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Socio-demographic and environmental factors associated with tuberculosis infection among children less than 15 years in Hhohho region of Eswatini (Swaziland)

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Objective: Tuberculosis (TB) is one of the most prevalent public health challenges, particularly in developing countries where poverty, lack of sanitation and improper housing exacerbate the spread of infectious diseases. This study aimed to determine the socio-demographic and environmental factors associated with TB infection among children in the Hhohho region of Eswatini.

Methods: We conducted a cross-sectional study among children under 15 years diagnosed with TB (2022–2023) in Eswatini's Hhohho region, identified through hospital records. Data were collected via a structured survey and medical record review to assess environmental and socio-demographic risk factors. A Social Vulnerability Index (SVI) was constructed using 13 binary indicators to quantify cumulative social and environmental disadvantage. Social Vulnerability Index (SVI) from the Centers for Disease Control and Prevention (CDC) was utilised to investigate whether higher vulnerability correlates with a greater prevalence of TB symptoms.

Results: A high proportion (64%) of children were socially vulnerable, indicating multidimensional disadvantage. Children who are socially vulnerable face a significantly higher burden of TB symptoms (94%) compared to their less vulnerable peers (78%). Thus, social disadvantage directly increases health risks in children. The Expanded SVI therefore serves as an important indicator of social determinants of TB risk in the study population

Conclusion: These results strongly suggest a need for targeted public health interventions that prioritize children who are economically disadvantaged. There is an ever-increasing need for policies that address upstream social determinants such as poverty, overcrowding, and poor nutrition that heighten TB risk.

KEYWORDS

Africa, environmental health, social determinants, social vulnerable index, vulnerability

1 Introduction

Tuberculosis (TB) primarily affects the lungs and is brought on by the *Mycobacterium tuberculosis* bacteria (1). In 2021, there were about 10.6 million new cases of TB, with 1.2 million of those cases involving children under the age of 15 (2). Globally, tuberculosis is one of the most prevalent infectious diseases that cause death. Of these cases, 23% were in the World Health Organization (WHO) African Region (2). *M. tuberculosis* propagates through air from one person to another. When people infected with lung TB cough, sneeze, or spit, they spread the TB bacteria into the air (1). After inhaling the bacteria, a person becomes infected but does not exhibit any symptoms and cannot spread the infection to others until they have active tuberculosis. After infection, active TB may appear two to ten weeks later (1). People with diabetes, weakened immune systems, malnutrition, and tobacco use are more likely to contract tuberculosis (3). A person who has TB may experience the following common symptoms: fever, night sweats, weakness, exhaustion, chest pain, and a persistent cough (3). TB can affect any part of the body, including the brain, bones and joints, lymph nodes, and other organs (4). Transmission of the disease can be prevented by timely diagnosis and treatment of active TB to stop infectiousness, good hygiene, good ventilation, natural light, as well as Bacillus Calmette-Guerin (BCG) vaccination (4). However, child and adolescent tuberculosis is not easy to diagnose and treat (2).

Eswatini is one of the low- and middle-income (LMIC) nations where the burden of TB is high, despite recent declines in the disease's prevalence (5). After TB disease was declared a national emergency in 2011, the nation launched a rapid, multi-sectoral response to end the TB crisis (6). Tuberculosis remains a public health issue in the county despite these initiatives. Several environmental factors, including living conditions like overcrowding, ambient tobacco smoke, poor smoking, inadequate ventilation, moisture, and temperature, are linked to TB infection (7). The study sought to determine the socio-demographic and environmental factors associated with TB among children in the Hhohho region of Eswatini.

It is increasingly acknowledged that tuberculosis in children contributes significantly to the burden of global tuberculosis. Households continue to incur substantial costs due to tuberculosis disease, despite significant progress in the fight against the disease following the implementation and scaling up of strategies of the World Health Organization (4). Eswatini is among the low-income countries still experiencing a high tuberculosis burden, yet there are few studies in the country that are specifically addressing issues of tuberculosis among children younger than 15 years old. Consequently, this research will contribute to existing literature. The study aimed to determine socio-demographic and environmental factors associated with tuberculosis disease among children younger than 15 years old in the Hhohho region, Eswatini, and to identify appropriate intervention measures to reduce the high prevalence of tuberculosis disease. There were three study objectives: (1) to determine the prevalence of tuberculosis among children under

the age of 15 in the Hhohho region, Eswatini; (2) to describe the socio-demographic and environmental factors associated with tuberculosis among children under the age of 15 in the Hhohho region, Eswatini; and (3) to determine the association between socio-demographic and environmental factors among children under the age of 15 in the Hhohho region of Eswatini and tuberculosis, taking into consideration confounders. The study objectives focused on estimating prevalence and examining associations within the study period and did not include assessment of temporal trends.

