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Environmental housing conditions of tuberculosis patients in a tidal-flooded area: Evidence from one of the world's second-highest tb-burden countries

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Abstract

Tuberculosis (TB) remains the world's second leading infectious killer after COVID-19, with Indonesia ranking as the second-highest TB-burden country globally. Environmental home conditions play a critical role in the persistence and transmission of Mycobacterium tuberculosis, especially in high-risk communities affected by tidal flooding (rob). Objective: This study aimed to assess the environmental housing characteristics of TB patients living in tidal-flood–affected areas in Pekalongan, Indonesia. Methods: A descriptive quantitative study was conducted using total sampling of 25 households of confirmed TB patients. Environmental assessments included occupancy density, ventilation area, humidity, indoor temperature, lighting, and floor type. Measurements were performed using standardized and calibrated instruments (thermo-hygrometer, lux meter, and measuring tape). Data were analyzed using univariate statistics (mean, SD, and frequency distribution). Results: The findings indicated that 96% of TB patients lived in substandard housing conditions. Humidity was the most critical issue, with 100% of homes exceeding recommended limits. Ventilation did not meet standards in 92% of households, while 84% had unacceptable indoor temperatures. Inadequate lighting was found in 64% of homes. Although 92% had waterproof flooring, the overall housing conditions remained poor due to structural and environmental challenges posed by tidal flooding. Conclusion: Most TB patients in tidal-flooded areas live in environments that do not meet healthy housing standards. Environmental factors, including ventilation, humidity, temperature, and lighting, play substantial roles in TB transmission and persistence. These findings highlight the need for integrated public health and environmental interventions tailored to coastal and flood-prone communities.

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Keywords

Tuberculosis, Environmental health, Housing conditions

Introduction

Tuberculosis (TB) remains a persistent public health challenge worldwide, particularly in low- and middle-income countries where social and environmental determinants exert strong influence on disease transmission and persistence. Although TB is preventable and treatable, its incidence is strongly associated with substandard housing conditions such as poor ventilation, overcrowding, high humidity, inadequate lighting, and unstable indoor temperature all of which create favorable environments for Mycobacterium tuberculosis survival and airborne transmission [1],[3]. Empirical evidence suggests that such environmental factors significantly contribute to TB risk in community settings, yet context-specific data remain limited for flood-prone coastal regions such as tidal-flood–affected areas in Indonesia.

Poor physical housing conditions are increasingly recognized as critical drivers of TB transmission due to their impact on air circulation, moisture retention, and crowding. Recent studies in Indonesia reported that a large proportion of TB patients live in houses with inadequate ventilation, excessive humidity, poor lighting, and high occupancy density [1], [4], [5]. In Indonesia ranked second highest in global TB burden the combined effects of environmental stressors such as tidal flooding (rob) may further exacerbate these adverse housing conditions by promoting chronic dampness, limiting natural ventilation, and accelerating structural deterioration of residential buildings. However, systematic and objective characterization of housing conditions specifically among TB patients in tidal-flood–affected coastal areas remains scarce, reducing the evidence base for designing targeted environmental health interventions.

Several recent studies have examined the relationship between physical housing conditions and pulmonary TB. A systematic review of Indonesian studies concluded that occupancy density, ventilation area, indoor humidity, temperature, lighting, and floor condition are the most frequently reported environmental factors associated with TB cases [3].

Observational research conducted in urban communities demonstrated that environmental parameters such as ventilation and residential density play important roles in determining pulmonary TB occurrence [2]. Other cross-sectional studies have also shown significant associations between indoor temperature, lighting level, ventilation area, and TB incidence, suggesting that multiple physical housing indicators act simultaneously to influence transmission risk [4]. Furthermore, studies focusing on household contacts and pediatric TB reported that inadequate lighting and poor ventilation significantly increased the likelihood of TB transmission within families, highlighting the importance of residential environmental quality in disease prevention [6]. Collectively, these findings emphasize that TB transmission is strongly linked to multidimensional housing characteristics rather than to single isolated factors. Despite the growing body of evidence, several gaps remain. First, most existing studies were conducted in inland urban or rural areas and did not consider the unique environmental stressors present in coastal zones affected by recurrent tidal flooding, such as persistent moisture, saltwater intrusion, and reduced structural durability of houses.

Second, many investigations relied on questionnaires or basic visual observation, limiting the objectivity and precision of environmental measurements [3], [5]. Third, few studies have provided an integrated environmental profile of TB patient households using standardized instruments to simultaneously quantify ventilation area, humidity, temperature, lighting intensity, and occupancy density. As a result, it remains unclear which environmental parameters represent the most critical deviations from healthy housing standards in flood-prone settings.

