Environmental Risk Factors and Spatial Distribution of Pulmonary Tuberculosis in Tanjung Morawa, Indonesia

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Abstract

Pulmonary tuberculosis remains a major public health issue, particularly in regions with poor living conditions that facilitate transmission. Understanding the interplay between environmental risk factors and spatial distribution is essential for designing effective interventions. This study examined environmental determinants and spatial clustering of pulmonary tuberculosis cases within the Tanjung Morawa Health Center area, Deli Serdang Regency, Indonesia. Using an observational analytic case-control design, 160 respondents (80 cases and 80 controls) were selected through simple random sampling. Environmental data, including ventilation, humidity, lighting, residential density, floor condition, and wall condition, were collected through systematic observation and direct measurement. Statistical analyses employed Chi-square tests and multiple logistic regression, whilespatial analysis utilized Geographic Information System (GIS) methods, including Average Nearest Neighbor, overlay, and buffer analyses. Results revealed that household humidity was the strongest predictor of pulmonary tuberculosis (OR=44.33), followed by inadequate lighting and poor floor conditions. Ventilation, wall quality, and residential density showed no significant associations. Spatial analysis demonstrated a clustered distribution pattern, indicating localized transmission in high-risk areas. These findings highlight the critical role of housing quality in tuberculosis transmission. Targeted interventions focusing on humidity control, housing improvements, and environmental health promotion are recommended to reduce disease burden in identified clusters

Keywords: Tuberculosis, Spatial Distribution Pattern, Environmental Risk Factors, Housing Quality

INTRODUCTION

Tuberculosis (TB) remains one of the most prevalent infectious diseases globally and continues to pose a major public health challenge despite decades of control initiatives led by the World Health Organization. Pulmonary tuberculosis, caused by *Mycobacterium tuberculosis*, is a persistent airborne infection characterized by granuloma formation and progressive lung tissue damage (WHO, 2020). Although global incidence and mortality rates have declined, the burden remains substantial in low- and middle-income countries, where environmental and socioeconomic conditions strongly shape disease transmission dynamics (Yang et al., 2024).

India, Indonesia, and China collectively account for the largest share of global tuberculosis cases, highlighting persistent disparities in disease control. Indonesia remains among the countries with the highest tuberculosis burden, reflecting ongoing challenges related to population density, housing conditions, and limited healthcare access (World

Health Organization, 2022). These challenges are further compounded by environmental conditions that facilitate airborne transmission, particularly in overcrowded and poorly ventilated dwellings (Gifari et al., 2024).

Tuberculosis transmission is shaped by the complex interaction of host, agent, and environmental factors. Housing conditions provide the primary setting for prolonged exposure, and substandard environments, characterized by poor ventilation, high humidity, limited natural light, and unstable flooring, can enhance the survival of *Mycobacterium tuberculosis* and increase transmission risk. In addition, socioeconomic determinants, such as low income and limited education, combined with behavioral factors such as smoking, poor hygiene practices, and inadequate awareness of tuberculosis prevention, further heighten vulnerability to infection (Pratama et al., 2024; Oktavia et al., 2025).

Tuberculosis continues to pose a serious challenge at both national and regional levels. In North Sumatra Province, reported cases increased from 17,303 to 19,147 in 2021, with a higher prevalence observed among males (Kemenkes RI, 2021). Within the province, Deli Serdang Regency recorded the highest incidence, totalling 2,967 cases, underscoring the significant disease burden in the area. The Tanjung Morawa Health Center reported 207 cases, placing it among the districts with the highest tuberculosis occurrence (Dinas Kesehatan Kabupaten Deli Serdang, 2024).

