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RESEARCH

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Physician Distribution Outweighs Climate Variability in Shaping Pulmonary Tuberculosis Patterns

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ABSTRACT

Pulmonary tuberculosis remains a public health burden in endemic urban areas, exacerbated by heterogeneous climate variability and limited health service capacity. This study aimed to describe the temporal patterns of climate variability and the spatial patterns of physician distribution and their relationship to tuberculosis cases in Palembang. Using a spatial-temporal ecological design, we analyzed monthly time series of tuberculosis cases and summarized monthly climate data from the Meteorology, Climatology, and Geophysics Agency of Indonesia, then mapped the cases and availability of general practitioners and pulmonologits in 18 subdistricts using geographic information system to explore distribution patterns and potential detection bias. The results showed that at the aggregate level, there was no consistent linear relationship between climate fluctuations and variations in pulmonary tuberculosis cases; instead, spatial mapping revealed heterogeneity in cases correlated with medical personnel availability, areas with higher health worker density reported higher cases (indicating increased detection), while resource-limited areas risked underreporting and delayed diagnosis. These findings underscore the need for equitable primary care services, strengthened active case finding, and integration of service indicators into spatial surveillance to improve programmatic detection and response.

Keywords: climate variability; physician availability; pulmonary tuberculosis; spatial-temporal patterns

INTRODUCTION

Tuberculosis remains one of the most lethal infectious diseases globally, causing an estimated 1.25 million deaths each year and continuing to be the leading cause of mortality from a single infectious agent worldwide [1]. Despite decades of intensive global control efforts, including expanded diagnostic coverage, standardized treatment regimens, and preventive therapy the overall burden of tuberculosis has not declined at a rate sufficient to meet international elimination targets. Current estimates indicate that approximately 10.8 million new tuberculosis cases occur annually, with the majority concentrated in low- and middle-income countries where structural vulnerabilities, socioeconomic disparities, and health system limitations perpetuate ongoing transmission [1].

Indonesia is among the countries most severely affected by tuberculosis, consistently ranking second globally in terms of total disease burden. National estimates suggest that 1.09 million new tuberculosis cases occur each year, accompanied by approximately 125,000 deaths, equivalent to nearly 14 deaths every hour highlighting the magnitude of the public health challenge [2]. Within Indonesia, the burden is unevenly distributed across provinces, with South Sumatra emerging as one of the regions contributing substantially to national incidence. Palembang, the provincial capital, represents the epicenter of tuberculosis transmission in the province. With a population density of 2,680 people per km^2 in 2023, the city reported 7,379 of the 23,256 tuberculosis cases documented in South Sumatra that year, making it the single largest contributor to provincial case counts [3].

The epidemiological profile of pulmonary tuberculosis in Palembang demonstrates marked demographic and spatial heterogeneity. Adults aged ≥15 years account for 85.9%, indicating that tuberculosis disproportionately affects the economically productive segment of the population and thereby imposes significant social and economic consequences at both household and community levels [3]. While classical microbiological and individual-level risk factors remain central to tuberculosis pathogenesis, a growing body of evidence highlights the pivotal role of environmental and contextual determinants in shaping transmission dynamics [4]. The epidemiological triad; comprising agent, host, and environment positions environmental factors as critical mediators that influence both the emergence and propagation of infectious diseases, including tuberculosis [5].

Climatic variables such as temperature, relative humidity, rainfall, wind speed, and solar radiation have been shown to directly affect the viability, aerosolization, and persistence of *Mycobacterium tuberculosis* in ambient air [6]. For example, high humidity may prolong droplet survival, while temperature fluctuations can modulate seasonal peaks in tuberculosis incidence. In parallel, non-climatic environmental determinants, including the distribution of healthcare facilities, diagnostic accessibility, and treatment success rates shape population susceptibility and exposure patterns by influencing care-seeking behavior and the timeliness of case detection [7]. Recent systematic reviews and meta-analyses have documented strong associations between specific meteorological parameters and tuberculosis risk, particularly in tropical and subtropical regions where climatic variability is more pronounced. Relative humidity exceeding 80% has been linked to extended viability of *M. tuberculosis* in respiratory droplets, whereas temperature-driven seasonality has been observed across multiple endemic settings. At the same time, intra-urban spatial heterogeneity in tuberculosis incidence is increasingly recognized as a reflection of unequal access to diagnostic and therapeutic services, resulting in localized clusters of persistent transmission [8,9].

Although scientific understanding of these relationships continues to advance, integrated analyses that simultaneously examine temporal climate variability and spatial patterns of non-climatic determinants remain limited, particularly in high-burden urban environments such as Palembang. Addressing this gap is essential for developing more precise, context-specific interventions that align with the complex ecological and social realities of tuberculosis transmission.

