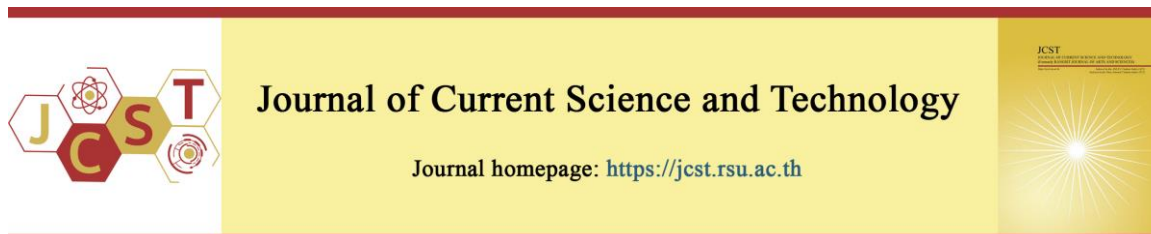


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Risk Factors for Tuberculosis in Children: A Case-Control Study of Environmental, Nutritional, and Contact-Related Determinants

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Abstract

Tuberculosis (TB) remains a major pediatric health concern, particularly in high-burden settings such as Indonesia. Objective: To identify environmental, nutritional, and contact-related risk factors for childhood tuberculosis. A case-control study of 50 TB cases and 50 controls was conducted at Garuda Health Centre, Bandung, Indonesia (August 2024). Data on nutritional status, contact history, parental factors, and housing conditions were collected through structured questionnaires. Statistical analysis included chi-square tests and multivariate logistic regression. Proper ventilation was the strongest protective factor (adjusted odds ratio [OR] = 0.264, $p < 0.001$), reducing TB risk by 73.6%. Contact history significantly increased risk (adjusted OR = 2.631, $p < 0.001$), and proper lighting provided substantial protection (adjusted OR = 0.451, $p = 0.007$). In univariate analysis, undernourished children had five times higher odds of TB (OR = 5.00, 95% confidence interval [CI]: 2.05 – 12.20, $p = 0.001$), though this effect was attenuated in multivariate models. Socioeconomic factors showed no independent associations. The model demonstrated good discriminatory performance (accuracy = 75%, area under the Receiver Operating Characteristic curve [AUC] = 0.834). Environmental factors, particularly ventilation and lighting, are key modifiable determinants of childhood TB risk. Housing improvements should be prioritised alongside traditional TB prevention strategies in comprehensive control programmes.

Keywords: childhood tuberculosis; risk factors; nutrition; contact history; housing conditions; Indonesia; environment

1. Introduction

Tuberculosis (TB) is an infectious disease caused by the pathogenic bacterium *Mycobacterium tuberculosis*, which primarily targets the respiratory system but can establish infection in diverse anatomical sites, including the central nervous system, kidneys, spine, and multiple organ systems simultaneously, such as concurrent pulmonary and lymphatic involvement (Soni & Rai, 2023). Exposure to tuberculous bacilli does not invariably result in clinical disease, creating two distinct states: latent infection, in which viable mycobacteria remain metabolically dormant within asymptomatic hosts who pose no transmission risk but may benefit from preventive therapy, and active disease, which develops when immune defences fail to contain bacterial replication, leading to symptomatic

illness and potential transmission to contacts. Children demonstrate heightened vulnerability compared with adults, particularly those under five years, who face an elevated risk of progression and shorter intervals between infection and clinical manifestation, with young children experiencing a disproportionate risk of severe disseminated forms, including tuberculous meningitis and miliary tuberculosis, that carry substantial morbidity and mortality (Thomas, 2017).

Indonesia is a major contributor to the global TB burden, ranking second worldwide and accounting for 10% of all cases between 2020 and 2022. Of particular concern is childhood TB, with approximately 1.1 million children worldwide affected in 2020. In Indonesia, 110,881 children aged 0–14 years were clinically diagnosed with TB in 2022, representing

15.31% of the national TB caseload (Kementerian Kesehatan Republik Indonesia, Direktorat Jenderal Pencegahan dan Pengendalian Penyakit, 2023; Lv et al., 2024; Palupi et al., 2024).

Childhood TB primarily affects those under 15 years of age, with the highest incidence occurring between ages 1-4 years due to immature immune systems. Multiple risk factors influence TB transmission, including host-related factors (nutritional status, Bacillus Calmette-Guérin (BCG) immunisation status, and contact history with TB patients), socioeconomic factors (parental education level, family income, knowledge, and behaviour), and environmental conditions (ventilation, lighting, and occupancy density) (Thomas, 2017).

Previous research has shown varying results regarding these risk factors. Nutritional status plays a significant role, as malnutrition can lead to immune dysfunction. Contact history with adult TB patients substantially increases transmission risk (Gupta et al., 2009). BCG immunisation shows variable effectiveness across studies. Parental knowledge and education may influence childhood TB outcomes. Socioeconomic status can affect TB risk through its effect on nutrition and healthcare access. Environmental factors such as poor ventilation, inadequate lighting, and high housing density have been associated with increased TB transmission (Liu et al., 2022).

Childhood TB can have lasting consequences even after treatment, including impaired lung function and reduced physical development. Diagnosis presents significant challenges because of the difficulty in obtaining bacteriological confirmation, often relying on clinical assessment, evidence of TB infection, and radiological findings (Huynh et al., 2025; Roya-Pabon & Perez-Velez, 2016).

Although previous studies have explored individual risk factors for childhood TB, the evidence remains fragmented. Nutritional status is inconsistently reported as an independent risk factor once socioeconomic variables are controlled. Similarly, environmental factors such as ventilation and lighting are often cited but seldom quantified in urban Indonesian settings. Moreover, few studies have simultaneously examined environmental, nutritional, and parental influences within a single model to determine their relative importance. In Bandung City, where childhood TB has risen dramatically, no case-control study has comprehensively evaluated these multiple domains together. This gap limits the development of integrated and context-specific prevention strategies.