Despite the substantial tuberculosis burden, critical gaps remain in local research and control strategies. The spatial distribution of cases has not been comprehensively analyzed using Geographic Information Systems (GIS), limiting the identification of high-risk clusters and the prioritization of targeted interventions. Similarly, environmental risk factors related to housing conditions have not been adequately assessed in relation to tuberculosis occurrence at the community level. The absence of integrated environmental and spatial approaches in tuberculosis control reduces the effectiveness of prevention efforts, particularly among vulnerable populations. This study aims to address these gaps by examining environmental risk factors associated with pulmonary tuberculosis and mapping their geographical distribution in the Tanjung Morawa region. By combining epidemiological analysis with GIS-based spatial mapping, the research seeks to generate evidence-based insights that support more precise, effective, and location-specific tuberculosis control initiatives.

METHOD

This study employed an observational analytic design using a case–control approach to investigate environmental risk factors associated with pulmonary tuberculosis and to analyze their spatial distribution within Tanjung Morawa Health Center, Deli Serdang Regency, Indonesia, in 2024. The case–control design was chosen for its efficiency in assessing multiple exposures linked to a relatively uncommon outcome and its suitability for retrospective analysis.

The study population comprised all residents recorded in the Tanjung Morawa Health Center database, totaling 414 individuals. The sample size was calculated using the Slovin formula, yielding 80 cases and 80 controls. Cases were defined as individuals diagnosed with pulmonary tuberculosis and registered at the health center, while controls were residents from the same area with no history of tuberculosis. Participants were selected through simple random sampling to ensure representativeness of the study population.

Data were collected through structured observations and standardized instruments to evaluate housing environmental conditions, including ventilation, humidity, lighting, residential density, floor condition, and wall quality. Socio-demographic information such as age, sex, education, and income was also obtained. Environmental measurements were conducted using validated tools, for example, a hygrometer to assess humidity and a lux meter to measure lighting, to ensure accuracy and reliability. Data analysis was conducted in three stages. First, univariate analysis was used to describe respondent characteristics through frequency distributions and percentages. Second, bivariate analysis was performed using the Chi-square test to assess associations between independent variables and pulmonary tuberculosis incidence, with the significance level set at $\alpha = 0.05$. Finally, variables with p-values <0.25 were entered into multivariate analysis using multiple logistic regression to identify dominant risk factors while controlling for potential confounders.

Spatial analysis was conducted using Geographic Information System (GIS) techniques to examine the distribution of tuberculosis cases. The Average Nearest Neighbor (ANN) method was applied to determine whether the spatial pattern was clustered, random, or dispersed. Overlay and buffer analyses were subsequently performed to explore the relationship between environmental risk factors and the geographic distribution of cases. Ethical approval for the study was obtained from the institutional ethics committee, and informed consent was secured from all participants prior to data collection.

RESULTS

Table 1. Characteristics of Respondents

Variable	Pulmonary TB				Total	
	Case		Control			
	n	%	N	%	n	%
Gender						
Male	46	58.97	32	41.03	78	50
Female	32	41.03	46	58.97	78	50
Total	**78**	**100**	**78**	**100**	**156**	**100**
Age						
< 25 years; > 55 years	36	46.15	17	21.79	53	33.97
25 – 55 years	42	53.85	61	78.21	103	66.03
Total	**78**	**100**	**78**	**100**	**156**	**100**
Income						
≥ Rp. 2.000.000	21	26.9	18	13.1	39	25
< Rp. 2.000.000	57	73.1	60	76.9	117	75
Total	**78**	**100**	**78**	**100**	**156**	**100**
Education						
Tall	49	62.8	40	51.3	89	57
Low	29	37.2	38	48.7	67	43
Total	**78**	**100**	**78**	**100**	**156**	**100**

Table 1 shows that males accounted for a larger proportion of the case group (58.97%), whereas females predominated in the control group. Individuals in high-risk age categories (<25 and >55 years) represented a greater share of cases (46.15%) compared to controls (21.79%). Most respondents in both groups reported low income (less than Rp 2.000.000), reflecting a predominance of lower socioeconomic status. Educational attainment was relatively similar across groups. Overall, pulmonary tuberculosis cases were more frequently observed among men, individuals at the extremes of age, and those with lower socioeconomic status.