This study aimed to describe the temporal patterns of climate variability and the spatial distribution of physicians in relation to adult pulmonary tuberculosis cases in Palembang City. By integrating meteorological time-series data from January 2020 to October 2025 with comprehensive geospatial analyses, the study seeks to identify periods of heightened transmission risk and map geographic clusters of vulnerability. The resulting insights are expected to inform spatially targeted and temporally optimized tuberculosis control strategies, thereby supporting local and national efforts to accelerate progress toward Indonesia's tuberculosis elimination target by 2030.

METHODS

This ecological study employed a descriptive temporal–spatial mixed design, beginning with the construction of the study framework and progressing through sequential stages of data acquisition, processing, and analysis. The study population consisted of all individuals aged ≥15 years residing in Palembang City, an urban area with an estimated population of 1.7 million in 2023 who were registered in the municipal tuberculosis surveillance system. Using a total enumeration approach, all newly diagnosed pulmonary tuberculosis cases that met the World Health Organization case definition and were reported during the study period were included. For spatial analysis, all 18 administrative subdistricts of Palembang City served as the geographical units of analysis.

The temporal component of the study was initiated by compiling monthly records of new adult pulmonary tuberculosis cases from January 2020 to October 2025, covering a continuous 70-month period. These data were extracted from the TB-01 reporting form within the Tuberculosis Information System (SITB) managed by the Palembang City Health Office. Case counts were aggregated by month and subdistrict to enable both temporal trend analysis and spatial disaggregation.

Meteorological data collection proceeded concurrently. Daily observations of temperature, relative humidity, rainfall, wind speed, and sunshine duration were obtained from the Indonesian Meteorology, Climatology, and Geophysics Agency (*BMKG*) through its online data portal (https://dataonline.bmkg.go.id). To align with the incubation period and epidemiological characteristics of tuberculosis, daily measurements were converted into monthly summaries: arithmetic means for temperature, humidity, wind speed, and sunshine duration, and cumulative totals for rainfall.

Spatial data acquisition followed, beginning with the retrieval of annual physician availability data, specifically the number of general practitioners and pulmonologists from the Palembang City Health Office for each calendar year from 2020 to 2025. Administrative boundary maps in shapefile format were downloaded from Lapak GIS (https://www.lapakgis.com) and subsequently imported into QGIS 3.38 (QGIS Development Team 2019) for spatial preprocessing and geospatial integration.

After all datasets were harmonized, descriptive statistical procedures were conducted. Means, standard deviations, and ranges were calculated for each meteorological variable and for monthly tuberculosis case counts. Time-series visualizations were then generated to illustrate monthly and seasonal fluctuations in climate variables and tuberculosis incidence across the 70-month period.

Spatial analysis was performed after temporal trends had been established. Annual tuberculosis case distributions were overlaid with annual physician availability at the subdistrict level to identify spatial disparities. Independent variable layers were digitized using single-band pseudocolor classification, while dependent variable layers were encoded using centroid symbols with severity-level labeling. These vector layers were subsequently converted into raster formats and overlaid within QGIS to enable integrated spatiotemporal visualization and to reveal potential geographic clusters of vulnerability.

RESULTS

The number of new monthly tuberculosis cases (Figure 1) in Palembang City during January 2020–October 2025 ranged from 111 cases (May 2020) to 623 cases (August 2023), with a median of around 380 monthly cases. The pattern shows a sharp decline coinciding with the early months of the COVID-19 pandemic (March–May 2020), followed by a recovery and subsequent increase until 2021–2023. The highest monthly cases occurred in August 2023 (623 cases), followed by stable monthly case numbers between 350 and 500 during 2024–2025. There was no significant decline during the study period, indicating persistent transmission intensity.