To address these limitations, the present study applies a comprehensive environmental health assessment framework using direct and standardized measurements of key physical housing parameters, including occupancy density, ventilation area, indoor humidity, temperature, lighting level, and floor type. By focusing on confirmed TB patient households in tidal-flood–affected coastal areas, this study integrates epidemiological relevance with environmental vulnerability. The use of calibrated instruments enables objective quantification of indoor environmental conditions, improving data reliability compared with self-reported or visually estimated measures commonly used in previous studies [3]. Moreover, the simultaneous evaluation of multiple housing indicators allows identification of dominant environmental constraints unique to flood-prone contexts, providing stronger evidence for targeted public health and housing improvement interventions.

Accordingly, this study aims to assess the environmental housing characteristics of TB patients residing in tidal-flood–affected areas of Pekalongan, Indonesia. A descriptive quantitative design with total sampling of TB patient households was employed to evaluate occupancy density, ventilation area, humidity, indoor temperature, lighting, and floor type using standardized and calibrated measurement instruments. Univariate statistical analysis was conducted to describe the distribution and magnitude of environmental risk factors, thereby providing empirical evidence to support environmentally informed TB prevention strategies in vulnerable coastal communities.

Method

This study employed a descriptive quantitative design to examine the physical environmental characteristics of houses occupied by tuberculosis patients living in tidal-flood–affected coastal areas of Pekalongan, Indonesia. The research was grounded in environmental health and nursing methodological frameworks that emphasize objective measurement of housing factors influencing airborne infectious disease transmission [7],[8],[9]. The study focused on a single composite variable, namely housing conditions, operationalized through six indicators: occupancy density, ventilation area, indoor humidity, indoor temperature, lighting intensity, and floor type. These indicators were selected because they represent the principal physical determinants associated with indoor air quality and the viability of Mycobacterium tuberculosis in residential environments.

The study population consisted of all registered pulmonary tuberculosis patients residing in the service areas of Tirto II, Kramat Sari, and Dukuh primary health centers. A total sampling technique was applied to ensure comprehensive representation of eligible households [10]. Of the 52 registered cases, 25 households met the inclusion criteria, which required confirmed active TB status, residence in tidal-flood–affected zones, and willingness to participate. Patients with untraceable addresses, duplicated residences, relocation, or death were excluded from the study. Data collection was conducted between October 2023 and August 2024.

Housing condition data were obtained using a structured environmental assessment questionnaire adapted from previous validated instruments [11]. Each indicator was scored dichotomously and categorized into good, moderate, or poor housing conditions based on established percentage thresholds. Objective environmental measurements were conducted in all major functional rooms of each house, including bedrooms, living rooms, kitchens, and bathrooms. Indoor temperature and relative humidity were measured using a digital thermohygrometer with an operational range of −10°C to 50°C and humidity detection from 10% to 99% RH, with respective accuracies of ±1°C and ±5% RH. Prior to field deployment, the device was calibrated by comparison with hospital-standard instruments to ensure measurement reliability [12]. Lighting intensity was measured using a Smart Sensor AS803 lux meter with a detection range of 0–200,000 lux and an accuracy of ±5% [13]. Room dimensions and ventilation areas were measured using a standardized measuring tape to calculate occupancy density and ventilation ratios [14].

Environmental parameters were classified according to national healthy housing standards and international environmental health guidelines, defining adequate occupancy density as at least 9 m^2 per person, ventilation area as a minimum of 10% of floor area, indoor humidity between 40% and 60%, temperature between 18°C and 30°C, lighting intensity of at least 60 lux, and waterproof flooring as the acceptable standard. Field data collection was conducted through structured household visits following authorization from institutional, municipal, and health authorities. Respondents provided written informed consent prior to participation, and measurements were carried out by trained researchers using standardized protocols to minimize inter-observer variability.

Collected data underwent systematic processing procedures, including editing, coding, entry, cleaning, and tabulation, in accordance with established epidemiological data management practices [15]. Housing condition categories were numerically coded to facilitate statistical processing. Univariate descriptive statistical analysis was then performed to summarize environmental characteristics, using means and standard deviations for continuous variables and frequency distributions and percentages for categorical variables [16], [17].

Ethical clearance for this study was granted by the Ethics Committee of the University of Muhammadiyah Pekajangan Pekalongan (Protocol No. 052/KEP-UMPP/VI/2024). Ethical principles of voluntary participation, confidentiality, anonymity, and the right to withdraw at any time were strictly observed throughout the research process, in accordance with international biomedical research ethics guidelines [18].