2. Objective

Given the alarming 177% increase in pediatric TB cases in Bandung City and the complex interplay of factors influencing childhood TB development, this case-control study was conducted with the following specific objectives: (1) to identify and quantify the association between environmental factors (ventilation, lighting, housing density) and childhood tuberculosis risk; (2) to assess the relationship between nutritional status and TB development in children; (3) to evaluate the impact of contact history with TB patients on childhood TB risk; (4) to examine the influence of parental factors (knowledge, education, economic status, behaviour) on pediatric TB occurrence; and (5) to determine which risk factors remain independently associated with childhood TB after controlling for potential confounders using multivariate analysis. By comprehensively evaluating these multiple risk domains in Indonesia's highest pediatric TB burden region, this study aims to provide evidence-based insights for developing targeted public health interventions that address the most significant modifiable determinants of childhood tuberculosis transmission and susceptibility.

3. Methods

3.1 Study Design

This study employed a quantitative, observational, analytical design with a case-control approach to identify factors associated with childhood tuberculosis. The research was conducted at the Garuda Health Centre in Bandung City from 29 July to 16 August, 2024.

3.2 Study Population and Sampling

Cases and controls were matched for age (± 2 years), gender, and recruitment period. The case group comprised 50 children aged 0 – 14 years with confirmed pulmonary tuberculosis diagnosed through chest X-rays, tuberculin skin tests, and clinical assessment according to WHO pediatric TB guidelines. All cases had pulmonary involvement with no extrapulmonary manifestations and were receiving treatment at the Garuda Health Centre. While the wide age range of participants (0 – 14 years, mean 5.5 years) encompasses the full spectrum of pediatric tuberculosis risk, this broad inclusion was necessary to achieve an adequate sample size in our case-control design and reflects the clinical reality of childhood TB affecting all pediatric age groups.

The control group consisted of 50 age-matched children who visited the same health centre for routine

care but were not diagnosed with tuberculosis. This 1:1 case-control ratio was determined using sample size calculations with a 95% confidence level ($z_{1-\alpha/2} = 1.96$) and 80% power ($z_{1-\beta} = 0.84$), assuming exposure proportions of 0.4 in cases and 0.2 in controls.

3.3 Demographic Data Variables and Operational Definitions

Tables 1 and 2 show definitions of variables and operations in this study. The measurement of children's nutritional status was conducted following the guidelines established by the Ministry of Health of the Republic of Indonesia (Permatasari & Chadirin, 2022). These guidelines provide standardised criteria for assessing children's nutritional status based on age and gender, aligned with established child development standards. For this study, researchers collected nutritional status data by measuring children's weight and height and by reviewing their weight monitoring cards. Body Mass Index (BMI) was calculated according to age and categorised based on the

Indonesian Ministry of Health's child anthropometric standards (Kementerian Kesehatan RI, 2020), which differentiate assessment criteria according to the child's age and gender. BMI has been independently validated as a significant predictor of metabolic and infectious disease outcomes in data-driven classification studies (Hanmanop et al., 2026).

Regarding contact history, various studies indicate that living under the same roof as individuals who have smear-positive pulmonary tuberculosis is a significant risk factor for suspected pulmonary tuberculosis. The duration and intensity of contact with tuberculosis patients can increase exposure to *Mycobacterium tuberculosis*. Kristini and Hamidah (2020), in her research entitled "Potential Transmission of Pulmonary Tuberculosis to Family Members of Patients," found that 71.4% of respondents ($n = 50$) had a high-risk intensity of contact (≥ 8 hours/day), whereas 28.6% had lower-risk contact (< 8 hours/day). Based on these findings, we established our research categories for contact history assessment (Fox et al., 2013).

Table 1 Child Factors Classification

Factor	Category	Definition	Classification Method
Nutritional Status*	Poor	< -3 Standard Deviation*	Weight-for-age (0–60 months), BMI-for-age (5–14 years)
	Underweight	-3 SD to < -2 SD	Weight-for-age or BMI-for-age
	Normal	-2 SD to $+1$ SD	Weight-for-age or BMI-for-age
	Overweight/obesity	$> +1$ SD	Weight-for-age or BMI-for-age
Contact History**	Positive	≥ 8 hours/day contact with TB patients	Direct exposure duration
	Negative	< 8 hours/day or no contact	Direct exposure duration
BCG Immunisation	Immunized	Received BCG vaccine	Vaccination record
	Not Immunized	No BCG vaccination	Vaccination record

*Nutritional status uses standard deviation (SD) from age-specific growth standards.

**Contact history is based on direct exposure to people with TB.

Table 2 Parental Factors Classification

Factor	Category	Definition	Classification Method
Parental Knowledge*	Less	< 6 correct answers	10-question TB knowledge assessment
	Good	≥ 6 correct answers	10-question TB knowledge assessment
Education Level	Low	Elementary or Junior High School	Highest educational attainment
	High	Senior High School or Tertiary Education	Highest educational attainment
Socioeconomic Status**	Lower than RMW	< 26.3 USD/month	Monthly household income
	Higher than RMW	≥ 26.3 USD/month	Monthly household income
Parental Behaviour ***	Negative	< 9 points	8-item behavioural questionnaire ****
	Positive	≥ 9 points	8-item behavioural questionnaire****

