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# Spatial Determinants of Tuberculosis Incidence in West Java Province, Indonesia: A Geospatial Analysis of 2024 Surveillance Data

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**Abstract**

Tuberculosis (TB) remains a major public health challenge in Indonesia, particularly in densely populated provinces such as West Java. This study aimed to examine the spatial determinants of TB incidence in West Java Province using a geospatial analysis of 2024 surveillance data. A quantitative descriptive-observational design was applied using multi-sectoral secondary data. TB incidence data and healthcare facility distribution were obtained from the West Java Provincial Health Office, while population density data were sourced from the Central Bureau of Statistics of West Java. Environmental variables, including annual rainfall and temperature, were extracted from the WorldClim database. Spatial data integration and overlay analyses were conducted using QGIS version 3.44.5 to assess the spatial relationships between TB incidence and demographic, environmental, and health system factors. The findings revealed a non-random spatial distribution of TB cases, with clear clustering in regencies characterized by high population density and urbanization, particularly in areas adjacent to the Jabodetabek metropolitan region. Population density emerged as the dominant spatial determinant associated with elevated TB incidence. Environmental factors, such as rainfall and temperature, were identified as indirect modifiers that influence indoor microclimatic conditions conducive to the persistence and transmission of *Mycobacterium tuberculosis*. In addition, regions with a higher concentration of healthcare facilities reported greater numbers of TB cases, reflecting variations in diagnostic capacity and surveillance performance rather than increased transmission alone. Overall, TB incidence in West Java is shaped by the interaction of demographic pressure, environmental context, and health system capacity. The application of Geographic Information Systems proved effective in identifying high-risk spatial clusters and elucidating complex spatial interactions, underscoring the importance of spatially targeted and context-specific TB control strategies to support evidence-based public health planning in West Java Province.

**Keywords:** Tuberculosis; Spatial Analysis; Geographic Information Systems; Population Density; Environmental Factors; West Java Province

## 1.Introduction

Tuberculosis (TB) is a directly transmissible infectious disease caused by *Mycobacterium tuberculosis*. Most TB infections affect the lungs; however, the bacteria may also involve other organs of the body (Kamitsuru, 2015). Mycobacterium tuberculosis is a rod-shaped bacterium with a thick lipid-rich cell wall, slow growth characteristics, and resistance to acid and alcohol, which is why it is commonly referred to as an acid-fast bacillus (AFB). The bacterium primarily enters the human body through the respiratory tract, although transmission may also occur via the skin, urinary tract, or digestive system (Puspasari, 2019). Pleural effusion can represent an early manifestation of tuberculosis that is often difficult to recognize due to its paucibacillary nature and non-specific clinical symptoms. Delayed diagnosis of tuberculosis may worsen patient outcomes and increase the risk of transmission within the community (Sari & Setyawati, 2022).

Various risk factors contribute to the occurrence of pulmonary tuberculosis, including residential environmental conditions, housing density, health-related behaviors, and access to healthcare services. Individuals living in densely populated areas with poor sanitation are at a higher risk of developing smear-positive pulmonary tuberculosis. In addition, limited access to healthcare facilities contributes to delays in diagnosis and treatment (Marsanda et al., 2025). Poor ventilation and high residential density facilitate airborne transmission of Mycobacterium tuberculosis. Behavioral factors, such as failure to cover the mouth when coughing and low awareness of seeking medical care, further increase the likelihood of disease transmission (Sutriyawan et al., 2022).

The infection process of pulmonary tuberculosis can be divided into primary and secondary infection. Primary infection occurs at the time of initial exposure to Mycobacterium tuberculosis. Infected individuals release droplet nuclei containing TB bacteria through coughing or sneezing, which may remain suspended in the air for 1–2 hours, depending on ultraviolet (UV) exposure, ventilation, and humidity. Under humid conditions, the bacteria can survive for days to several months. When inhaled by healthy individuals, the bacteria attach to the respiratory tract and lung tissue (Yasmara et al., 2017). Secondary infection occurs when the host's immune system becomes weakened and is unable to control bacterial replication, allowing the bacteria to multiply rapidly. Secondary TB infection typically develops within five years following primary infection (Umar, 2023).