Table 2. Association Between Environmental Factors and Pulmonary Tuberculosis

Variables	Pulmonary TB				OR 95% CI	*P-value*
	n	%	n	%		
Ventilation						
Qualify	40	26	32	21	0.66	0.970
Not eligible	38	24	46	29	(0.35-1.24)	
House Floor						
Qualify	51	33	72	46	6.35	0.002
Not eligible	27	17	6	4	(2.44-16.50)	
Wall						
Qualify	45	29	58	37	2.12	0.297
Not eligible	33	21	20	13	(1.07-4.19)	
Residential Density						
Qualify	51	33	61	39	1.9	0.246
Not eligible	27	17	17	11	(0.93-3.87)	
Humidity						
Qualify	2	1	42	27	44.33	0,000
Not eligible	76	49	36	23	(10.16-193.37)	
Lighting						
Qualify	17	11	58	37	10.4	0,000
Not eligible	61	39	20	13	(4.96-21.8)	

Table 2 demonstrates a significant association between housing conditions, specifically floor quality, humidity, and lighting, and pulmonary tuberculosis incidence ($p < 0.05$). Substandard flooring increased the risk of tuberculosis by 6.35 times (95% CI: 2.44 – 16.50; $p = 0.002$). Elevated household humidity showed the strongest correlation (OR=44.33; 95% CI: 10.16–193.37; $p<0.001$), succeeded by inadequate illumination (OR=10.4; 95% CI: 4.96–21.8; $p<0.001$). In contrast, ventilation, wall quality, and residential density were not significantly associated with tuberculosis incidence ($p > 0.05$). Overall, environmental housing factors, particularly humidity and lighting, emerged as key predictors of pulmonary tuberculosis risk.

Spatial analysis was employed to examine the distribution of tuberculosis cases in the Tanjung Morawa region using Geographic Information System (GIS) techniques. At the village level, this approach identified areas with high case concentrations (clusters) as well as areas with lower incidence. The analysis also explored relationships between case distribution and environmental conditions, population density, and socioeconomic factors. Results from the *Nearest Neighbor Ratio (NNR)* method showed *a z-score* of 18.908 with *a p-value of 0.00.* The highly negative Z-score and p-value <0.05 indicate that the spatial distribution of tuberculosis cases is not random but clustered. These findings suggest that tuberculosis cases are not random but clustered. These findings suggest that tuberculosis cases tend to be concentrated in specific high-risk areas rather than being evenly distributed across the study region.

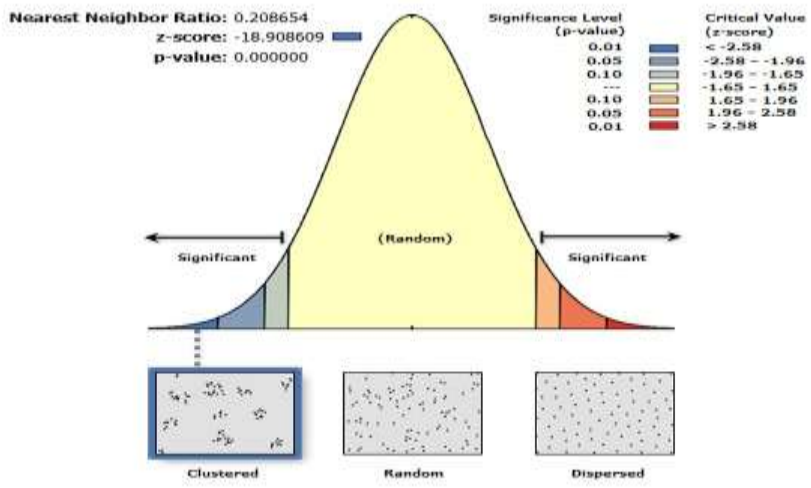

Figure 1. Results of Analysis of the Distribution Pattern of Pulmonary TB Cases in the Tanjung Morawa Community Health Center

The clustered distribution of tuberculosis within the Tanjung Morawa Community Health Center highlights the need to prioritize high-incidence areas in prevention and control planning. Interventions should be concentrated in the core outbreak zones, as illustrated in Figures 2 and 3, to maximize the effectiveness of targeted strategies.