*Parental knowledge assessed through a standardised questionnaire

**Socioeconomic status uses the regional minimum wage as a benchmark

***Parental behaviour evaluated through a comprehensive questionnaire

****Provided in the supplementary material.

Table 3 Environmental Factors Classification

Factor	Category	Definition	Classification Method
Lighting	Good	Adequate natural light during daytime	
	Poor	Insufficient natural light during daytime	
Ventilation	Proper	$\geq 10\%$ of floor area open/ventilated	Proportion of floor area with ventilation
	Not proper	$< 10\%$ of floor area open/ventilated	Proportion of floor area with ventilation
Lighting	Proper	Sunlight enters the home	Direct sunlight penetration
	Not proper	No sunlight enters the home	Lack of direct sunlight
Residential Density	Proper	$\geq 4 \text{ m}^2$ per person	Living space per occupant
	Not proper	$< 4 \text{ m}^2$ per person	Living space per occupant

3.4 Data Collection

Primary data were collected through structured questionnaires and direct observations of participants' home environments. Secondary data were obtained from medical records at the Garuda Health Centre in Bandung City. Data were collected using structured questionnaires comprising multiple sections (supplementary material)

3.5 Statistical Analysis

Data were analysed using Python (version 3.8) with pandas, SciPy, and scikit-learn libraries, consistent with established Python-based frameworks for disease classification in similar settings (Hanmanop et al., 2026). Descriptive statistics were calculated for all variables. For univariate analysis, chi-square tests or Fisher's exact tests (when expected cell counts < 5) were performed to assess associations between risk factors and TB status, with $p < 0.05$ considered statistically significant. Crude odds ratios (OR) with 95% confidence intervals were calculated to quantify the strength of these associations. For multivariate analysis, logistic regression was conducted, including variables that showed significant associations in univariate testing. Adjusted odds ratios were derived from the regression coefficients, and variables were ranked by the absolute values of their coefficients to determine relative importance. The model's performance was evaluated using accuracy (75%) and the area under the Receiver Operating Characteristic curve (ROC-AUC = 0.834). All statistical tests were two-sided, and analyses were conducted using standardised procedures for case-control studies. No missing values were found in the dataset.

3.6 Instrument Validation

The questionnaire instruments underwent validity and reliability testing. The parental behaviour

questionnaire demonstrated validity, with coefficients ranging from 0.467 to 0.824 ($r\text{-table} = 0.444$). Reliability was confirmed using Cronbach's Alpha ($0.714 > 0.6$ threshold), indicating acceptable internal consistency.

3.7 Collection Procedure

Data collection involved both case and control groups. For the case group, patients undergoing treatment for TB from September 2023 to August 2024 were recruited. Home visits were conducted for environmental assessments (ventilation, lighting, residential density). The control group was selected using accidental sampling among children aged 0 – 14 years visiting the general pediatric and dental clinics who had not been diagnosed with tuberculosis.

3.8 Ethical Considerations

The study adhered to ethical principles, including respect for human dignity (informed consent was obtained from all participants), beneficence and non-maleficence (maximising benefits while minimising risks), and justice (ensuring fair treatment of all participants). Data confidentiality was maintained throughout the research process. The Bandung City Health Office granted preliminary ethics approval (Number: B/PP.06.02/6766-Dinkes/III/2024) on March 18, 2024, followed by the research permit letter (Number: PK.03.04.05/1597-BKBP/VII/2024), issued on 18 July, 2024.

4. Results

This study examined children with tuberculosis aged 0 – 14 years at the Garuda Health Centre. The research involved 50 children with TB (case group) and 50 children without TB (control group) who were receiving care at the health centre's general polyclinic.

Table 4 Demographic Data of Case and Control Groups

Characteristic	Cases (n = 50)	Controls (n = 50)	Total (N = 100)	p-value
Age Groups (years)				0.845
0 – 4	25 (50.0%)	23 (46.0%)	48 (48.0%)	
5 – 9	15 (30.0%)	18 (36.0%)	33 (33.0%)	
10 – 14	10 (20.0%)	9 (18.0%)	19 (19.0%)	
Gender				0.688
Male	26 (52.0%)	24 (48.0%)	50 (50.0%)	
Female	24 (48.0%)	26 (52.0%)	50 (50.0%)	
Study Period				-
July-August 2024	50 (100.0%)	50 (100.0%)	100 (100.0%)	
Disease Classification				-
Pulmonary TB	50 (100.0%)	0 (0.0%)	50 (50.0%)	
No TB	0 (0.0%)	50 (100.0%)	50 (50.0%)	
BCG Vaccination Status				0.241
Vaccinated	50 (100.0%)	47 (94.0%)	97 (97.0%)	
Not Vaccinated	0 (0.0%)	3 (6.0%)	3 (3.0%)	

4.1 Characteristics of the Study Population: TB Cases vs. Controls

As shown in Table 4, the case and control populations demonstrated distinct characteristics across several key risk factors:

4.1.1 Nutritional Status

Children with TB (cases) showed markedly different nutritional profiles compared with controls. Only 28.6% of TB cases had normal/good nutrition, compared with 71.4% of controls. Undernourishment was substantially more common in TB cases (66.7%) than in controls (33.3%), resulting in a five-fold increased risk (OR = 5.00). Overnutrition was also more prevalent in cases (61.5%) than in controls (38.5%), with a four-fold increased risk (OR = 4.00). This significant difference ($p = 0.001$) suggests that nutritional status is strongly associated with TB vulnerability.

4.1.2 Contact History

A history of contact with TB patients was much more common among cases, with 69.0% of TB cases reporting positive contact compared with only 31.0% of controls. Conversely, 63.8% of controls had a negative contact history, compared with 36.2% of cases. This significant difference ($p = 0.002$) yielded an odds ratio of 3.93, confirming contact history as a major risk factor.

