. Also, the long-term impacts of the disruptions, such as the COVID-19 pandemic, on the TB control indicators at the community level are not fully comprehended. It is also necessary to have further evidence on how to optimize early detection strategies under resource limited context, especially in both pulmonary and extrapulmonary TB.

The research will examine the tuberculosis control measures by putting into perspective the enhancement of detection and treatment outcomes. It aims at evaluating the important TB indicators, such as Case Detection Rate and treatment success, analyzing the efficiency of the current control measures, with special emphasis put on the community-based interventions, detecting the gaps in the early diagnosis and case detection, and suggesting ways of reinforcing the TB control activities and helping to achieve the elimination targets.

2. Methodology

2.1. Research Design

The research design adopted in this study was an ecological, longitudinal study based on country-level panel data. The analysis assessed the time-lapse patterns and the relationships between the burden and detection of tuberculosis (TB) in various countries over 24 years (2000-2024). The ecological method was suitable due to the aggregated data of the data and emphasis on patterns of population level and health system performance indicators.

2.2. Data Source

The data source was a publicly available global tuberculosis database compiled by the World Health Organization (WHO), which gives country-based estimates of TB incidence, mortality and associated measures. Standardized measures of the member states are given on a yearly status and the dataset can be compared across countries over time. WHO surveillance systems and models that were employed in estimating TB burden in incompletely reporting settings generated the variables. It has data on 217 countries during the period between 2000 and 2024 (World Health Organization, 2025).

2.3. Study Population and Unit of Analysis

The population used in the study was all the countries that had data in the dataset at the time of the study. The country-year was used as the unit of analysis. Each of the observations is a set of aggregate national-level estimates per year, such as TB burden indicators, and metrics of case detection.

2.4. Study Variables

TB incidence and TB mortality were the key outcome variables and they were reported as per 100,000 of the population. TB/HIV incidence and TB/HIV mortality were also included as secondary outcomes, with the outcomes standardized per 100,000 population. The primary explanatory variable was the ratio of case detection (CDR), which is a percentage and is the proportion of estimated TB cases detected and notified. The variable year was added to test the changes in time, and the stratified analyses were made with the WHO region to test the regional difference.

2.5. Data Processing

Data cleaning entailed eliminating variables with total missingness and the identification of important variables with respect to the study objectives. The analysis excluded observations with missing values in core variables (incidence, mortality and year). Variables were reconciled and renamed in a readable manner, and all rates were kept in their standardized measures per 100,000 population.

2.6. Statistical Analysis

The descriptive statistics were calculated to estimate the distribution of all variables in terms of means, standard deviations, medians, and ranges. Annual means of TB incidence, mortality, and case detection were computed to determine the temporal trends. To determine annual percent change (APC) in terms of the average yearly percentage change of each indicator, log-linear regression models were used. Comparisons were made regionally by summing data by WHO region and mean values of each indicator were calculated. Pearson correlation and simple linear regression were used to analyze the association between case detection ratio and TB mortality. The regression model approximated the influence of the adjustments in case detection on the death rate of TB on the national scale.

3. Results

3.1. Descriptive Characteristics of the Study Dataset

After cleaning the data, 5,322 country-year observations were used in the analysis. The dataset was in 217 countries in six WHO regions between the years 2000 and 2024. The mean prevalence of tuberculosis (TB) was 138.21 per 100,000 population with a wide range (SD: 214.28), indicating major differences between low- and high-burden environments. The median incidence (53.50 per 100,000) was significantly smaller than the mean, which implies a right-skewed distribution caused by the high-burden countries. Similarly, TB mortality averaged 31.41 per 100,000 (SD: 70.45), with a median of 4.80 per 100,000. There was also a high heterogeneity in terms of TB/HIV co-infection indicators. The mean TB/HIV incidence was 38.03 per 100,000 (SD: 119.06), while TB/HIV mortality averaged 14.50 per 100,000 (SD: 45.21). The mean case detection ratio (CDR) was 66.16% (SD: 20.59), with a range of 2.6% to 190%; that is, there was large variability in the diagnostic performance of different countries. Table 1 presents the descriptive statistics of all the key variables.