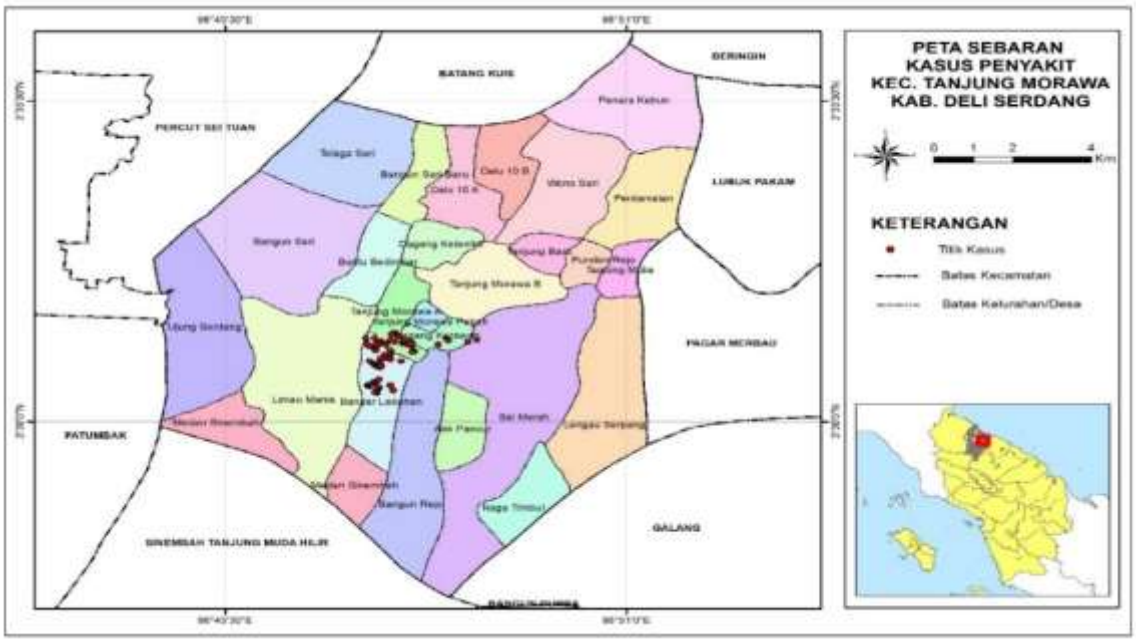

Figure 2. Map of Disease Case Distribution in Tanjung Morawa District, Deli Serdang Regency