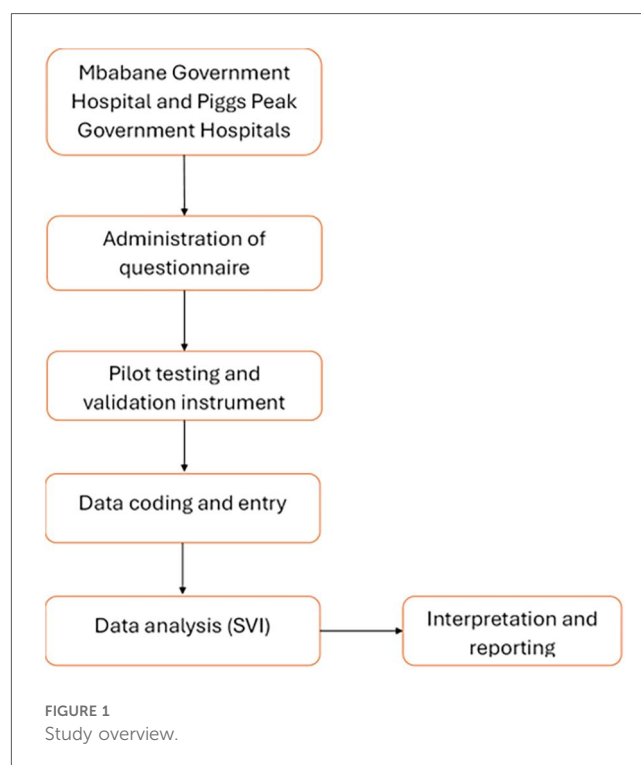
2 Materials and methods

2.1 Study design and setting

This was a cross-sectional, retrospective study. Medical records from Mbabane Government Hospital and Piggs Peak Government Hospital were used to extract data for TB cases (Figure 1). These hospitals were selected because they are the main referral facilities for their respective regions and maintain complete paediatric TB records. Health centres do not routinely maintain comparable admission registers.

2.2 Data sources and data collection procedures

A purposive, feasibility-based sampling technique was employed for the questionnaire component of the study (Figure 1). Probability or random sampling was not employed



since the medical records are retrospective in nature and facility-based and the sampling frame was limited to children with confirmed TB diagnoses recorded at Mbabane Government Hospital and Piggs Peak Government Hospital who had complete medical records and available caregiver contact information. Incomplete contact details, loss to follow-up, and caregiver unavailability further constrained the use of random sampling methods.

2.2.1 Review of medical records

Admission and outpatient TB registers for all available paediatric admissions and outpatient visits were systematically reviewed to calculate the percentage of the total admissions related to TB in children under 15 years.

2.2.2 Administration of questionnaires

Questionnaires were administered to parents/caregivers/guardians of children below 15 years old who were diagnosed with TB from 2022 to 2023 in the Hhohho region of Eswatini and checked for correctness, completeness, and accuracy. The variables that were measured in the study questionnaires were tuberculosis, environmental factors (i.e., overcrowding in the house, cold conditions in the house, lack of air circulation in the house, energy source used for cooking in the house, energy source used for heating in the house, and sanitation conditions in the house), socio-demographic factors (age, gender, caregiver/parent/guardian's educational level, and history of TB in the family, employment status of the child's caregiver/parent/guardian). Data coding to facilitate data entry was then carried out using Statistical Package for Social Sciences version 25 software.

2.3 Pilot testing of the questionnaire

A pilot study with 12 participants was conducted to guarantee the reliability of the study questionnaires. The participants were asked the same questions that were asked to study participants on one day and then after a day, the same 12 subjects were asked the same questions again. The researcher then checked whether they answered the same answers and any questions where answers were confusing or inconsistent were revised.

2.4 Validity procedures for data collection instrument

Proper and inclusive response options were made available for each question to be certain that they cover every possible response needed to answer all research questions. The content of the questions was checked against the reviewed literature and the research questions. In addition, the researcher made sure that the language used when writing questions was clear and unambiguous to minimise misinterpretation and response errors. The instrument was piloted to check that all questions were valid in relation to the study population.

2.5 Inclusion and exclusion criteria

The inclusion criteria were parents/guardians/caregivers of children below the age of 15 years diagnosed with tuberculosis in the Hhohho region, Eswatini; parents/guardians/caregivers of children diagnosed with tuberculosis between 2022 and 2023; and parents/guardians/caregivers of children who had adequate information on the child and household conditions. Exclusion criteria were parents/guardians/caregivers with children above 15 years old; parents/guardians/caregivers of children below the age of 15 years who were not diagnosed with tuberculosis between 2022 and 2023 in the Hhohho region; and participants who did not have adequate information on the child and household conditions.