4.1.3 Environmental Factors

Housing conditions showed marked differences between groups: Most TB cases (64.2%) lived in homes with improper ventilation, whereas most controls (78.8%) had proper

ventilation; this difference was highly significant ($p < 0.001$) and produced the highest odds ratio (OR = 6.67). Improper lighting was more common among cases (69.4%) than controls (30.6%), showing a significant association ($p = 0.007$; OR = 3.55). Improper housing density was also more frequent in cases (70.6%) than controls (29.4%), although the association was not statistically significant ($p = 0.110$).

4.2 Immunisation Status

BCG immunisation was nearly universal in both groups (94-100%), making it difficult to detect statistical differences. All cases (100%) had received BCG, while 3 controls (6%) had not, contrary to expected protective effects, though this was not statistically significant ($p = 0.241$).

4.3 Socioeconomic Factors

Socioeconomic characteristics were broadly comparable between the case and control groups. Parents of TB cases were somewhat less likely to demonstrate good knowledge than parents of controls (60% vs. 80%); however, this difference was not statistically significant ($p = 0.127$). Parental education levels were predominantly high in both groups (90–94%), with no significant between-group difference ($p = 0.712$). Economic status showed identical distributions across groups, with 84% of both cases and controls reporting income below the Regional Minimum Wage ($p = 1.000$). Similarly, parental behaviour was largely positive in both groups (96–100%), and the difference was not statistically significant ($p = 0.475$).

Table 5 presents the results of the univariate analysis for risk factors associated with tuberculosis

in children, examining each factor's relationship with TB status without adjusting for other variables.

The analysis revealed several statistically significant risk factors for tuberculosis. Nutritional status showed a strong association with TB ($p = 0.001$), with undernourished children having five

times higher odds of TB (OR = 5.00, 95% CI: 2.05 – 12.20) compared with children with normal/good nutrition. Similarly, children with overnutrition had four times higher odds of TB (OR = 4.00, 95% CI: 1.10 – 14.55), indicating that both forms of malnutrition increase TB risk.

Table 5 Distribution of Risk Factors and Univariate Analysis Results

Risk Factor	Category	Cases (n = 50)	Controls (n = 50)	Crude OR	95% CI	p-value
Nutritional Status						0.001*
	Normal/Good Nutrition	12 (28.6%)	30 (71.4%)	Reference		
	Undernourished	30 (66.7%)	15 (33.3%)	5.00	2.05 – 12.20	
	Overnutrition and obesity	8 (61.5%)	5 (38.5%)	4.00	1.10 – 14.55	
Contact History						0.002*
	Negative	21 (36.2%)	37 (63.8%)	Reference		
	Positive	29 (69.0%)	13 (31.0%)	3.93	1.69 – 9.15	
BCG Immunisation						0.241
	Ever	50 (51.5%)	47 (48.5%)	Reference		
	Never	0 (0.0%)	3 (100.0%)	0.00	0.00 – ∞	
Parental Knowledge						0.127
	Good	39 (55.7%)	31 (44.3%)	Reference		
	Less	11 (36.7%)	19 (63.3%)	0.46	0.19 – 1.11	
Parental Education						0.712
	High	47 (51.1%)	45 (48.9%)	Reference		
	Low	3 (37.5%)	5 (62.5%)	0.57	0.13 – 2.55	
Economic Status						1.000
	Higher than RMW	8 (50.0%)	8 (50.0%)	Reference		
	Lower than RMW	42 (50.0%)	42 (50.0%)	1.00	0.34 – 2.91	
Parental Behavior						0.475
	Positive	48 (49.0%)	50 (51.0%)	Reference		
	Negative	2 (100.0%)	0 (0.0%)	∞	0.00 – ∞	
Ventilation						< 0.001*
	Proper	7 (21.2%)	26 (78.8%)	Reference		
	Not Proper	43 (64.2%)	24 (35.8%)	6.67	2.50 – 17.77	
Lighting						0.007*
	Proper	25 (39.1%)	39 (60.9%)	Reference		
	Not Proper	25 (69.4%)	11 (30.6%)	3.55	1.49 – 8.42	
Housing Density						0.110
	Proper	38 (45.8%)	45 (54.2%)	Reference		
	Not Proper	12 (70.6%)	5 (29.4%)	2.84	0.91 – 8.88	

*Statistically significant ($p < 0.05$)