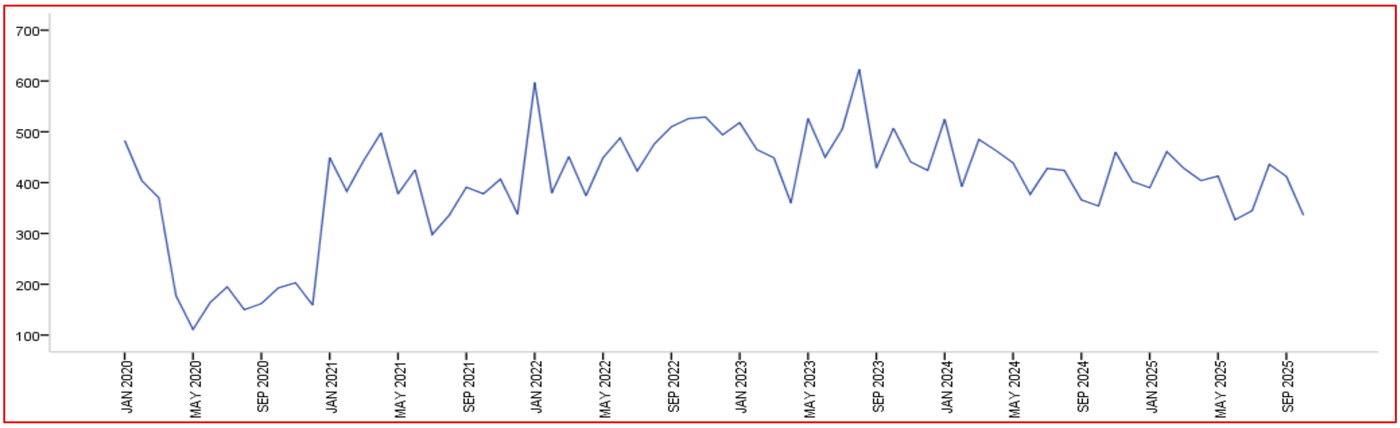

Figure 1. Monthly pulmonary tuberculosis cases in Palembang from January 2020 to October 2025

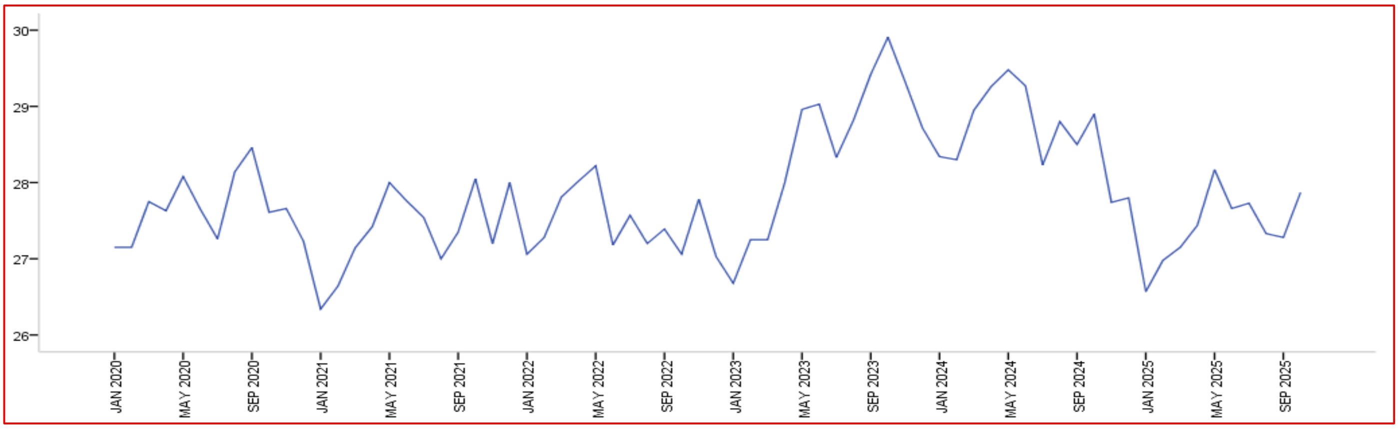

Figure 2. Monthly temperature in Palembang from January 2020 to October 2025

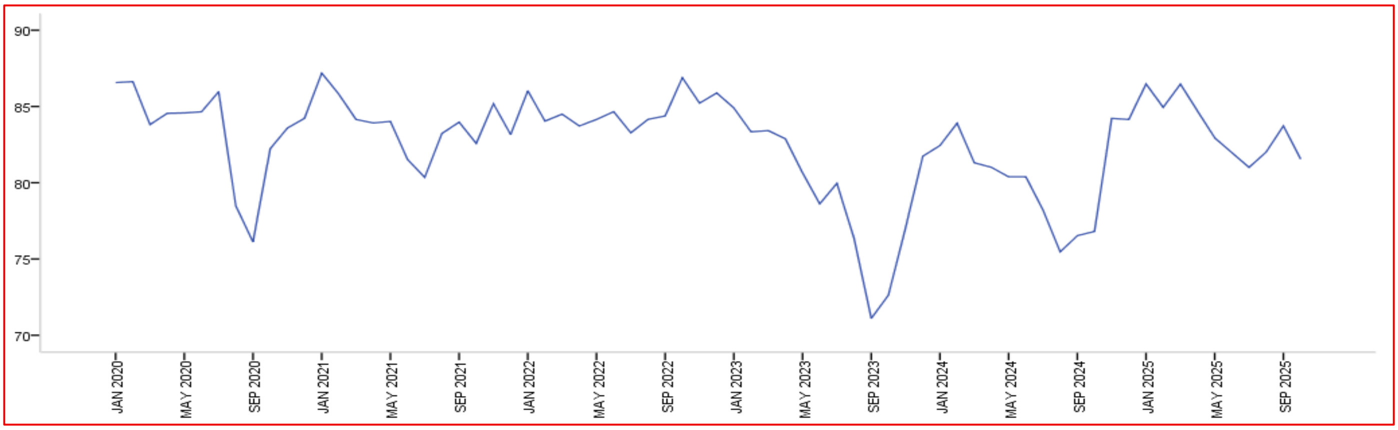

Figure 3. Monthly humidity graph for the city of Palembang, January 2020–October 2025