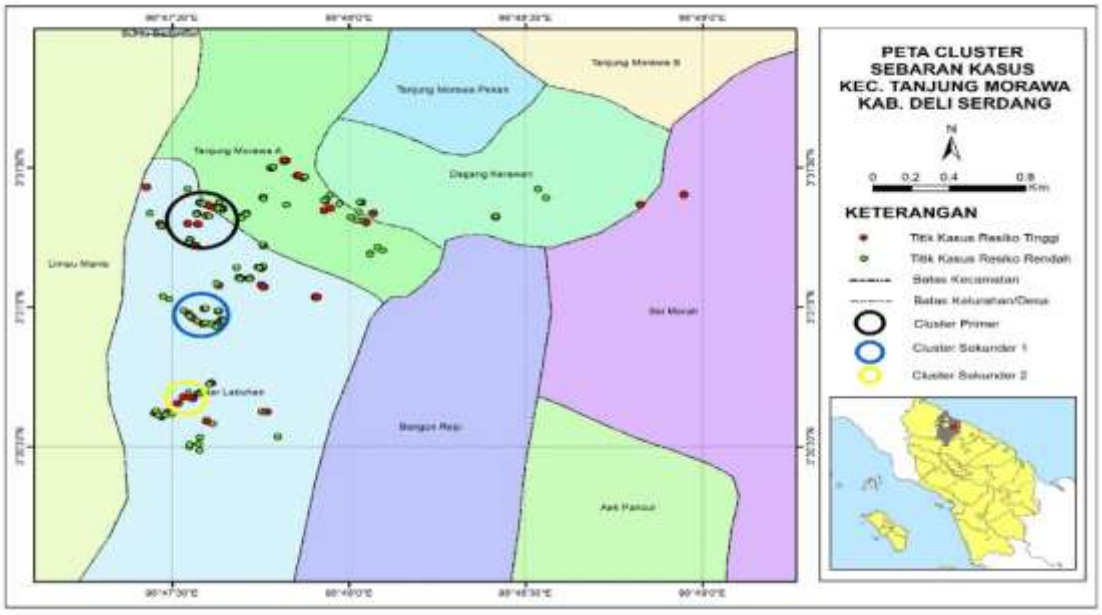

Figure 3 Map of the Distribution of Disease Cases Based on Dominant Risk Factors in Tanjung Morawa District, Deli Serdang Regency

The spatial analysis identified both primary and secondary clusters of tuberculosis cases in Tanjung Morawa, Bandar Labuhan Village. The primary cluster represents the area with the highest concentration of cases and the greatest risk of transmission, serving as the

central source of spread to surrounding communities. In contrast, the secondary cluster reflects a lower concentration of cases but still contributes significantly to the overall burden. The emergence of secondary clusters can be influenced by environmental factors such as population mobility, which facilitates the spread of infection to adjacent areas. Recognizing primary and secondary clusters is therefore essential for determining intervention priorities: primary clusters should be the main focus of tuberculosis control programs, while secondary clusters require ongoing monitoring and preventative measures to avoid their progression into new centers of transmission.

DISCUSSION

The Influence of Gender on the Incidence of Tuberculosis

Table 1 shows that pulmonary tuberculosis cases were predominantly male (58.97% of the 78 cases), whereas the control group was predominantly female (58.97%). This imbalance may be partly explained by the absence of gender-based matching in the selection of case and control respondents.

Epidemiologically, pulmonary tuberculosis is consistently reported to be more common in males than in females, and male has been identified as a significant risk factor in numerous studies. The predominance of men among TB cases is thought to be linked to behavioral and social factors, including higher rates of smoking, alcohol consumption, and broader social interactions, all of which increase exposure risk. Conversely, women are often more health-conscious and may seek medical care earlier, leading to quicker diagnosis and treatment that can slow disease progression (Rusnoto et al., 2020).

Research by Sunarmi & Kurniawaty (2022), reported a statistically significant relationship between gender and the incidence of pulmonary tuberculosis, with males experiencing the disease more frequently than females. This finding is consistent with the results of Fahdhienie et al., (2024). Supporting evidence also comes from data in Ponorogo Regency (2011-2015), which documented a consistently higher proportion of pulmonary tuberculosis cases among men across multiple years (Harahap et al., 2025).

However, the gender imbalance between the case and control groups represents a methodological limitation that may introduce bias. In case-control studies, matching is recommended to control for confounding variables such as gender and thereby strengthen the validity of the analysis. Without matching, differences in gender distribution can act as confounders, making it difficult to determine whether observed variations in disease

incidence are attributable to genuine risk factors or simply to differences in the sample populations (Gordis, 2014).