Globally, more than 1.6 million people die from tuberculosis each year. In 2019, TB-related deaths were estimated at approximately 1.4 million, increasing to 1.6 million deaths annually by 2021. In 2021, the prevalence of TB cases was highest in Southeast Asia (45%), followed by Africa (23%), the Western Pacific (18%), the Americas (2.9%), and Europe (2.2%). Southeast Asia remains the region with the highest TB burden worldwide, with India, China, and Indonesia identified as the three highest-burden countries in the region (WHO, 2022).

The Jakarta–Bogor–Depok–Tangerang–Bekasi (Jabodetabek) region, which represents the largest and most densely populated metropolitan area in Indonesia, serves as a critical microcosm for understanding and addressing TB-related challenges in the country. High population density is a major factor influencing TB incidence, particularly in West Java, which encompasses much of the Jabodetabek area, including Bogor, Depok, and Bekasi (Saifudin et al., 2024). According to data from the Indonesian Central Bureau of Statistics (2024), TB cases in West Java remain substantial, with Bogor Regency reporting the highest number of detected TB cases (28,527 cases), followed by Bandung Regency (13,678 cases), Sukabumi Regency (12,251 cases), Cianjur Regency (11,924 cases), and Garut Regency (9,404 cases). The high number of cases in these areas indicates a strong association between TB incidence and population density, urbanization, and high community mobility.

## 2. Materials and Methods

### *2.1. Study Design and Setting*

This research was conducted between December 2025 and January 2026, focusing on the geographical context of West Java Province. The study utilized multi-sectoral secondary data from 2024 to ensure a comprehensive analysis. Epidemiological data regarding Tuberculosis (TB) incidence and the distribution of healthcare facilities were retrieved from the West Java Provincial Health Office. Demographic variables, specifically population density, were sourced from the Central Bureau of Statistics (Badan Pusat Statistik) of West Java. To account for environmental determinants, annual precipitation and regional temperature data were extracted from the WorldClim database.

### *2.2. Research Design and Analytical Framework*

The study employed a quantitative descriptive-observational design using a survey-based approach to characterize existing phenomena without experimental intervention. The analytical framework integrated univariate, bivariate, and spatial analyses. Specifically, environmental components, including annual rainfall and ambient temperature, were examined in relation to TB incidence through a spatial approach facilitated by Geographic Information Systems (GIS).

*2.3. Spatial Analysis and Cartographic Modeling*

Spatial data integration and overlay analyses were executed using QGIS 3.44.5 software to generate new mapping units, enabling the identification of spatial correlations between independent environmental/demographic variables and the dependent variable (TB incidence). The resulting cartographic output comprises five fundamental layers designed to facilitate rigorous results analysis:
Isolines (Continuous Lines): Representing regional temperature gradients through distinct color gradations.
Hachure Patterns: Categorizing annual precipitation levels.
Choropleth Surface: Indicating population density variations.
Point Symbols: Utilizing blue and red circles to differentiate healthcare facility classifications.
Graduated Symbols (Green Squares): Representing the total TB cases per regency.
Given that regional temperature remains a constant characteristic within this spatial model, the analysis was streamlined into a consolidated overlay map. This final map integrates temperature gradients as the primary background layer with superimposed bar charts to represent the quantitative distribution of TB cases across each regency for the 2024 period.

## 3. Results

This figure presents a thematic map of West Java Province illustrating the spatial distribution of tuberculosis (TB) cases in relation to environmental factors and health system capacity. Administrative areas are shaded according to TB case counts, classified into five categories ranging from low to high incidence. Annual mean temperature is represented by a color gradient (purple to blue), while annual precipitation is visualized using a green-to-red gradient, reflecting variability in climatic conditions across the province.