Table 1. Descriptive statistics of key study variables

Variable	n	Mean	Standard deviation	Minimum	Median	Maximum
TB incidence (per 100,000)	5322	138.21	214.28	0.0	53.50	2700.0
TB mortality (per 100,000)	5322	31.41	70.45	0.0	4.80	1320.0
TB/HIV incidence (per 100,000)	4452	38.03	119.06	0.0	2.60	1320.0
TB/HIV mortality (per 100,000)	4532	14.50	45.21	0.0	0.62	510.0
Case detection ratio (%)	4983	66.16	20.59	2.6	66.00	190.0

3.2. Global Trends in TB Incidence, Mortality, and Case Detection

There were convergent and divergent trends in global TB indicators (Figure 1). The incidence of TB decreased continuously with the figures in 2000 being about 186 per 100,000 population and the figures in 2024 being below 100 per 100,000 population. The reduction in TB mortality was even more pronounced and the death rate dropped to about 53-15 per 100,000 in the identical period. Conversely, the ratio of detection of cases grew at a slow pace with high rates of about 54% in 2000 and above 75% in recent years. It was found that there was a temporary disruption around 2020, and then there was a recovery in the following years. The incidence of TB decreased at an annual rate of 3.15 percent ($p < 0.001$), whereas the rate of TB mortality fell at an average of 5.59 percent per year ($p < 0.001$). Meanwhile, the case detection increased 1.32%/year ($p < 0.001$) (Table 2). These results imply that the significant decline in TB mortality has been accompanied by the improvements in the detection and management.

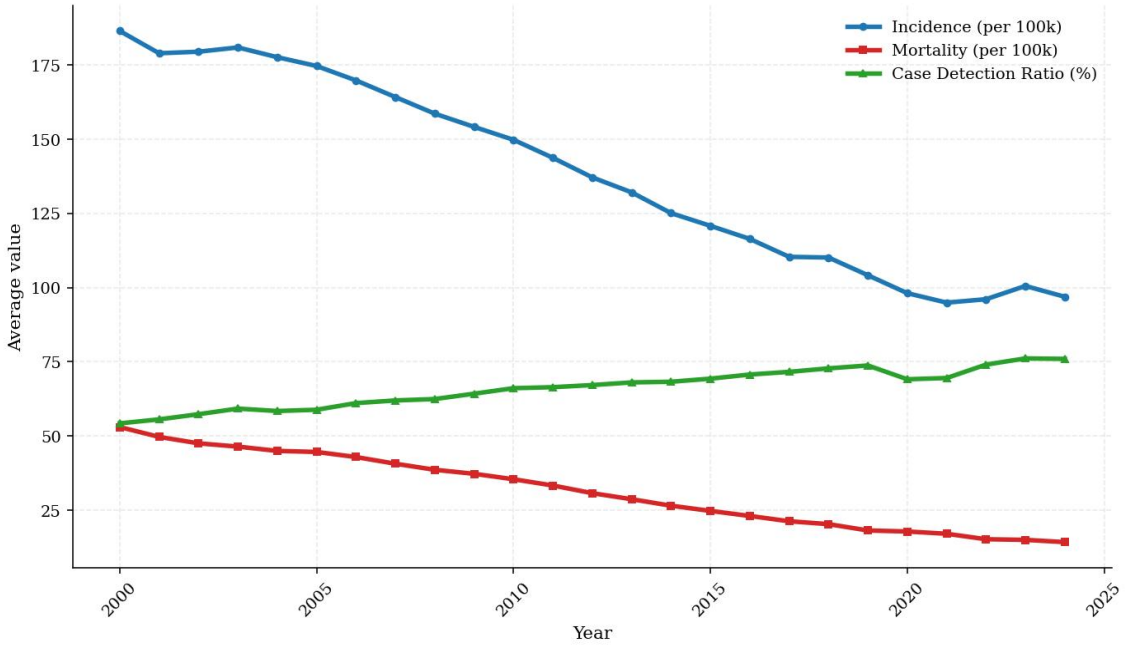

Figure 1. Global trends in tuberculosis incidence, mortality, and case detection ratio, 2000–2024.

Table 2. Trend and association results

Analysis	Annual percent change (%/year)	P-value	R^2
TB incidence (per 100,000)	-3.15	<0.001	0.973
TB mortality (per 100,000)	-5.59	<0.001	0.983
Case detection ratio (%)	1.32	<0.001	0.938
Association: TB mortality vs case detection ratio		<0.001	0.190

Table 2. Trend and association results

3.3. Regional Disparities in TB Burden and Case Detection

There were identified pronounced regional variations of the TB burden and the health system performance (Table 3; Figure 2). The African Region (AFR) was the most affected with the highest mean TB incidence (294.61 per 100,000) and mortality (88.83 per 100,000) followed by the South-East Asia Region (SEA), with incidence and mortality of 282.93 and 62.28 per 100,000. The lowest case detection ratios were also observed in these high-burden areas, and the CDR mean of 53.38% in AFR and 50.73% in SEA were the lowest. Conversely, the European Region (EUR) and Region of the Americas (AMR) had much lower TB burden and better detection performance with the CDR values of more than 75. The African Region bore a disproportionate burden of TB/HIV with a significantly higher incidence of TB/HIV (127.28 per 100,000) and mortality (50.90 per 100,000) compared to other regions.