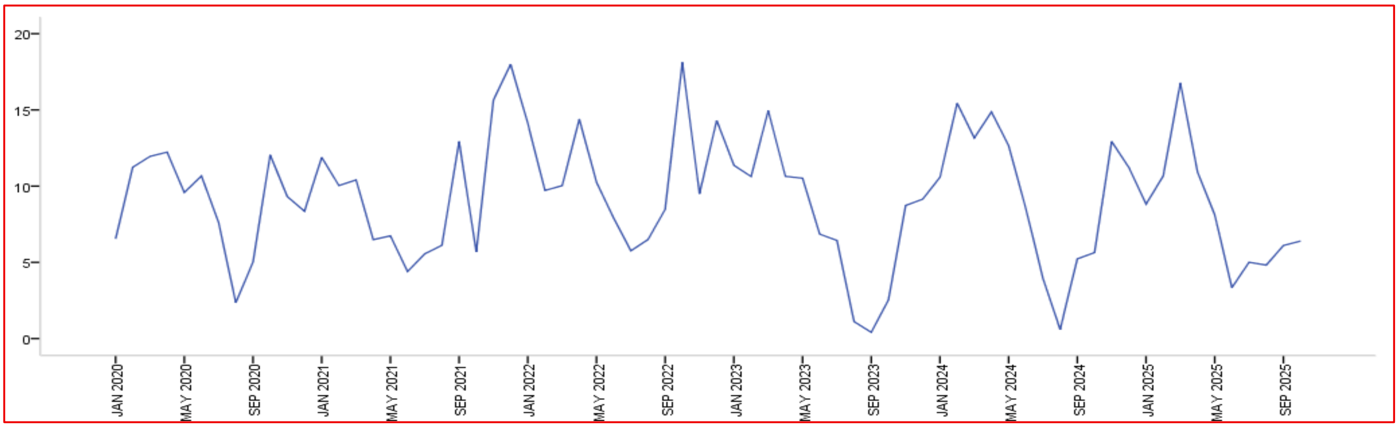

Figure 4. Monthly rainfall in Palembang from January 2020 to October 2025

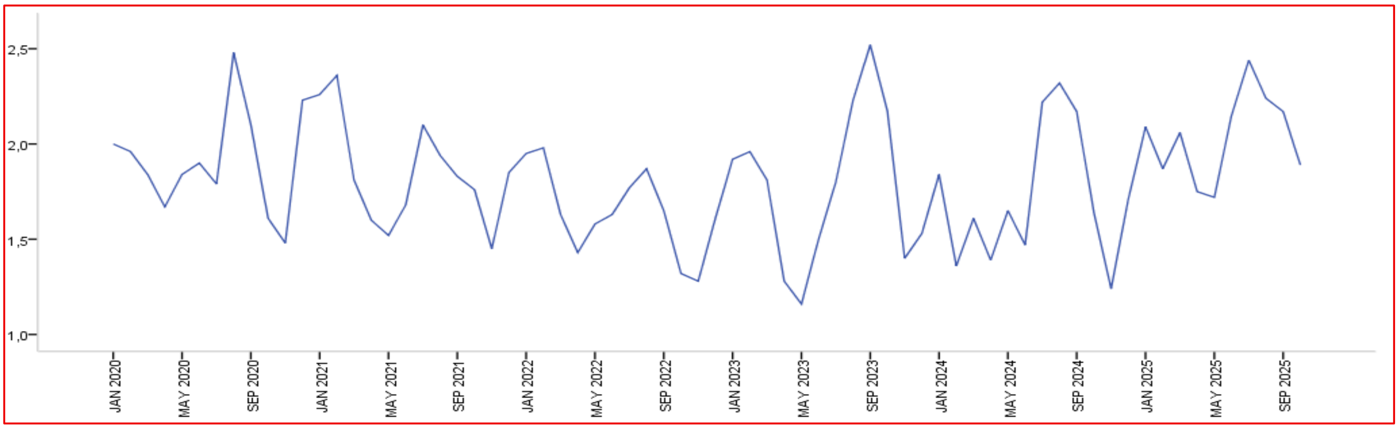

Figure 5. Monthly wind speed in Palembang from January 2020 to October 2025

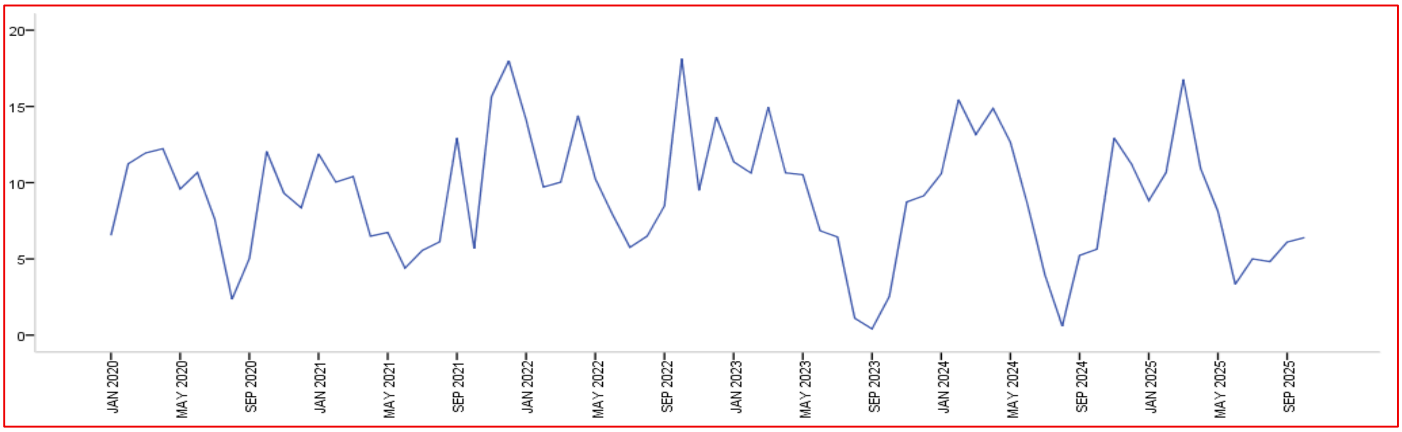

Figure 6. Monthly sunshine duration in Palembang from January 2020 to October 2025

The monthly average temperature ranged from 26.3°C (January 2021) to 30.0°C (October 2023), with a consistent seasonal pattern, marked by relative cooling during December–February and warming during May–October. The annual average temperature is close to 28.5°C (SD = 0.9°C), typical for a lowland tropical environment (Figure 2). Relative humidity fluctuates between 71.1% (September 2023) and 87.2% (January 2021), remaining relatively high throughout the study period. Monthly averages ranged from 78–85%, with a systematic increase during the rainy months (December–February) and a moderate decrease during the dry season (August–October) (Figure 3). Rainfall shows clear seasonality, with cumulative monthly rainfall reaching a maximum of 400+ mm during the peak rainy months (November–January) and a minimum of 50–150 mm during the dry season (July–September). The average amount of rain that falls each year is about 3,000 mm (Figure 4). The average monthly wind speed ranges from 2.1 to 3.8 m/s, with moderate seasonal variations and peaks during the transition between seasons (Figure 5). The average duration of sunshine is 5.5 hours per day, with minimal variation between months but a measurable decrease during the rainy season (Figure 6).

There is no consistent relationship between climate variability and the number of tuberculosis cases; in some periods, increases in temperature (Figure 7), humidity (Figure 8), rainfall (Figure 9), sunshine (Figure 10), and wind speed (Figure 11) were followed by a spike in tuberculosis cases, but in other periods, they were followed by a decline in tuberculosis cases, and vice versa. This inconsistency in trends indicates that temporal climate variability does not have a clear direct influence on fluctuations in pulmonary tuberculosis cases.