Pie-chart symbols located within each district indicate the relative proportion of large and small healthcare facilities, where red segments represent large health facilities and blue segments represent small health facilities. These symbols provide an overview of healthcare accessibility and service capacity at the district level. Hatched patterns delineate the administrative boundary of West Java Province.

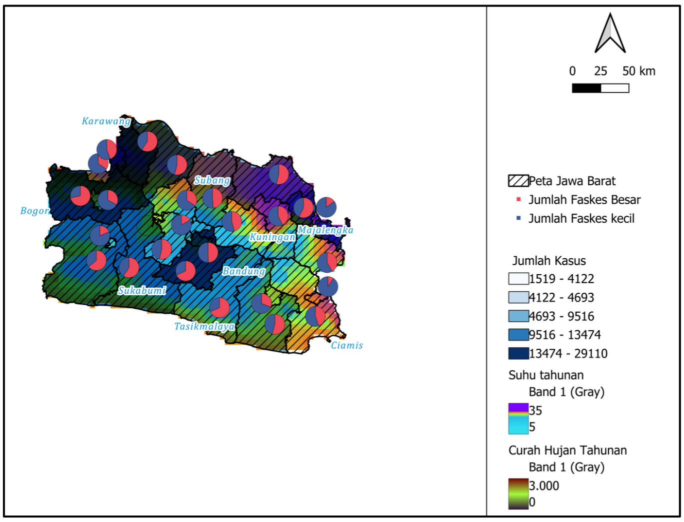


**Figure 1.** Spatial Distribution of Tuberculosis (TB) Cases in West Java Province in Relation to Climatic Factors and Health Facility Availability

By integrating epidemiological data, climatic variables, and healthcare infrastructure, this map highlights spatial heterogeneity in TB distribution and underscores the potential influence of environmental conditions and health facility availability on TB transmission patterns. This spatial approach supports environmental health and public health surveillance frameworks recommended by the World Health Organization for understanding geographically driven disease dynamics.

## 4. Discussion

Observational findings indicate that West Java Province exhibits heterogeneous environmental conditions across its constituent regencies and municipalities. Topographically, the region is characterized by a sloping elevation gradient that descends from the southern highlands toward the northern coastal lowlands. This topographical diversity facilitates distinct localized meteorological patterns, encompassing atmospheric pressure, ambient temperature, relative humidity, wind velocity, and precipitation. Furthermore, epidemiological data from the West Java Provincial Health Office for the 2024 period reveal significant disparities in Tuberculosis (TB) incidence rates across various regional classifications. The spatial distribution of tuberculosis (TB) cases in West Java reveals a pronounced pattern of geographic clustering rather than random dispersion. High-incidence areas are consistently concentrated in regencies characterized by intense urbanization and demographic pressure, particularly Bogor, Bandung, Sukabumi, Cianjur, and Garut. This spatial aggregation indicates that TB transmission in West Java is strongly shaped by place-based determinants, where demographic, environmental, and infrastructural factors interact to sustain transmission (Wulandini et al., 2019). The GIS overlay analysis confirms that TB incidence reflects spatial vulnerability rather than isolated epidemiological events (Emilia Pandin Madao et al., 2024).