Table 3. Regional comparison of tuberculosis indicators

WHO Region	n (countries)	Mean TB incidence	Mean TB mortality	Mean TB/HIV incidence	Mean TB/HIV mortality	Mean CDR (%)
AFR	47	294.61	88.83	127.28	50.90	53.38
SEA	9	282.93	62.28	13.35	4.98	50.73
WPR	37	173.20	24.31	8.03	2.13	64.93
EMR	22	110.76	28.52	13.66	3.43	61.59
EUR	55	45.63	4.42	2.15	0.57	75.67
AMR	46	42.18	5.18	8.86	3.59	75.65

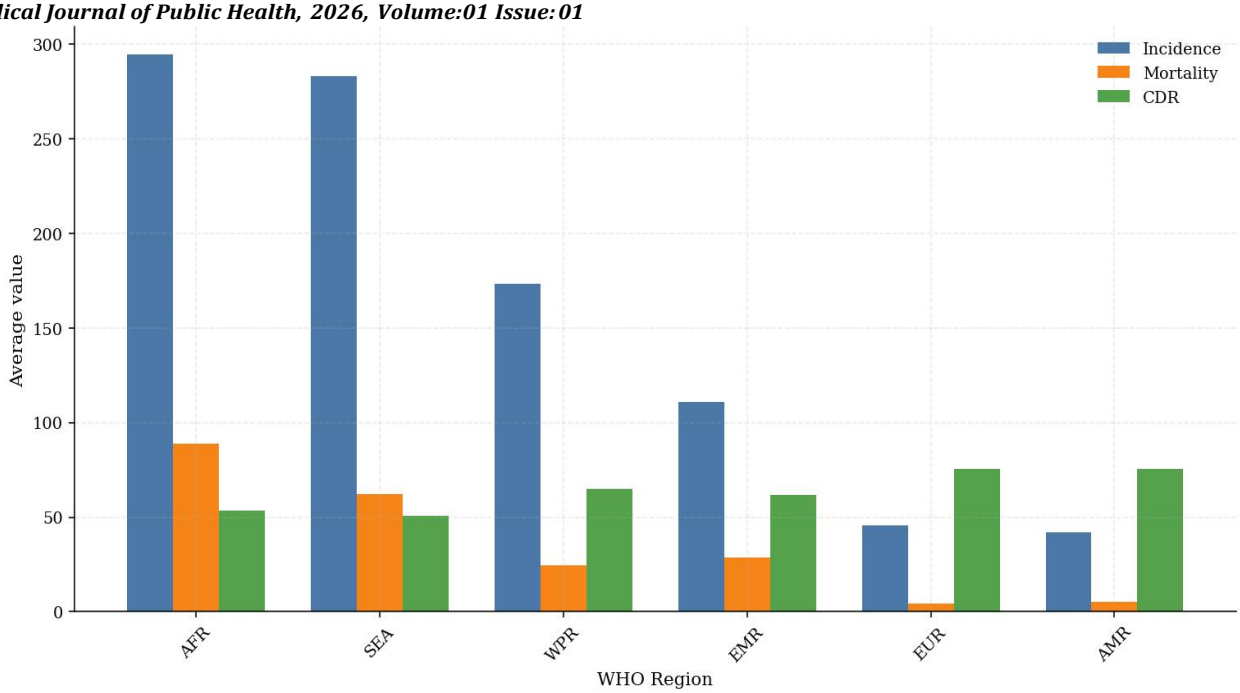

Figure 2. Regional comparison of tuberculosis incidence, mortality, and case detection across WHO regions.

3.4. Association Between Case Detection and TB Mortality

Figure 3 demonstrated that there was a statistically significant negative correlation between case detection and TB mortality. The Pearson correlation coefficient was moderately negative (r = -0.436), which means that the greater the level of detection, the lower the mortality. This relationship was affirmed by regression analysis. An increase in the case detection ratio by one unit corresponded to a 1.52-unit reduction in the number of deaths per 100, 000 population (β = -1.52, p < 0.001). According to the model, it described a variation in mortality of about 19% (R2 = 0.190), meaning that although detection of cases is a significant determinant, other factors influence the outcome of mortality.