2.6 Sample size calculation

The population size is the total population of children under 15 years old in the Hhohho region, which is 115 642 (Eswatini Statistics, 2023). Using EPINFO 7.2, with an estimated 2023 population of 115 642 in the Hhohho region of Eswatini, the acceptable error margin is 5% (95% confidence), and with one cluster the estimated sample size at 95% confidence level is $N = 383$ (Table 1).

In this study, the actual sample size was 50 participants, determined based on the number of cases with available contact information identified during the review of hospital registers at Mbabane Government Hospital and Piggs Peak Government Hospital. The 50 participants were a total of all cases with available contact information from the number of cases identified during medical records review at Mbabane Government hospital and Piggs Peak Government hospital.

2.7 Ethical approval

For review and approval, the research proposal was sent to the Higher Degrees and Research Ethics Committee and the Departmental Research Committee of the University of Johannesburg. Approval was given from the Eswatini Health and Human Research Review Board to conduct the study (EHHRRB 105/2024). Participants were made aware of the purpose of the study as well as the requirements for their participation. We informed them that they could withdraw from

TABLE 1 Sample size estimation using EPINFO 7.2.

Confidence level (%)	Cluster size (n)	Total sample (N)
80	164	164
90	270	270
95	383	383
97	469	469
99	660	660
99.9	1 073	1 073
99.99	1 495	1 495

the study at any time without facing any consequences and that participation was completely voluntary. Informed consent forms were given to participants who agreed to participate in the study, asking them to sign them to confirm their participation.

2.8 Data analysis

In the analysis a social vulnerability index (SVI) was computed. An SVI is a composite measure designed to capture multiple dimensions of social and environmental disadvantage that may predispose individuals or households to adverse health outcomes. This approach is grounded in the US CDC framework and was adapted using local relevance, as guided by the (8). model, which applied an SVI to the South African context. The objective was to use available variables from our dataset to calculate an SVI score and investigate whether higher vulnerability correlates with TB symptom prevalence.

From the dataset, 13 variables identified as directly relevant to social and environmental vulnerability were selected. These variables were unemployment (caregiver), low education level (primary or no education), food insecurity, household crowding (>4 people), lack of basic sanitation (no flush toilet), unsafe water source (river, well, borehole), stored water in large containers, condensation/mould, dust exposure, lack of windows (poor ventilation), indoor smoking, presence of animals/pets indoors, and polluting fuel use (firewood, paraffin). Each variable was recoded as a binary indicator (1 = vulnerability present, 0 = absent). The 13 binary indicators were added for each participant to obtain a total SVI score ranging from 0 to 13. The threshold for high vulnerability was set at SVI Score ≥ 7 , based on the median distribution and precedent from similar studies. For each variable percentile ranks were calculated. A new binary classification was created: socially vulnerable expanded = 1 if score ≥ 7 and socially vulnerable expanded = 0 if score < 7 . Out of 50 participants: 32 (64%) were classified as socially vulnerable (SVI ≥ 7) and 18 (36%) were classified as not socially vulnerable (SVI < 7).

To examine the associations between vulnerability indicators and TB symptoms more formally, a Fisher's Exact Test was conducted, two sided, alpha 0.05, in IBM SPSS Statistics version 29. This test compared TB symptom status (Yes vs. No) across each indicator: caregiver unemployment, household crowding, defined as 5 or more people per household, polluting cooking fuel, absence of basic sanitation, no flush toilet, indoor smoking, and poor ventilation, fewer openable windows.

3 Results

3.1 Characteristics of the population

The sample consisted of 50 children. A total of 46% of participants were between 0 and 4 years of age, 30% were aged 5 to 9 years, and 24% were between 10 and 14 years. This skew toward younger children reflects higher biological susceptibility

to TB in early childhood. The gender distribution showed a predominance of males (60%) compared to females (40%).

Regarding caregiver employment, a higher proportion of caregivers in the vulnerable group were unemployed (65.2%) compared to 48.1% in the non-vulnerable group. Similarly, 43.5% of vulnerable caregivers had only primary education, and only 13% had tertiary education, in contrast to 40.7% of caregivers in the non-vulnerable group with tertiary education. These disparities suggest a link between higher social vulnerability and poorer socio-economic status.

Overall, 88% of the children presented with TB symptoms, with symptom prevalence being slightly higher among the non-vulnerable group (88.9%) compared to the vulnerable group (87.0%), possibly due to random variation or unmeasured protective factors. Table 2 presents a composite summary of these characteristics.

3.2 Prevalence of tuberculosis among children (<15 years) in study facilities

To provide epidemiological context for the vulnerability and symptom analyses, the prevalence of tuberculosis among children younger than 15 years was assessed using outpatient and inpatient TB registers at Mbabane Government Hospital and Piggs Peak Government Hospital for the years 2022 and 2023. The results, summarized in Table 3, show the proportion of TB cases among all paediatric (under 15 years of age) hospital attendees.