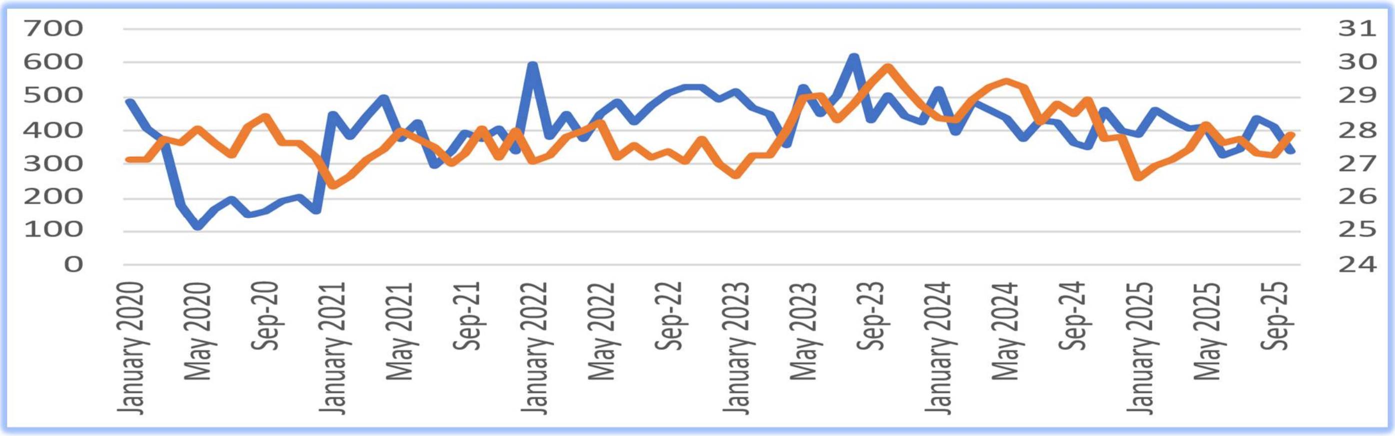

Figure 7. Comparison graph of temperature with pulmonary tuberculosis cases in Palembang City from January 2020 to October 2025

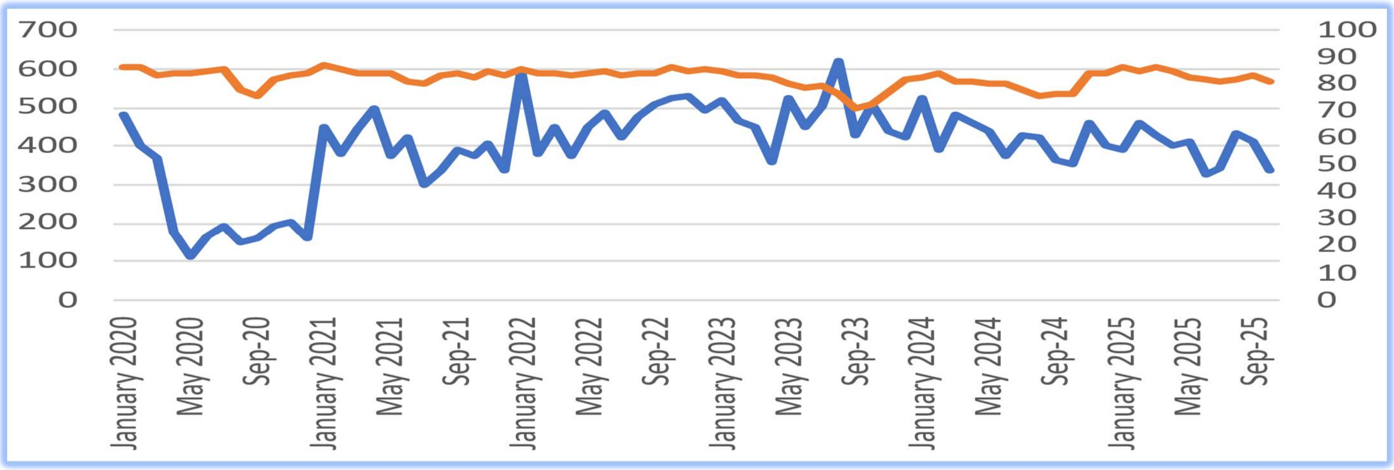

Figure 8. Comparison graph of humidity with pulmonary tuberculosis cases in Palembang City from January 2020 to October 2025