Note: OR = Odds Ratio; CI = Confidence Interval; RMW = Regional Minimum Wage

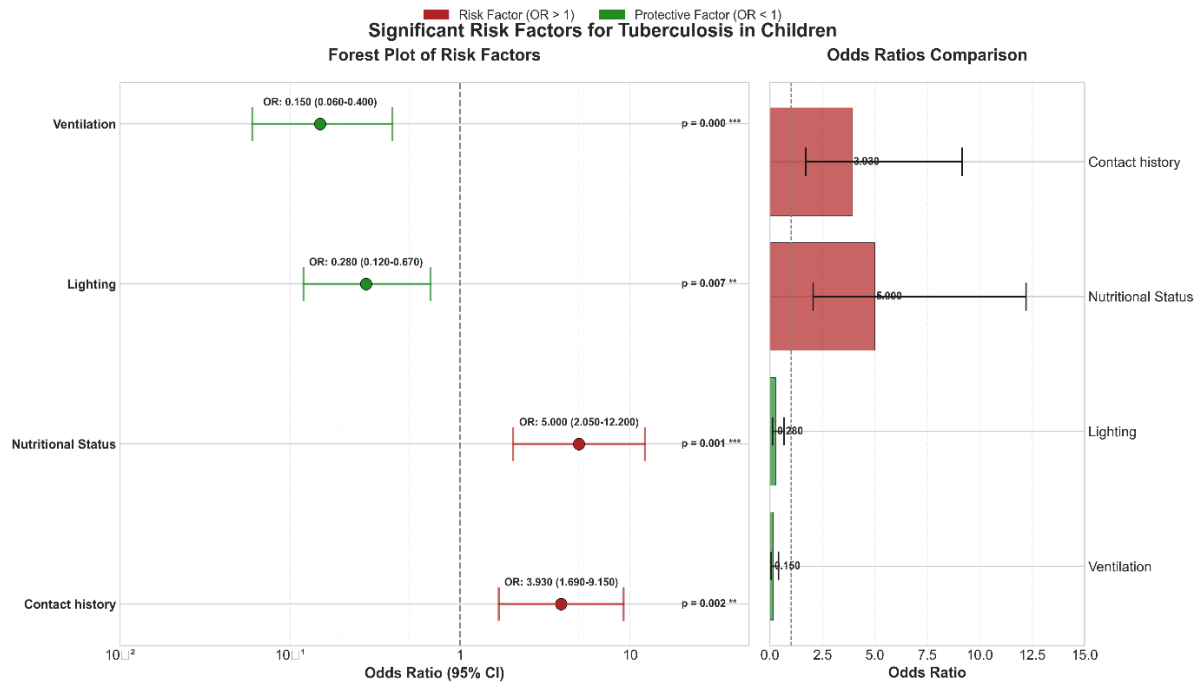


Figure 1 Significant Risk Factors for Tuberculosis in Children

Table 6 presents the results of the multivariate logistic regression analysis, which examines the independent association of each risk factor with tuberculosis while simultaneously controlling for all other variables in the model. This approach provides adjusted odds ratios that account for potential confounding effects among risk factors.

The logistic regression model demonstrated good discriminatory performance, with an accuracy of 75% and an area under the ROC curve (AUC) of 0.834, indicating strong predictive ability for distinguishing between TB cases and controls based on the included risk factors.

The risk factors were ranked by the absolute values of their regression coefficients, reflecting their relative importance in the model. Ventilation emerged as the most influential factor (coefficient = -1.333), with proper ventilation associated with a 73.6% reduction in TB risk (adjusted OR = 0.264). This finding reinforces the critical importance of adequate air circulation in preventing TB transmission, even after accounting for other risk factors. Interestingly, BCG immunisation appeared as the second most important factor in the multivariate model (coefficient = 1.041), with immunisation associated with 2.8 times

higher odds of TB (adjusted OR = 2.831). This counterintuitive finding opposite to the expected protective effect of BCG may reflect selection bias in a case-control design in which vaccination rates are very high (97%) and potentially indicate that vaccination status is confounded with other unmeasured variables or risk behaviours. Contact history maintained its significance in the multivariate model (coefficient = 0.967), with positive contact associated with 2.6 times higher odds of TB (adjusted OR = 2.631). This underscores the persistent importance of exposure to TB patients as a risk factor, independent of other variables. Lighting was the fourth most important factor (coefficient = -0.796), with proper lighting associated with a 54.9% reduction in TB risk (adjusted OR = 0.451), further emphasising the role of housing conditions in TB prevention. Parental behaviour and housing density showed similar magnitudes of effect (coefficients = -0.702 and -0.695 , respectively), both associated with an approximately 50% reduction in TB risk when positive/proper (adjusted ORs = 0.496 and 0.499). These findings suggest that behavioural and environmental factors both play important roles in TB risk.

Unexpectedly, several socioeconomic and knowledge factors showed positive associations with TB risk in the adjusted model. Parental knowledge, economic status, and education all had adjusted ORs greater than 1 (1.671, 1.422, and 1.195, respectively), suggesting potential increases in TB risk associated with higher levels of these factors. These counterintuitive findings may reflect complex interactions between socioeconomic factors and care-seeking behaviours that are not fully captured in the model, or they may be artifacts of the case-control design. Most notably, nutritional status, which showed one of the strongest associations in the univariate analysis, had no independent effect in the multivariate model (coefficient = 0.000, adjusted OR = 1.000). This suggests that the effect of nutrition on TB risk might be mediated through other factors included in the model, such as socioeconomic status or housing conditions.

Table 6 Multivariate Logistic Regression Analysis for TB Risk Factors

Rank	Risk Factor	Coefficient	Adjusted OR
1	Ventilation	-1.333	0.264
2	BCG Immunisation	1.041	2.831
3	Contact History	0.967	2.631
4	Lighting	-0.796	0.451
5	Parental Behaviour	-0.702	0.496
6	Housing Density	-0.695	0.499
7	Parental Knowledge	0.513	1.671
8	Economic Status	0.352	1.422
9	Parental Education	0.179	1.195
10	Nutritional Status	0.000	1.000