Across both facilities and years, the overall prevalence of tuberculosis among children under 15 was 0.2%. The prevalence was slightly higher at Mbabane Government Hospital and increased in 2023 compared to 2022. This facility-based prevalence provides important context for interpreting the much higher burden of TB symptoms identified in the subsequent SVI-targeted analysis.

TABLE 2 Socio-demographic and TB symptom characteristics of the study population by SVI classification (N = 50). Percentages do not add to 100% due to missing data.

Variable	Category	Not vulnerable (%)	Vulnerable (%)
Gender of Child	Female	41	39
	Male	59	61
Age Group (Years)	0–4	48	44
	5–9	30	30
	10–14	22	26
Caregiver Employment Status	Employed	52	35
	Unemployed	48	65
Caregiver Education Level	No education	4	4
	Primary	26	44
	Secondary	30	39
	Tertiary	41	13
TB Symptoms Reported by Child	No	11	13
	Yes	89	87

TABLE 3 Facility-based prevalence of TB among children <15 years, Hhohho Region, Eswatini (2022–2023).

Facility name	Year	All Patients <15, n	TB Cases <15, n (%)
Mbabane Government Hospital	2022	7,865	11 (0.14)
Piggs Peak Govt Hospital	2022	5,513	4 (0.07)
Mbabane Government Hospital	2023	7,650	25 (0.33)
Piggs Peak Govt Hospital	2023	4,219	10 (0.23)
All Facilities, Both Years		25,247	50 (0.20)

An additional 13 TB cases at Mbabane Government Hospital (8 in 2022, 5 in 2023) were not included due to unavailable contact information.

3.4 SVI score distribution

SVI scores in this population revealed a marked concentration of vulnerability. While scores ranged from 0 to 10, the distribution was right-skewed, with most children exhibiting moderate to high cumulative exposure to risk factors. Nearly two-thirds of participants scored 7 or above—the defined threshold for high vulnerability in this analysis.

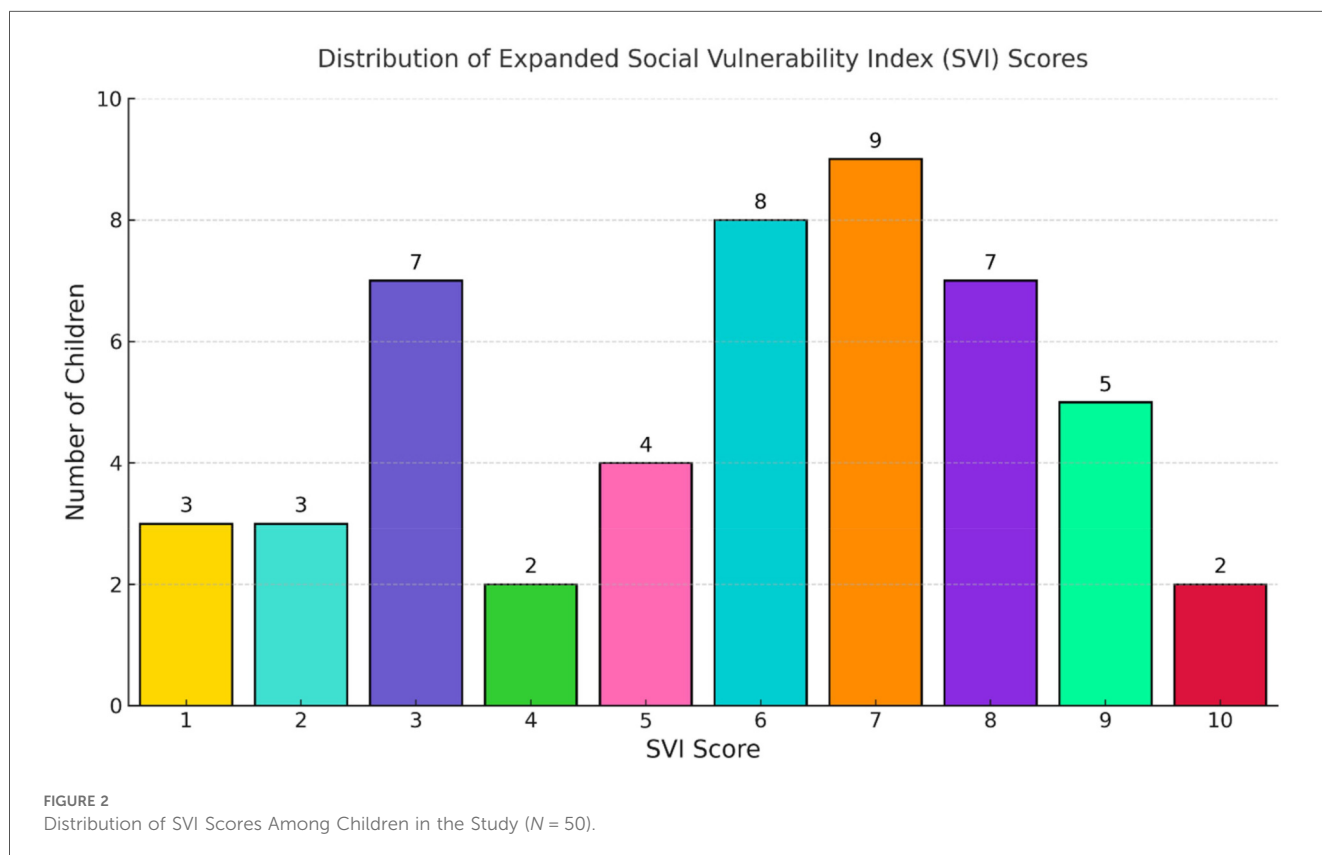
Figure 2 illustrates the distribution of vulnerability levels among participants, showing a noticeable skew toward higher vulnerability. A significant proportion of children meet 6–9 of the criteria. Additionally, the figure highlights that most participants scored between 6 and 9, with a peak at score of 7. This supports the use of 7 as a cutoff point for defining social vulnerability.