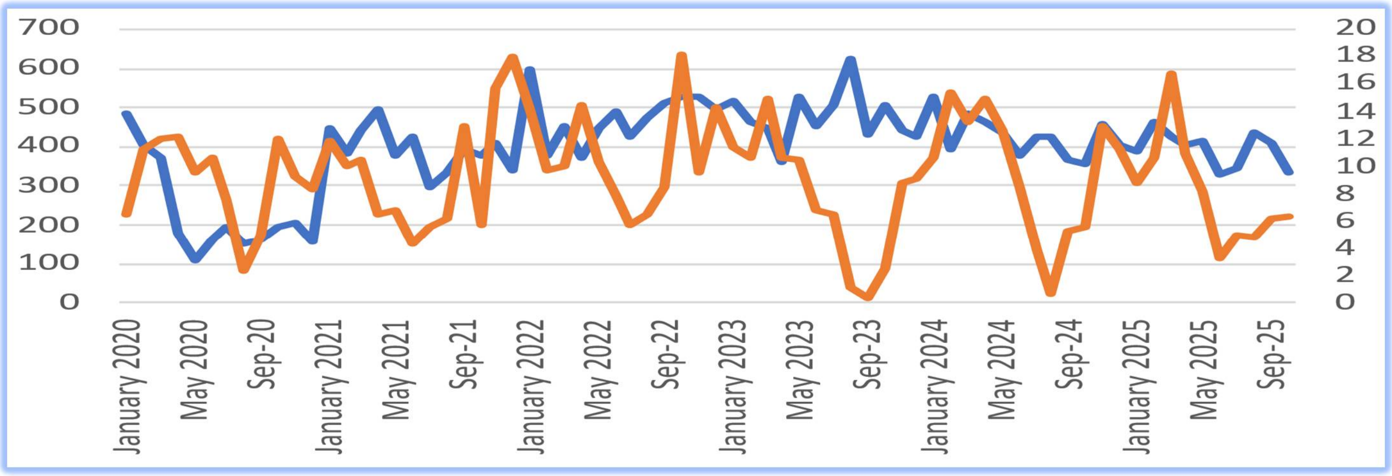

Figure 9. Comparison graph of rainfall with pulmonary tuberculosis cases in Palembang City from January 2020 to October 2025

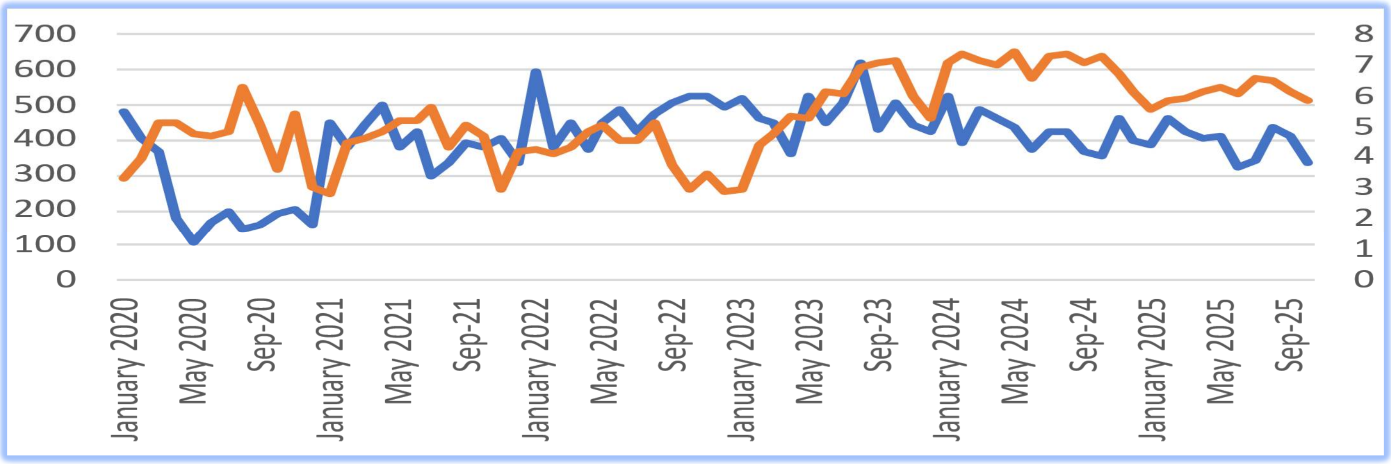

Figure 10. Comparison graph of sunshine duration with pulmonary tuberculosis cases in Palembang City from January 2020 to October 2025