Population density shows a strong spatial correspondence with TB incidence, as depicted in (Figure 1) densely populated regencies in western and central West Java consistently exhibit higher TB case counts compared to less populated eastern regions. High residential density increases the frequency of close interpersonal contact and prolongs exposure to infectious droplets, thereby facilitating airborne transmission of *Mycobacterium tuberculosis* (Inggarputri et al., 2023). These findings reinforce the epidemiological premise that TB remains closely associated with overcrowded living conditions, particularly in urban and peri-urban environments with limited ventilation and suboptimal housing quality (Lönnroth et al., 2009). The continuity of high TB incidence across Jabodetabek-adjacent regencies reflects the influence of urban mobility and metropolitan integration. Bogor, Depok, Bekasi, and Bandung function as interconnected urban systems with substantial daily commuting and population movement, weakening administrative boundaries as effective barriers to disease transmission (Inggarputri et al., 2023). The spatial alignment of TB hotspots along urban corridors highlights the role of human mobility and regional connectivity in sustaining TB transmission across West Jawa. The distribution of healthcare facilities (Figure 1) demonstrates that a higher number of facilities does not necessarily correspond to lower TB incidence. Instead, regencies with relatively dense healthcare infrastructure often report higher case numbers, suggesting a surveillance and detection effect. Improved access to diagnostic services increases case finding and reporting, while areas with limited healthcare coverage may underestimate the true TB burden (Lönnroth et al., 2010). This pattern underscores the importance of interpreting TB incidence data within the context of health system capacity and reporting efficiency.

Environmental factors, particularly annual rainfall, appear to modify TB transmission indirectly. Regions with higher precipitation levels, especially in southern and western West Java (Figure 4), tend to overlap with areas of elevated TB incidence. While rainfall does not directly influence TB infection, increased humidity may enhance indoor bacterial persistence and encourage indoor crowding during prolonged rainy periods (Wang et al., 2019). These conditions may intensify exposure in densely populated households, particularly where housing quality and ventilation remain inadequate (Mahato et al., 2025). Spatial analysis of annual temperature patterns (Figure 5) indicates that regencies with moderate and relatively stable temperature ranges coincide with higher TB incidence. Temperature functions as a background environmental modifier by influencing the survival of aerosolized *Mycobacterium tuberculosis* and indoor microclimatic conditions (Rao et al., 2016). Although temperature alone is insufficient to explain spatial variation in TB cases, its interaction with humidity, ventilation, and housing structure contributes to the persistence of transmission in endemic areas (Fares, 2011).

The integrated overlay of demographic, environmental, and health system variables demonstrates that TB incidence in West Java emerges from the convergence of multiple spatial determinants. Population density amplifies transmission opportunities, climatic conditions shape indoor exposure environments, and healthcare accessibility affects detection and reporting patterns (Emilia Pandin Madao et al., 2024). This interaction explains the persistence of TB hotspots despite variations in individual determinants, emphasizing the value of GIS-based approaches in capturing complex spatial epidemiology. From a public health perspective, these findings support the need for spatially targeted TB control strategies in West Java. Interventions should prioritize high-density urban and peri-urban clusters, combining active case finding, early diagnosis, and environmental improvements such as ventilation enhancement. The use of geospatial analysis enables more precise resource allocation and strengthens TB surveillance by aligning interventions with localized transmission dynamics rather than uniform administrative boundaries.

## 5. Conclusions

This study demonstrates that TB incidence in West Java Province exhibits a non-random spatial pattern shaped by the interaction of demographic, environmental, and health system determinants. Population density emerged as the primary spatial factor associated with elevated TB incidence, particularly in urban and peri-urban regencies within the Jabodetabek metropolitan area. Environmental variables, including annual rainfall and temperature, functioned as contextual modifiers that influenced indoor microclimatic conditions conducive to the persistence and transmission of *Mycobacterium tuberculosis*, although they did not act as direct causal drivers. The spatial distribution of healthcare facilities affected reported TB case patterns, reflecting variations in diagnostic capacity and surveillance performance across regions. The GIS-based spatial overlay approach applied in this study effectively identified high-risk clusters and clarified the spatial relationships between TB incidence and its determinants. These findings highlight the importance of incorporating geospatial analysis into TB control strategies and support the implementation of spatially targeted, context-specific interventions to reduce TB transmission in West Java Province.

**Conflicts of Interest:** The authors declare that there is no conflict of interest regarding the publication of this research.

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