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This figure illustrates the distribution of vulnerability levels among participants, showing a noticeable skew toward higher vulnerability. A significant proportion of children meet 6–9 of the criteria. Additionally, the figure highlights that most participants scored between 6 and 9, with a peak at score of 7. This supports the use of 7 as a cutoff point for defining social vulnerability. These results suggest that the SVI is not only a valid tool for summarising risk, but also a potentially powerful instrument for guiding targeted TB screening and response strategies in resource-constrained settings (9).

3.5 TB symptoms prevalence by vulnerability classification

A clear disparity emerged in TB symptom prevalence between vulnerable and non-vulnerable children. Among those classified as vulnerable (SVI ≥ 7), 94% exhibited TB symptoms. In contrast, 78% of children with lower vulnerability scores were symptomatic. While TB symptoms were common across both groups, the gap suggests that children exposed to greater cumulative disadvantage are substantially more likely to be symptomatic.



Although overall prevalence was high, the data reveal an intensifying effect of cumulative vulnerability (Figure 3). This distinction underlines the value of the SVI in differentiating levels of risk within a uniformly high-burden population.

3.6 TB symptom prevalence across individual SVI scores

When examined across the full range of SVI scores, TB symptom prevalence displayed a non-linear but consistently elevated pattern. Children with mid-range scores (2–6) were universally symptomatic. A modest dip was observed at score 7, where symptom prevalence fell to 77.8%, but rose again at scores 9 and 10.

Figure 4 visualises the percentage of children with and without TB symptoms across different SVI scores (0–10). First it reveals high TB symptom prevalence across all SVI scores: All children with SVI scores from 2 through 6 show 100% prevalence of TB symptoms; and even children with SVI scores of 0 and 1 still show notable symptom rates (83% and 67%, respectively). Secondly, it reveals that there is no linear pattern, but consistently high vulnerability: while one might expect increasing SVI scores to correspond with increasing TB symptoms, the relationship is not strictly linear, but symptom prevalence is consistently high (above 80%) for most scores; and this suggests that even low to moderate social vulnerability may significantly contribute to TB symptom burden. Thirdly, it reveals that score 7+ contains a mix: At SVI Score 7, there's a

visible drop in symptomatic percentage (to ~75%), indicating the presence of asymptomatic children even in vulnerable settings; and this might reflect noise due to small sample size or other mediating factors (e.g., care-seeking behaviour, nutrition, immunity).