The Influence of Age on the Incidence of Tuberculosis

Table 4.2 shows that among the total respondents, 53 (34%) belonged to the non-vulnerable age group, while 103 (66%) were classified as vulnerable. Within the non-vulnerable group, 36 (23%) were cases and 17 (11%) were controls. In contrast, the vulnerable group included 42 (27%) cases and 61 (39%) controls. These findings align with several epidemiological studies in Indonesia, which consistently report that individuals in the productive age range (approximately 15-55 or 15-64 years) are more susceptible to pulmonary tuberculosis compared to the elderly or non-productive age groups. Septiani & Mita (2020), for example, found a significant association between age and pulmonary tuberculosis incidence in the Walantaka Community Health Center, with productive-age individuals at higher risk due to greater mobility and social interaction, which facilitates transmission ($p < 0.05$). Similarly, a study at Depati Hamzah Pangkalpinang Regional Hospital reported a significant relationship between age and pulmonary tuberculosis incidence, with an odds ratio of 4.439 (95% CI 1.708-11.537), indicating that the risk of pulmonary tuberculosis is substantially higher among those in the productive age group ($p = 0.003$) (Irawan et al., 2025).

Several factors contribute to the elevated risk of pulmonary tuberculosis among individuals in susceptible age groups. These include increased mobility and frequent social interactions in workplaces, educational institutions, and community settings; reduced physical resilience resulting from intense physical exertion and stress; and immunological characteristics that heighten vulnerability in certain age demographics (Susilawaty et al., 2024).

In contrast, a study conducted in Palembang on relapsed pulmonary tuberculosis found no significant association between age and the incidence of recurrent cases($p = 0.309$). This suggests that age exerts a stronger influence on the occurrence of initial pulmonary tuberculosis than on relapse (Pangaribuan et al., 2020). Overall, the findings of this study are consistent with broader scientific evidence demonstrating that vulnerable, or productive, age groups statistically account for a greater proportion of pulmonary tuberculosis cases compared to non-vulnerable groups, thereby underscoring age as an important risk indicator for disease control and prevention.

The Influence of Income on the Incidence of TB

These results indicate that the majority of respondents, both cases and controls, belonged to low-income groups. This distribution shows no significant differences between the case and control groups based on income, suggesting that income may not be a key differentiating factor in the incidence of pulmonary tuberculosis within this population. Supporting evidence comes from an analytical observational study conducted in the Wundulako Community Health Center, Kolaka, which found no significant association between economic status and pulmonary tuberculosis incidence ($p = 1.000$), despite most respondents being of low economic status. These findings suggest that unfavorable socioeconomic conditions are widespread in the studied population and that other factors, such as exposure to Mycobacterium tuberculosis and access to health services, play a more decisive role in determining disease incidence (Rusnoto et al., 2020).

However, other studies have reported different findings. Research conducted in West Sulawesi demonstrated that income significantly influenced the incidence of pulmonary tuberculosis, with an odds ratio (OR) of 2.632 (95% CI: 1.009–6.864), indicating a higher risk among low-income groups. Similarly, a study in the Serang region also identified income as a significant risk factor, showing that lower income substantially increases the risk of pulmonary tuberculosis (Mauliyana & Hadrikaselma, 2021).

Variations in study results are likely attributable to factors such as sample size, definition of income categories, and differences in local socioeconomic and environmental conditions. These findings suggest that economic status may contribute to pulmonary tuberculosis risk, but its influence can vary depending on social context and other contributing factors. In conclusion, both this study and the broader literature indicate that income is not a universally conclusive determinant of pulmonary tuberculosis incidence. Nevertheless, economic conditions remain an important consideration within the broader framework of social risk factors that shape susceptibility and exposure. Therefore, analyses of income as a risk factor should be interpreted in light of the population context and other supporting variables.

The Influence of Education on the Incidence of TB

This study presents an interesting finding, as low levels of education are generally associated with a higher risk of infectious diseases, including pulmonary tuberculosis. Limited education is often linked to reduced knowledge and awareness regarding TB prevention, transmission, and treatment, thereby increasing vulnerability to infection and the likelihood of onward transmission. However, in this study, TB cases were more frequently

observed among individuals with standard levels of education. This unexpected pattern may be explained by other factors not controlled for in the analysis, such as occupational exposure, social environment, and behavioral practices.