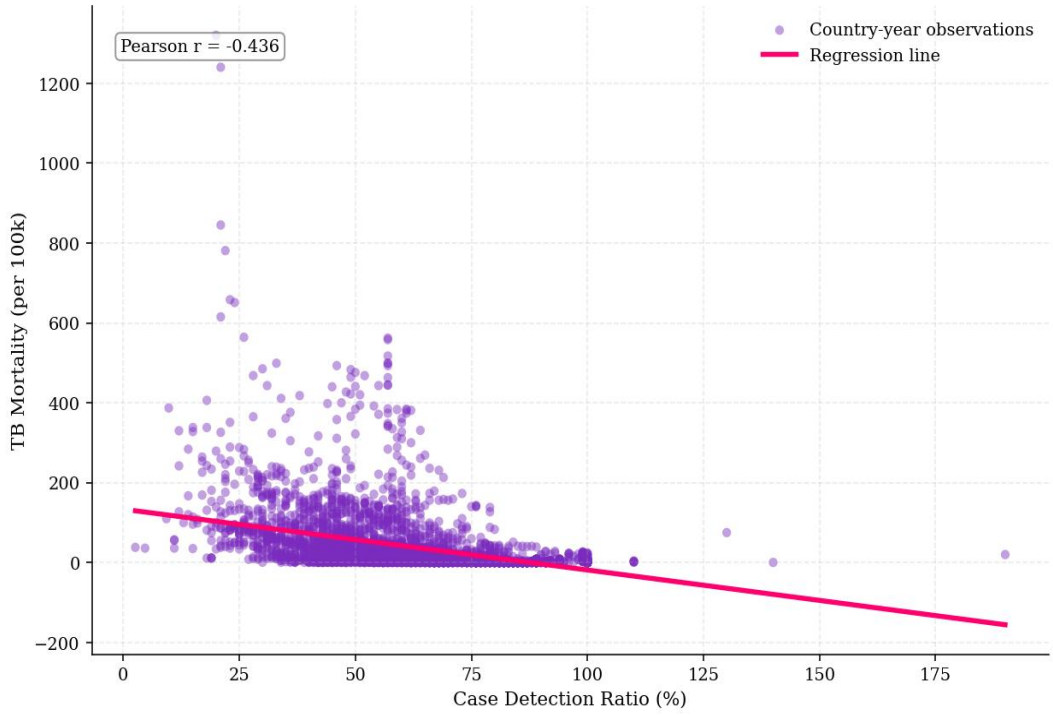

Figure 3. Association between case detection ratio and tuberculosis mortality at the country level.

Over 24 years of worldwide statistics, the incidence and mortality of TB dropped significantly, as mortality decreased more rapidly than incidence. These gains were accompanied by slow rises in case detection. Nevertheless, there exist large regional variations, with the greatest load being put on Africa and South-East Asia, where detection rates are still low. The negative correlation in the detection of cases and mortality as observed highlights the importance of early diagnosis and good performance of the health system in minimizing TB-related deaths.

4. Discussion

The reported decrease in the prevalence and mortality of tuberculosis (TB) during the period under study shows that there is an objective improvement in the world in the area of TB control, but the dissimilarity in the rate of decrease of indicators reveals the significance of underlying dynamics. The death rate declined faster than the incidence rate, which indicates that changes in access to treatment, case management, and survival rates have been more significant than the transmission decrease. Simultaneously, the progressive rise in the ratio of case detection (CDR) is indicative of the gradual reinforcement of the diagnostic systems. The presence of the inverse correlation between CDR and TB mortality proves that the higher the level of detection, the lower the number of deaths, which supports the significance of early diagnosis in the process of stopping the disease process and improving the outcomes. However, the comparatively low explanatory value of this correlation indicates that mortality is determined by a variety of factors that are not identifiable, such as the quality of healthcare, comorbidities and socioeconomic status. These interpretations are aligned with the trends and patterns of the data in the study. The unequal nature of TB control is further highlighted by the regional disparities. Both incidence and mortality, and lower rates of detection were observed in high-burden regions, especially Africa and South-East Asia. This implies that the disparities in access to diagnostic and health system capacity are still a significant problem. The TB/HIV co-infection is also concentrated in certain areas, and that is also evidence of the compound effect of overlapping epidemics that increase disease burden and complicate disease management strategies.