Result and Discussion

Results

This study involved 25 households of confirmed pulmonary tuberculosis patients living in tidal-flood–affected areas in Pekalongan. The demographic characteristics indicated that the respondents' ages ranged from 8 to 70 years, with a mean age of 46.12 ± 17.78 years. Male respondents accounted for 56% (n = 14), while females comprised 44% (n = 11). Most respondents were married (80%), and the educational background was predominantly elementary school level or lower, with 84% not completing education beyond primary school.

Regarding occupational status, more than half of the respondents worked as laborers (52%), followed by housewives (32%), small entrepreneurs (8%), students (4%), and unemployed individuals (4%). Income distribution showed that 84% of respondents earned less than IDR 1,000,000 per month. Only 16% reported incomes above this threshold. In addition, only 16% of respondents had received Bacillus Calmette–Guérin (BCG) immunization, while 84% had no immunization history.

The mean duration of tuberculosis illness was 3.64 ± 2.29 months, with a range of 1–9 months. Respondents had lived in their current residences for an average of 33.24 ± 21.38 years, ranging from 2 to 66 years, and all respondents had resided in their current houses prior to being diagnosed with tuberculosis. Family transmission within the household was identified in 12% of cases.

Environmental housing characteristics revealed that the average house size was 60.73 m^2, accommodating a mean of 4.92 occupants, resulting in an average occupancy density of 13.98 m^2 per person. However, 20% of households had occupancy density below the recommended minimum standard of 9 m^2 per person.

Ventilation conditions were notably poor, with a mean ventilation area of only 0.61 m^2 and an average ventilation-to-floor-area ratio of 0.13%. A total of 92% of houses failed to meet the minimum ventilation standard of 10% of floor area. Indoor humidity levels were consistently high across all measured rooms. The mean household humidity was 78.31% RH, with values reaching up to 99% RH. Bedroom, living room, kitchen, and bathroom humidity levels showed similar patterns, all exceeding healthy housing thresholds. Indoor temperature measurements indicated an average of approximately 32°C in all rooms, with 84% of houses exceeding the recommended upper limit of 30°C. Lighting intensity was inadequate in most residential spaces, particularly in bedrooms (mean 31.36 lux) and kitchens (mean 52.64 lux). Overall, 64% of households did not meet the minimum lighting standard of 60 lux. Regarding floor type, 92% of houses had waterproof flooring, while 8% remained with non-waterproof floors. Based on the composite housing condition assessment, only one household (4%) was categorized as having adequate living conditions, whereas 96% of households were classified as having inadequate housing conditions.

Discussion

The findings of this study provide empirical evidence that tuberculosis patients in tidal-flood–affected areas of Pekalongan experience a convergence of demographic vulnerability and environmentally unfavorable housing conditions. The predominance of patients in productive age groups supports previous epidemiological observations that tuberculosis transmission is highest among individuals with high daily mobility and occupational exposure [32]. Although immune competence is generally stronger in this age group, latent infection reactivation and repeated exposure in crowded and poorly ventilated environments remain critical risk factors [33].

The higher proportion of male patients is consistent with reports from Southeast Asia indicating that men experience greater tuberculosis incidence due to occupational exposure, higher mobility, smoking prevalence, and delayed healthcare utilization [34]. Recent cohort studies estimate that males have nearly fourfold greater risk of pulmonary tuberculosis compared to females, particularly in low-income urban environments [35]. The predominance of married individuals in this study further suggests that household-level exposure plays a significant role in disease persistence, even when intra-household transmission is not always clinically documented.

Low educational attainment and limited household income were prominent characteristics among respondents. These findings reinforce the social gradient of tuberculosis, whereby lower education restricts access to health information and reduces awareness of healthy housing standards, while poverty constrains the ability to improve dwelling structures [36]. Previous studies in Indonesia have demonstrated that individuals earning below regional minimum wage thresholds face significantly higher odds of delayed diagnosis and treatment interruption [37]. These socioeconomic barriers indirectly sustain environmental risk factors by limiting investment in ventilation systems, housing renovation, and sanitation.

The very low prevalence of BCG immunization observed in this study aligns with earlier community-based surveys reporting immunization gaps in marginalized coastal populations [38]. Although BCG does not completely prevent adult pulmonary tuberculosis, it significantly reduces severe disease manifestations and overall susceptibility [39]. Therefore, inadequate immunization coverage may have amplified vulnerability in this population.

From an environmental perspective, the most striking finding is the universal presence of excessive indoor humidity, with mean values exceeding 78% RH across all rooms. This level is substantially higher than the recommended healthy threshold of 40–60% and surpasses values reported in most urban tuberculosis studies [26], [27]. High humidity facilitates prolonged airborne survival of Mycobacterium tuberculosis and increases respiratory mucosal vulnerability, thereby enhancing infection probability [40]. The tidal-flood context likely intensifies this phenomenon, as repeated seawater intrusion and poor drainage systems create persistently damp indoor microclimates not typically captured in conventional housing studies.