A study by Salsabilah & Afriansya (2024), in Semarang found a significant association between education level and the incidence of pulmonary TB, with most patients coming from low-educated groups (elementary and junior high school). This supports the role of education as a risk factor, as individuals with lower education often have limited knowledge of TB prevention and treatment and may lack motivation to seek care consistently.

In contrast, Hartina et al., (2019) reported no statistically significant association between education and pulmonary TB incidence at Girian Weru Community Health Center in Bitung City, suggesting that education was not a major determinant in that context. These contrasting findings highlight the diversity of research outcomes, which may be influenced by population characteristics, sampling methods, and other confounding variables such as income and access to health services (Sa'adah et al., 2022).

In conclusion, although many studies suggest that low education contributes to TB risk, the present study found nearly equal proportions of cases between standard and substandard education groups. This indicates that education alone may not fully explain TB incidence, and other factors, such as environmental conditions, economic status, and individual behaviors, must also be considered in TB control efforts.

The Influence of Occupation on the Incidence of TB

The data show that TB cases were more common among employed individuals than the unemployed. Occupation can be linked to transmission risk, particularly in jobs involving frequent contact with others or exposure to unhealthy environments. Work in the informal sector, factories, or occupations with dust and chemical exposure may increase susceptibility. Additionally, stressful and demanding work schedules can weaken immunity, making individuals more vulnerable to *Mycobacterium tuberculosis.*

Hasnita et al., (2025) reported a significant association between occupation and pulmonary TB in the Korleko Community Health Center area, East Lombok ($p=0.031$; OR = 3.45), indicating that employed individuals had a greater risk. Similarly, Ayomi et al., (2012) found a significant relationship between occupation and TB incidence in Palembang.

However, other studies, such as one conducted in the Amurang Community Health Center, South Minahasa, found no significant association ($p>0.05$), suggesting that environmental factors such as housing conditions and ventilation in population

characteristics, employment types, and concurrent risk factors such as nutrition and smoking. Overall, this study supports the finding that employed individuals have a higher proportion of TB cases, but emphasizes that occupational context and other contributing factors must be considered for accurate interpretation.

Environmental Risk Factors for Tuberculosis Incidence

The study results revealed significant associations between several household environmental factors and TB incidence, particularly floor conditions, humidity, and lighting. Residences with dirt or non-permanent floors were more likely to report TB cases, as such floors are damp, difficult to clean, and conducive to microorganism growth. High household humidity also contributed to TB incidence by worsening air quality and supporting the survival of *Mycobacterium tuberculosis* indoors. Poor natural lighting further increased risk, as limited sunlight reduces natural disinfection that can kill TB bacteria.

These findings are consistent with Ayomi et al., (2012), who identified natural lighting (*p-value* = 0.006) and room humidity (*p-value* = 0.012) as significant risk factors for TB spread. Epidemiologically, housing conditions are critical determinants of TB incidence. Dirt floors, often associated with low socioeconomic status, indirectly increase risk by creating environments favorable to pathogen survival. High humidity exacerbates exposure to airborne droplets and prolongs bacilli survival, while poor lighting reduces natural protective factors. Together, these environmental conditions significantly influence TB transmission dynamics.

CONCLUSION

This study demonstrates that pulmonary tuberculosis in the Tanjung Morawa Health Center area exhibits a clear spatial clustering pattern, indicating localized transmission. Household environmental factors, particularly humidity, flooring conditions, and lighting, emerged as critical predictors of TB incidence, while ventilation and residential density showed no significant association. These findings underscore the importance of housing quality in shaping disease transmission.

Effective TB control initiatives should prioritize improving household environmental conditions through community-based interventions, strengthening health promotion on healthy housing, and implementing targeted strategies in high-risk areas. Enhancing active case detection is also essential to reducing transmission. Future research should expand to broader geographic areas and incorporate environmental, social, and behavioral determinants to provide a more comprehensive understanding of TB risk factors.

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