Model performance: Accuracy = 75%, ROC-AUC = 0.834

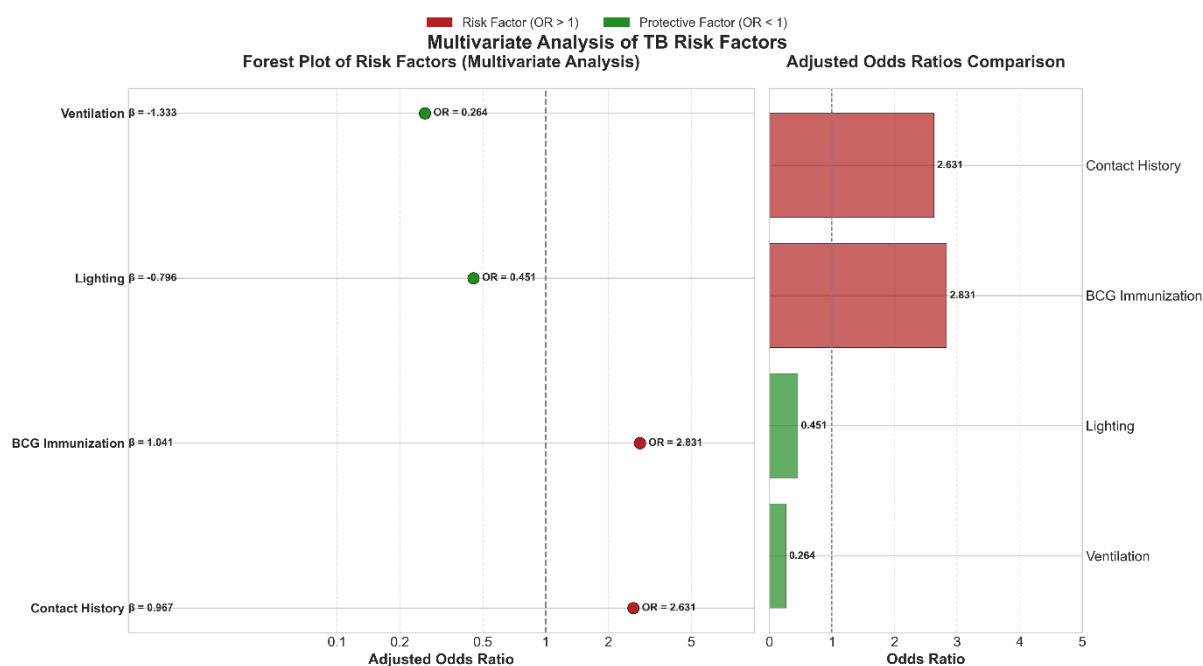


Figure 2 Multivariable Analysis of TB Risk Factors

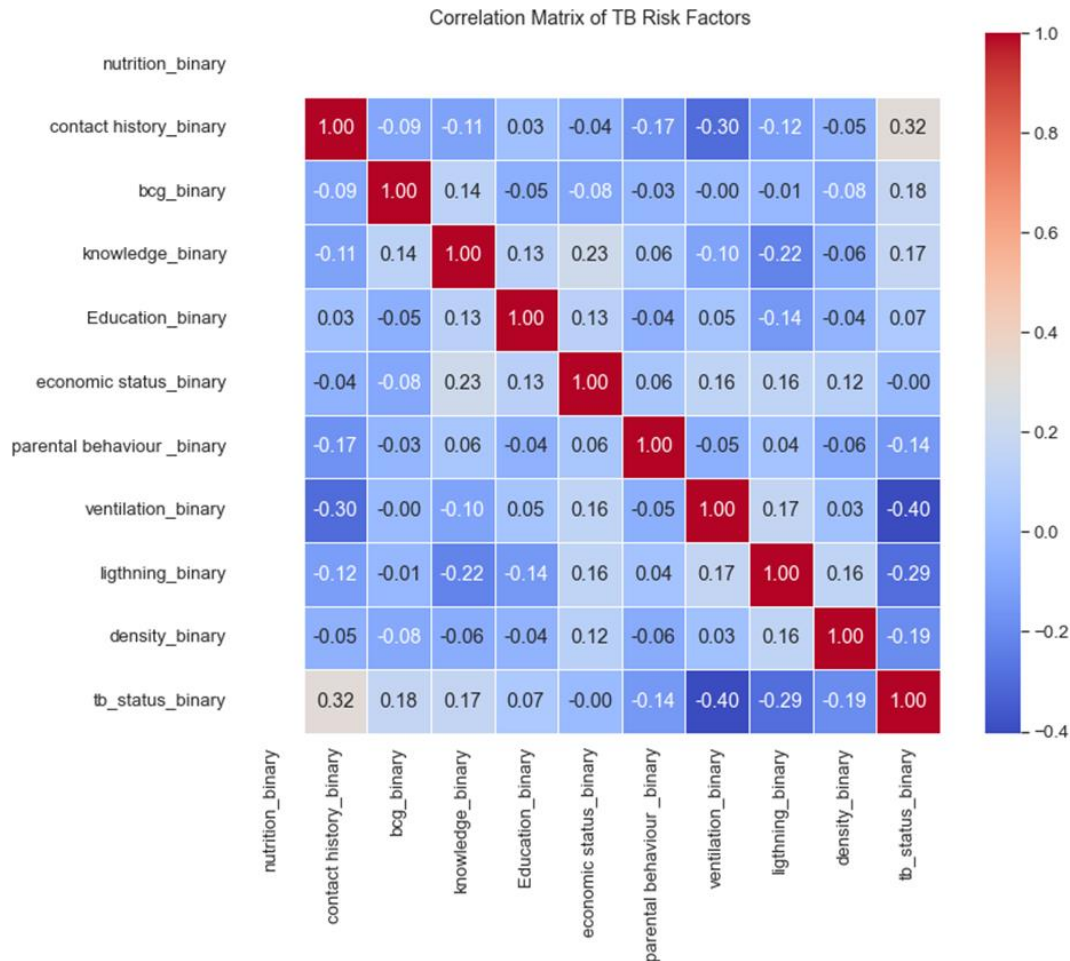


Figure 3 Correlation matrix for factors included

The correlation matrix of tuberculosis risk factors demonstrates that proper ventilation has the strongest negative correlation with TB status (-0.40), indicating that it is the most protective environmental factor. Positive contact history shows a substantial positive correlation (0.32), confirming its role as a significant transmission risk, followed by proper lighting, with its negative correlation (-0.29) and appropriate housing density (-0.19). Interestingly, most risk factors display weak correlations with each other (values near 0), suggesting that they represent independent dimensions of risk rather than redundant measures. However, there are notable associations between ventilation and contact history (-0.30), knowledge and lighting (-0.22), and economic status and knowledge (0.23). This reflects the complex interplay between socioeconomic, behavioural, and environmental factors in childhood TB transmission and aligns well with the significant associations

identified in the logistic regression analysis, particularly reinforcing the critical importance of home environment factors in TB prevention strategies.