The results are consistent with the evidence in the world showing a slight decrease in the incidence of TB, with inequalities remaining in regions. The long-term trend analysis has revealed that the reduction in the incidence in the whole world has been uneven and strongly correlated with socioeconomic and healthcare disparities (Bai and Ameyaw, 2024). In a similar manner, the studies that have looked at the patterns of burden in the regions have indicated that Africa and Southeast Asia are still bearing an unequal burden of TB cases, mainly because of structural and systemic obstacles (Xie et al., 2025). The reported TB/HIV co-infection burden is also in line with the literature that has shown that the disease is strongly clustered in the region, especially in sub-Saharan Africa, where HIV is a strong predictor of the disease and mortality (Wang et al., 2022). Moreover, the rate at which mortality is decreasing compared to incidence is consistent with the results of longitudinal studies indicating that even slower transmission reduction can be used to decrease deaths by improving treatment and healthcare delivery (Zou et al., 2022).

The continued deadly effect in spite of detection may also be an indication of the current difficulty of multidrug-resistant TB. Drug resistance has been found to be one of the leading causes of persistent TB burden, especially in areas with a low level of diagnostic and treatment services (Ou et al., 2021). Moreover, spatial analyses have established a close relationship between TB incidence and socioeconomic inequalities and uneven development, which leads to the localization of high-risk areas (Wang et al., 2021). These results are also reinforced by the larger global burden measures that prioritize the fact that TB is still closely interconnected with the structural causes like poverty and healthcare accessibility (Kyu et al., 2018). The social vulnerability has also been mentioned as an important factor in ecological studies because it defines high-risk areas that need specific interventions (de Paiva et al., 2022).

The findings indicate that case detection is most crucial in minimizing the mortality associated with TB, which makes it important to ensure that diagnostic systems are strengthened, especially in areas with high rates of the disease. Increasing the availability of early and accurate diagnosis would go a long way in minimizing the delays in treatment taking and the disease progression. The results, however also show that detection is not enough. TB control should be addressed using integrated approaches that would focus on treatment quality, drug resistance, and comorbidities like HIV. The high state inequalities imply that global strategies can be ineffective. Rather, context-specific interventions that are to be adapted to local epidemiological and socioeconomic circumstances are to be implemented. Enhancement of community-based strategies, betterment of health system infrastructures and social determinants of health are key pillars of an integrated TB control strategy. Moreover, high TB/HIV burden still remains, and it is important to consider the necessity of incorporating TB and HIV services to address the outcomes of patients.

This research has a number of limitations. The ecological design restricts the possibility of causal relation and fails to capture individual-level

differences in risk factors, diagnosis and treatment outcomes. The country-level data can also hide the subnational differences, especially in areas where there are high levels of socioeconomic heterogeneity. Moreover, it is possible that the detection ratio of cases can be affected by differences in the accuracy of reporting and estimations of the countries.

Research in the future should also aim at integrating the individual-level and subnational data to improve the determinants of TB burden and the control outcomes. It is also necessary to investigate the contribution of drug-resistant TB and the quality of healthcare systems to the trends in mortality. The longitudinal research on the effects of changes in TB control indicators over the long term caused by the disruptions, e.g. global health crises, would be valuable. Also, to the extent that the effectiveness of integrated and community-based interventions in various settings is evaluated, the findings may be used to inform more specific and sustainable TB control measures.

5. Conclusion

The incidence and mortality of tuberculosis in the world significantly decreased during the period 2000-2024, although there were still uneven developments across the regions. The death rates decreased at a higher rate than the rates of incidence, whereas the detection of cases was gradually increasing, which means that the tightened diagnosis and management have played a beneficial role. Nevertheless, the stagnant high burden in Africa and South-East Asia, along with a relatively low case detection in these areas, indicates that significant inequities in the performance of the health systems are still unaddressed. The negative correlation between the cases and mortality emphasizes why early diagnosis is essential in decreasing the deaths caused by TB. Simultaneously, the humble explanatory value of this connection implies that mortality is influenced also by more global factors such as the quality of treatment, HIV co-infection, drug resistance, and socioeconomic susceptibility. The outcomes of TB elimination will rely on both scaling up detection and on enhancing integrated care, health system strengthening, and dealing with structural hindrances that perpetuate transmission and unfavorable results. The region-specific targeted approaches are needed to reduce the inequality and speed up the global TB control.

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