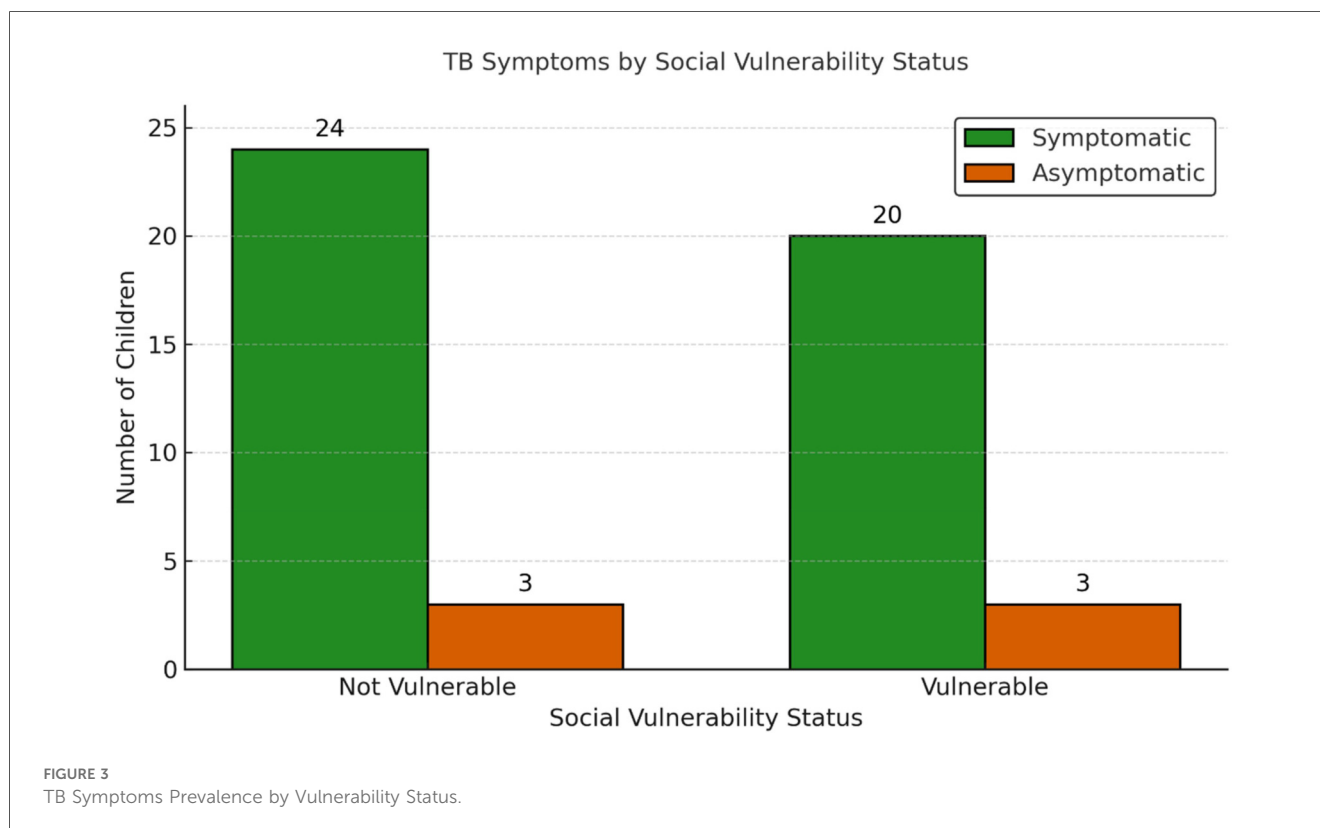
3.7 TB symptoms by individual vulnerability indicators

Several individual SVI indicators were particularly associated with elevated symptom prevalence (Table 4). These included caregiver unemployment, household crowding, use of polluting fuels, and poor sanitation—each contributing to symptom rates exceeding 90%. Indoor smoking, although less common, was universally associated with TB symptoms in the small subset of children affected.

The high prevalence associated with specific indicators reinforces the rationale for composite vulnerability measurement. These findings support targeting interventions not just based on disease incidence but also on upstream predictors of exposure and delayed care-seeking.

3.8 Fishers exact test

As summarised in Table 5 below, none of the differences reached statistical significance, p greater than 0.05. This is consistent with the small sample size ($n = 50$) and the uniformly