5. Discussion

The findings of this case-control study provide important insights into the risk factors associated with tuberculosis in children. Our results highlight the critical role of environmental factors, nutritional status, and contact history in TB transmission and susceptibility among pediatric populations.

5.1 Environmental Factors: Ventilation and Lighting

Our multivariate analysis identified proper ventilation as the most significant protective factor against childhood TB (adjusted OR = 0.264 , $p < 0.001$). Proper ventilation reduces the concentration of infectious particles, substantially decreasing the

risk of transmission by 73.6% according to our model. This strong protective effect remained significant even after controlling for other factors, underscoring the fundamental importance of adequate air circulation in TB prevention. Homes with poor ventilation had nearly seven times higher TB risk, a finding consistent with evidence that inadequate ventilation increases TB risk, as proper airflow dilutes airborne pathogens and reduces transmission probability (Aynalem et al., 2023). Similarly, proper lighting emerged as another significant environmental protective factor (adjusted OR = 0.451, $p = 0.007$). Our findings align with historical TB prevention strategies that emphasised sunlight exposure and suggest that simple housing modifications to improve lighting could substantially reduce childhood TB risk by approximately 55%. This is consistent with Escombe et al. (2009), who found that insufficient sunlight creates favourable conditions for *Mycobacterium tuberculosis* survival because of the bactericidal effects of UV radiation. The strong independent effects of these environmental factors highlight the potential for housing interventions as a complementary approach to traditional TB control strategies. Particularly in resource-limited settings, structural improvements to enhance ventilation and lighting may represent cost-effective preventive measures against childhood TB. Meta-analytic evidence supports our environmental findings: pooled data showed that people living in densely populated areas had a 2.41 times higher risk of tuberculosis compared to those in non-crowded areas, whereas residents of dwellings with non-standard ventilation had a 2.14 times higher tuberculosis risk compared with those with standard ventilation areas (Riza et al., 2021). This supports our findings and suggests that this relationship transcends geographic and socioeconomic boundaries.

5.2 Contact History

Positive contact history with TB patients was strongly associated with increased risk (adjusted OR = 2.631, $p < 0.001$), confirming the importance of exposure to infectious cases in TB transmission. Children with a positive contact history had 2.6 times higher odds of developing TB, highlighting the critical need for thorough contact tracing and prophylactic management. The strength of this association in our multivariate model suggests that the effect of contact exposure remains significant regardless of other environmental and nutritional factors. Given that 42% of our study population reported a positive TB contact history, with a significantly higher proportion among

cases (69%) compared with controls (31%), our findings emphasise the importance of implementing active case finding strategies and preventive therapy for children exposed to TB patients. Strengthening contact investigation protocols could substantially reduce TB transmission to children.

5.3 Nutritional Status

Univariate analysis revealed a strong association between nutritional status and TB, with undernourished children having five times higher odds of TB compared with well-nourished children (crude OR = 5.00, 95% CI: 2.05 – 12.20, $p = 0.001$). Interestingly, this effect was attenuated in the multivariate model (adjusted OR = 1.000), suggesting that nutritional status may operate through other pathways captured by our model, such as socioeconomic factors or housing conditions. The high prevalence of undernourishment in our study population (45%) reflects the significant nutritional challenges facing children in this community. The substantial difference in the distribution of nutritional status between cases (66.7% undernourished) and controls (33.3% undernourished) highlights the potential role of nutrition in TB susceptibility (Gupta et al., 2009). These findings suggest that nutritional support programmes could be an important component of comprehensive TB prevention strategies, particularly in communities with high rates of malnutrition.

Undernourished children face significantly higher TB infection risks because malnutrition weakens the immune system by reducing essential micronutrients such as zinc and vitamin A. Protein deficiencies further compromise antibody production. Studies have shown that zinc deficiency is an independent predictor of pneumonia in children aged 2 months to 14 years. Paradoxically, recent large-scale studies involving over 167,000 participants found that obese children have substantially lower TB infection rates, with obese individuals showing 67% and 64% reductions in tuberculosis hazard compared with normal-weight individuals, and incidence rates decreasing from 82.8 per 100,000 in underweight populations to 15.7 per 100,000 in obese populations. This occurs through dual pathways, while obesity increases TB risk through diabetes (0.8 – 2.7% increased odds), it provides much stronger direct protective effects not mediated through diabetes (72% and 67% decreased odds). However, obese children still face increased infection risks from other pathogens because of chronic inflammation, immune dysfunction, and disruptions in gut microbiota caused

by high sugar intake and metabolic changes, making the relationship between nutrition and infection risk highly complex and pathogen-specific rather than uniformly protective or harmful (Lin et al., 2018; Morales et al., 2023).

5.4 BCG Immunisation

Our multivariate analysis revealed an unexpected finding regarding BCG immunisation, which showed an association with increased TB risk (adjusted OR = 2.831, $p < 0.001$). This counterintuitive result conflicts with the established protective effect of BCG vaccination against severe forms of childhood TB (Roy et al., 2014). Several factors may explain this finding:

- 1) The extremely high BCG coverage in our population (97%), with all TB cases having received BCG, limits the statistical power to detect protective effects.
- 2) Selection bias may have influenced our results, as BCG vaccination status might be correlated with other unmeasured variables.
- 3) Our case definition may have included less severe forms of TB, for which BCG has limited efficacy.

This finding should be interpreted with caution and highlights the need for further research with larger samples and a more detailed immunisation history to clarify the relationship between BCG vaccination and TB risk in this specific population.