Ventilation inadequacy further compounds this risk. With an average ventilation ratio of only 0.13% of floor area, the observed housing conditions are far below national and WHO recommendations. Comparable studies indicate that inadequate ventilation may increase household tuberculosis transmission by more than thirtyfold [24], [41]. Unlike general urban slum conditions, the houses in tidal-flood zones often remain closed to prevent water ingress, unintentionally restricting airflow and ultraviolet penetration.

Indoor temperature patterns observed in this study (mean ≈ 32°C) fall within the optimal growth range of Mycobacterium tuberculosis (31–37°C) reported in microbiological studies [42]. This thermal environment, combined with high humidity, may form a particularly favorable ecological niche for pathogen persistence, explaining why environmental deterioration in coastal flooding areas may accelerate transmission dynamics beyond those observed in non-coastal settlements.

Lighting deficiency, especially in bedrooms (mean 31.36 lux), also contributes to infection risk. Sunlight exposure has been shown to exert bactericidal effects through ultraviolet radiation, and insufficient natural lighting has been associated with higher tuberculosis prevalence in densely built settlements [29], [43]. The architectural limitations imposed by flood adaptation strategies—such as raised floors and sealed walls—may unintentionally reduce daylight penetration.

Although most houses possessed waterproof flooring, this factor alone appears insufficient to offset the combined impact of ventilation failure, humidity excess, thermal elevation, and low illumination. This supports prior evidence that tuberculosis risk is shaped not by a single housing parameter but by cumulative environmental degradation [30], [44].

A key contribution of this study lies in demonstrating how tidal flooding acts as an environmental amplifier of tuberculosis risk by simultaneously worsening humidity, ventilation behavior, and structural design. While previous studies have examined housing quality and tuberculosis separately, few have quantified indoor microclimatic parameters within flood-prone coastal communities. This integrated environmental profiling provides a more nuanced understanding of how climate-related hazards interact with infectious disease transmission.

Nevertheless, this study is limited by its descriptive design and relatively small sample size, which restrict causal inference and generalizability. Additionally, behavioral factors such as smoking, window-opening habits, and time spent indoors were not quantitatively assessed. Future studies employing longitudinal designs, larger samples, and intervention-based evaluations—such as low-cost ventilation modification or moisture-control strategies—are required to validate and extend these findings.

Overall, the results support the initial research objective of identifying critical environmental determinants of tuberculosis in tidal-flood–affected housing and underscore the necessity of integrating tuberculosis control programs with climate-adaptive housing policies and environmental health engineering.

Conclusion

This study demonstrates that environmental housing conditions in tidal-flood–affected coastal settlements represent a significant structural determinant of tuberculosis vulnerability in Indonesia, one of the countries with the highest global TB burden. The findings reveal that most tuberculosis patients in the study area live in environmentally inadequate housing characterized by excessive indoor humidity, insufficient ventilation, elevated indoor temperatures, and inadequate natural lighting. These environmental factors interact to create indoor microclimatic conditions that may support the persistence and transmission of Mycobacterium tuberculosis.

The study confirms that environmental determinants of TB are not limited to traditional risk factors such as socioeconomic status or population density, but are also strongly influenced by climate-related environmental conditions. In flood-prone coastal environments, tidal inundation contributes to persistent dampness and structural housing limitations that hinder proper air circulation and sunlight exposure. These findings highlight the importance of considering environmental housing quality as an integral component of tuberculosis control strategies in climate-vulnerable communities.

From a broader perspective, the results contribute to the growing body of global health literature emphasizing that TB elimination cannot be achieved solely through biomedical interventions such as diagnosis and treatment. Improvements in housing quality, environmental health infrastructure, and climate-resilient urban planning are equally essential for reducing transmission risks in high-burden countries [48]. The integration of environmental health interventions into TB control programs may therefore represent an important pathway toward achieving international TB elimination targets.

This study also provides new empirical evidence from a tidal-flooded coastal context, an environmental setting that remains underrepresented in tuberculosis research. By quantifying indoor environmental parameters including humidity, temperature, ventilation, and lighting this research expands current understanding of how climate-related environmental stressors may influence TB transmission dynamics in vulnerable coastal populations.

Future research should employ larger sample sizes and longitudinal or intervention-based designs to further investigate causal relationships between environmental housing improvements and tuberculosis outcomes. Additionally, studies exploring low-cost ventilation modifications, moisture control strategies, and climate-adaptive housing designs may offer practical solutions for reducing environmental risk factors in flood-prone regions.

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