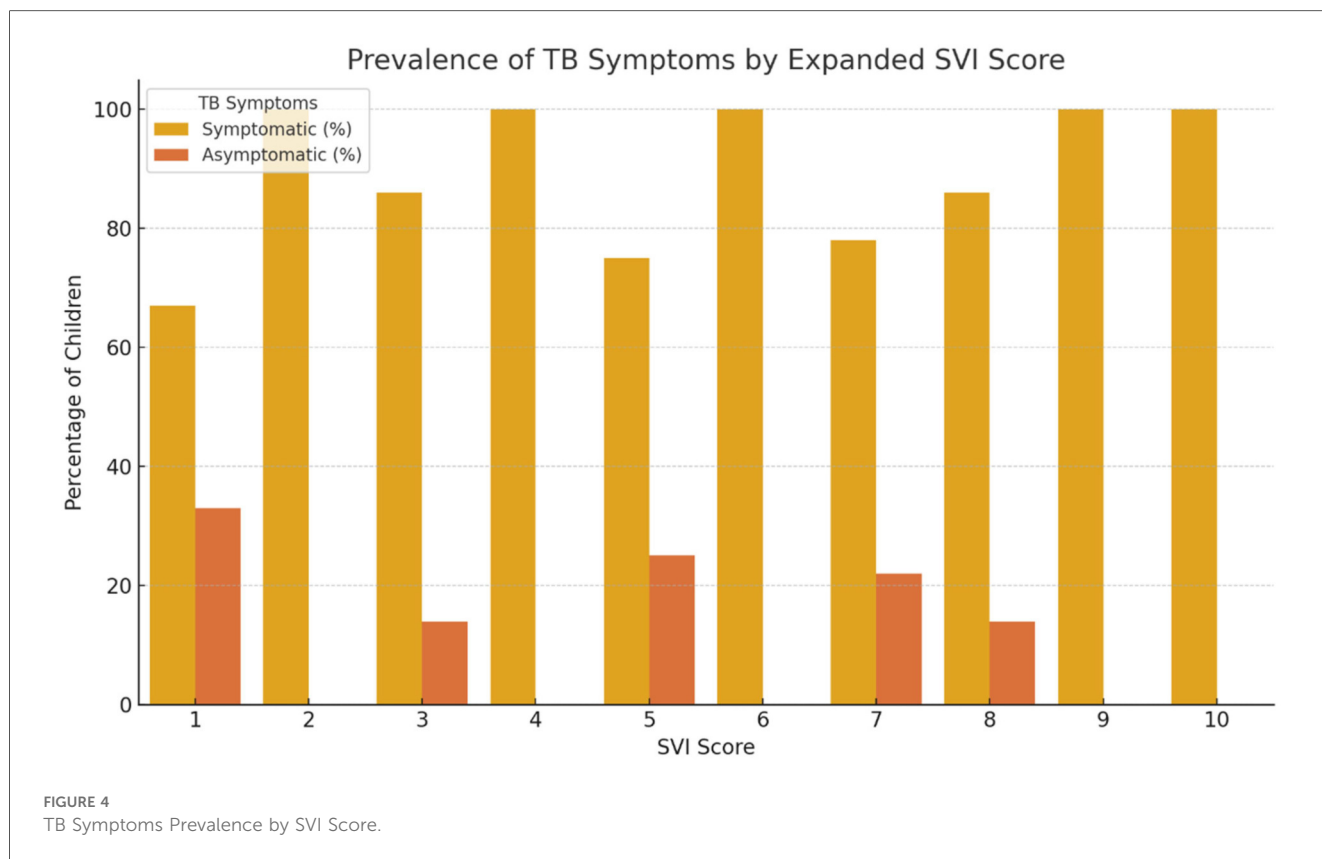


TABLE 4 TB symptom prevalence by selected vulnerability indicators.

SVI Indicator	Present (n)	TB Symptoms (n)	Prevalence (%)
Caregiver unemployed	28	26	92.9
Crowded household	33	30	90.9
Polluting fuel used	25	23	92.0
No flush toilet	30	28	93.3
Indoor smoking	4	4	100.0

high symptom prevalence across exposure categories, which reduced statistical power. Even so, the descriptive patterns align directionally with known social determinants of childhood TB, indicating that children living in socioeconomically disadvantaged or environmentally constrained households experienced higher symptom burden.

4 Discussion

This chapter discusses the key findings of the study in relation to existing evidence on the social determinants of tuberculosis (TB) in children, particularly within low- and middle-income countries (LMICs) like Eswatini. The discussion explores the implications of using a Social Vulnerability Index (SVI) to identify risk for TB symptoms, contextualises results with local and global literature, acknowledges methodological limitations,

and provides actionable recommendations for practice, policy, and future research.

The central finding of this study was the exceptionally high prevalence of TB symptoms (88%) among children under 15 years in the Hhohho region. This burden was disproportionately concentrated in households classified as socially vulnerable (SVI ≥ 7), where 94% of children exhibited TB symptoms. Even in households with lower SVI scores, TB prevalence remained strikingly high, suggesting that any accumulation of social risk factors sharply increases TB vulnerability in children.

Importantly, TB symptoms were not randomly distributed across the sample but were patterned according to systemic social and environmental factors. For instance, children living in households with unemployed caregivers, poor sanitation, use of polluting cooking fuels, or inadequate housing ventilation experienced the highest levels of TB symptomatology. These results are consistent with longstanding knowledge that TB is a disease of poverty, exacerbated by undernutrition, overcrowding and poor environmental hygiene.

The non-linear pattern observed in symptom prevalence across SVI scores (e.g., high rates at mid-range scores, a dip at SVI=7, and a return to 100% at scores 9–10) suggests a possible “saturation” effect. Once multiple vulnerabilities are present, the child’s risk of TB symptoms approaches certainty. The slight variability may reflect unmeasured protective factors such as better nutrition, more proactive care-seeking, or variations in immune response, which warrant further investigation.

TABLE 5 Fisher's exact test for tuberculosis symptoms and individual vulnerability indicators.

Indicator	Present (n) ^a	TB symptoms if present (%) ^b	Absent (n)	TB symptoms if absent (%) ^b	Odds ratio	Fisher <i>p</i> value (two-sided)*
Caregiver unemployed	28	82.1	22	95.5	0.22	0.2109
Crowded household (≥ 5 people)	0	—	50	88.0	—	1.0000
Polluting cooking fuel	17	88.2	33	87.9	1.03	1.0000
No basic sanitation (no flush toilet)	15	93.3	35	85.7	2.33	0.6540
Indoor smoking	11	81.8	39	89.7	0.51	0.6014
Poor ventilation (fewer openable windows)	14	92.9	36	86.1	2.10	0.6627

^a“Present” indicates exposure present, ^bpercentages are row percentages within exposure strata. Odds ratios may be undefined when cell counts are zero, * $\alpha = 0.05$.