5.5 Socioeconomic Factors

Interestingly, socioeconomic factors, including parental education, economic status, and parental behaviour, showed no significant independent associations with TB risk in our multivariate model. In our study, the majority of participants came from lower socioeconomic backgrounds (84% below the Regional Minimum Wage), which may have limited our ability to detect socioeconomic gradients in TB risk.

The absence of significant socioeconomic associations in our multivariate model, despite the strong environmental and contact-related effects, suggests that the impact of socioeconomic status on TB risk might be mediated through specific environmental and behavioural pathways that we measured directly. The predominance of environmental factors in our model highlights the potential for targeted interventions to improve housing conditions even in economically disadvantaged populations.

5.6 Study Implications

This study has several important implications for public health practice and TB control strategies, particularly in settings with high TB burden among children. The strong associations between environmental factors, nutritional status, contact history, and TB risk highlight the need for a comprehensive approach to TB prevention. Healthcare providers, especially nurses, play a crucial role in implementing evidence-based TB prevention strategies. Nurses can provide vital education to parents about maintaining proper child nutrition, avoiding contact with TB patients, and creating healthy home environments with adequate ventilation and lighting (Ramos et al., 2023). Our findings particularly emphasise the importance of focusing on ventilation improvements, which reduced TB risk by 73.6%, making this an essential component of preventive education.

The significant association between contact history and TB risk (adjusted OR = 2.631) underscores the importance of contact tracing and management. Nurses should be actively involved in monitoring and raising awareness about the importance of prevention, including BCG immunisation and monitoring close contacts with TB patients. This helps in the early detection and control of infection spread. Community health workers can be trained to identify and refer high-risk children for screening and preventive therapy.

Additionally, nurses can promote environmental health by providing practical advice on house layout, ventilation, and adequate lighting according to health standards. Our results showing the protective effects of proper lighting (reducing risk by 54.9%) suggest that simple housing modifications could substantially reduce TB transmission. Special attention should be given to high-risk children, particularly those with malnutrition or those with a history of contact with TB patients. Regular monitoring and follow-up are essential to ensure effective interventions.

For policymakers, these findings highlight the potential impact of integrating housing improvement programmes with traditional TB control strategies. Collaborative efforts between health, housing, and social welfare sectors could address the environmental and socioeconomic determinants of TB more effectively. Investment in community-based interventions that improve housing conditions, particularly ventilation and lighting, could yield significant returns in reducing childhood TB burden. Future research should explore the cost-effectiveness of housing interventions compared with traditional TB control

measures and evaluate the feasibility of implementing these interventions at scale. Longitudinal studies examining the impact of improved ventilation and lighting on TB incidence rates would provide valuable evidence to guide public health policy.

6. Research Limitations and Benefits

The study faced several limitations. The data collection process was challenging because it required door-to-door visits, leading to issues with respondents refusing to participate, changes in domicile, or absence during interviews. Measurement limitations included a lack of proper tools, such as a lux meter for lighting measurements, which had to be replaced with alternative methods, as well as the relatively small sample size, which may have limited statistical power for detecting associations with less prevalent risk factors. The cross-sectional nature of the data collection prevents establishing temporal relationships between exposures and TB development. Additionally, recall bias may have influenced responses, particularly regarding contact history and past exposures.

Despite these limitations, this study offers several important benefits to the field of TB prevention and control. First, it provides comprehensive data on multiple risk factors for childhood TB in a high-burden setting, contributing valuable evidence to inform targeted interventions. The simultaneous assessment of environmental, nutritional, and social factors allows for a more holistic understanding of TB risk dynamics.

The strong associations identified between environmental factors (particularly ventilation and lighting) and TB risk highlight modifiable targets for intervention that have received less attention in traditional TB control programmes. These findings could inform practical, cost-effective strategies to complement existing TB prevention approaches.

Our study's focus on children addresses an important gap in TB research, as pediatric TB is often underdiagnosed and understudied despite its significant burden. The findings contribute to the limited evidence base on risk factors specific to childhood TB, which may differ from those in adults.

The use of both univariate and multivariate analyses allowed us to identify both crude associations and independent risk factors, providing a more nuanced understanding of how different factors interact to influence TB risk. This approach helped distinguish direct effects from those mediated through other pathways.

Finally, the study's local context in Bandung

City makes the findings directly relevant to TB control efforts in similar urban settings in Indonesia and other middle-income countries with comparable TB epidemiology. The results can inform context-specific interventions tailored to the needs and resources of these communities.

7. Conclusion

This case-control study identifies home environment factors, particularly ventilation and lighting, as the strongest modifiable determinants of tuberculosis risk in children. The findings highlight the importance of addressing environmental conditions alongside traditional clinical approaches to TB prevention. Future research should explore the effectiveness of housing improvement interventions as a TB prevention strategy, as well as the interactions between environmental, nutritional, and immunological factors in determining TB risk in pediatric populations.

8. Abbreviations

Abbreviation	Full Term
AUC	Area Under the Curve
BCG	Bacillus Calmette–Guérin
BMI	Body Mass Index
CI	Confidence Interval
OR	Odds Ratio
RMW	Regional Minimum Wage
ROC	Receiver Operating Characteristic
SD	Standard Deviation
TB	Tuberculosis
USD	United States Dollar
UV	Ultraviolet
WHO	World Health Organization

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10. CRediT Statement

All authors contributed to the manuscript. MM curated data, conducted analysis, interpreted data, wrote, reviewed, and edited. TP collected data, handled administrative tasks, wrote, reviewed, and edited. SN wrote drafts, interpreted data, reviewed,

and edited. AS curated data, wrote drafts, interpreted data, reviewed, and edited

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