The findings of this study align with previous research highlighting how structural and environmental determinants are critical in shaping TB risk among children. For example (8), applied a multidimensional SVI in a South African context and found similar clustering of disease burden in communities with high social vulnerability. Our use of a similar index in Eswatini further validates this approach in identifying vulnerable children who may otherwise be overlooked using conventional risk criteria.

Additionally, WHO (2) reports that paediatric TB remains underdiagnosed in many LMICs due to systemic challenges in health access and lack of child-sensitive diagnostics. The high rates of TB symptoms observed here could reflect both true infection and delayed detection, particularly in marginalized, high-SVI households with reduced access to healthcare facilities (10).

Notably, studies in other high-burden settings have similarly implicated crowding, caregiver education level, and use of biomass fuels as consistent predictors of childhood TB (1). This triangulates well with the current study, where these factors were prominent in both the overall SVI and the individual indicators most strongly associated with TB symptoms.

4.1 Limitations

A limitation of the study is that the cross-sectional design precludes establishing causality. Associations observed between vulnerability and TB symptoms cannot confirm temporal or causal relationships. Another limitation of the study was the small sample size. With only 50 participants, the study could not perform multivariable logistic regression or explore subgroup analysis (e.g., by HIV status or age group). Data were collected from the two main referral hospitals for their respective regions and maintain complete paediatric TB records and not other health centres.

4.2 Future research perspective

This study highlights critical links between social vulnerability and paediatric TB in Eswatini, yet it also underscores several areas where further research is urgently needed. First, longitudinal studies are required to better understand the causal pathways through which social disadvantage, household crowding, poor

nutrition, and environmental exposures interact to elevate childhood TB risk. Cross-sectional designs, while informative, cannot fully capture the temporal dynamics of exposure, infection, and progression to active disease.

Future work should refine and validate SVI tools for low-resource African settings. Although the adapted SVI proved useful in quantifying disadvantage, locally contextualised indices—incorporating factors such as informal settlement characteristics, caregiver HIV status, biomass fuel exposure, and food insecurity—may provide greater predictive accuracy. Mixed-methods studies involving community stakeholders could strengthen the cultural relevance and interpretability of these indices. Spatial epidemiological studies integrating geocoded SVI data with environmental, climatic, and housing-quality indicators would help identify high-risk neighbourhoods and micro-environments. Such analyses could guide targeted interventions, including ventilation improvements, social protection programmes, and enhanced TB screening in vulnerable communities.

5 Conclusion

This study explored a range of socioeconomic factors, including parental/guardian unemployment, crowded households, use of dirty fuels, absence of flushing toilets, and indoor smoking, among other socioeconomic determinants. Our study indicates that children who are exposed to these socioeconomic conditions are more vulnerable to TB and report higher rates of TB-related symptoms than their less vulnerable peers. Notably, symptom prevalence was highest among children facing multiple, overlapping socioeconomic disadvantages, highlighting the cumulative impact of these structural inequalities on child health. In addition, our study was likely the first to see that social vulnerability is a powerful determinant of TB symptom burden among children in the Hhohho region. Using a multidimensional SVI, we demonstrated that exposure to overlapping socio-environmental risks—such as poor housing, caregiver unemployment, and air pollution—correlates with significantly higher TB symptom prevalence. Thus, incorporating tools like the SVI into local TB strategies offers a practical, data-driven way to enhance equity, prioritise limited resources, and move closer to TB elimination in Eswatini. The findings of this study affirm global calls to address TB not only as

a biomedical issue but as a socially determined disease, rooted in poverty and inequality.

The strength of the study is that it is among the first in Eswatini to apply a multidimensional vulnerability index in a TB context, expanding the methodological toolkit for local epidemiology. The study utilised actual TB register data combined with household-level assessments, improving ecological validity. The findings directly inform Eswatini's strategic priorities under the End TB Strategy, particularly regarding early childhood interventions and equity-driven programming.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by The Higher Degrees and Research Ethics Committee and the Departmental Research Committee of the University of Johannesburg. Approval was given from the Eswatini Health and Human Research Review Board to conduct the study (EHHRRB 105/2024). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

AG: Methodology, Conceptualization, Writing – review & editing, Investigation, Formal analysis, Writing – original draft, Visualization, Project administration. NN: Software, Writing – original draft, Supervision, Writing – review & editing. CW: Supervision, Writing – original draft, Writing – review & editing.

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The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenvh.2026.1738173/full#supplementary-material>

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