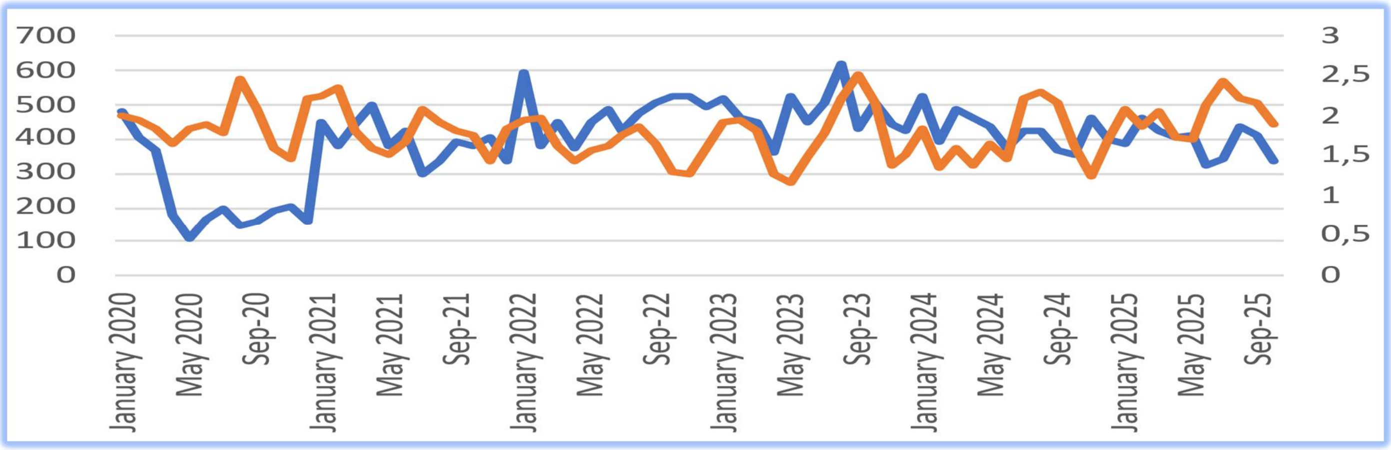

Figure 11. Comparison graph of wind speed with pulmonary tuberculosis cases in Palembang City from January 2020 to October 2025

Based on Figure 12, the distribution of pulmonary tuberculosis cases in Palembang City varies between subdistricts, and this can be linked to the number of general practitioners in each area. Districts with a high number of general practitioners, such as Ilir Barat I (32 doctors), Ilir Timur I (25 doctors), Seberang Ulu I (24 doctors), Kalidoni (20 doctors), Ilir Timur II (19 doctors), and Sukarami (19 doctors), tend to have better capacity for TB screening and treatment. Many of these subdistricts are categorized as having medium to high TB cases on the map (around 171–232 cases), indicating that a high number of health workers can encourage increased case detection and reporting.

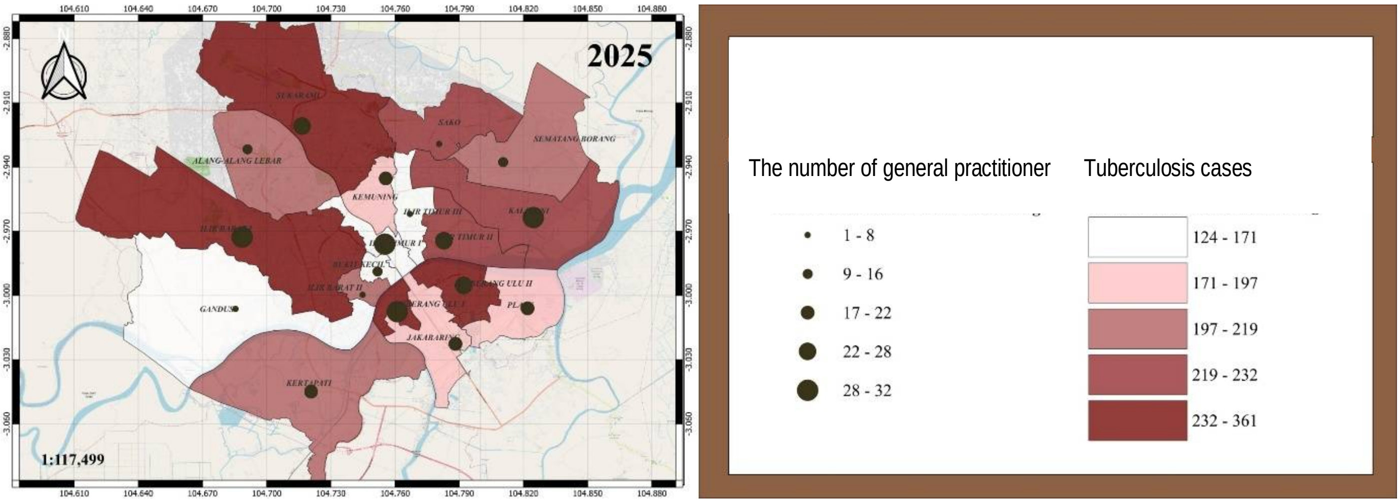

Figure 12. Spatial map of general practitioner availability with pulmonary tuberculosis cases in Palembang City in 2025

Based on Figure 13, spatial analysis shows that several subdistricts, such as Sukarami, Kalidoni, Kertapati, and Ilir Barat II, are in the high category in terms of TB cases. Meanwhile, subdistricts such as Bukit Kecil, Kemuning, Ilir Timur I, and Seberang Ulu I–II show the presence of pulmonologists with a variation in numbers ranging from 1 to 9 pulmonologists, where Kemuning has the most pulmonologists (9 people), and several other subdistricts do not have any pulmonologists at all. The imbalance between the number of pulmonologists and the TB case load is quite evident. For example, subdistricts with high TB cases, such as Sukarami, have seven pulmonologists, but other areas that do not have pulmonologists also show fairly high cases, such as Kalidoni, Kertapati, and Sematang Borang.

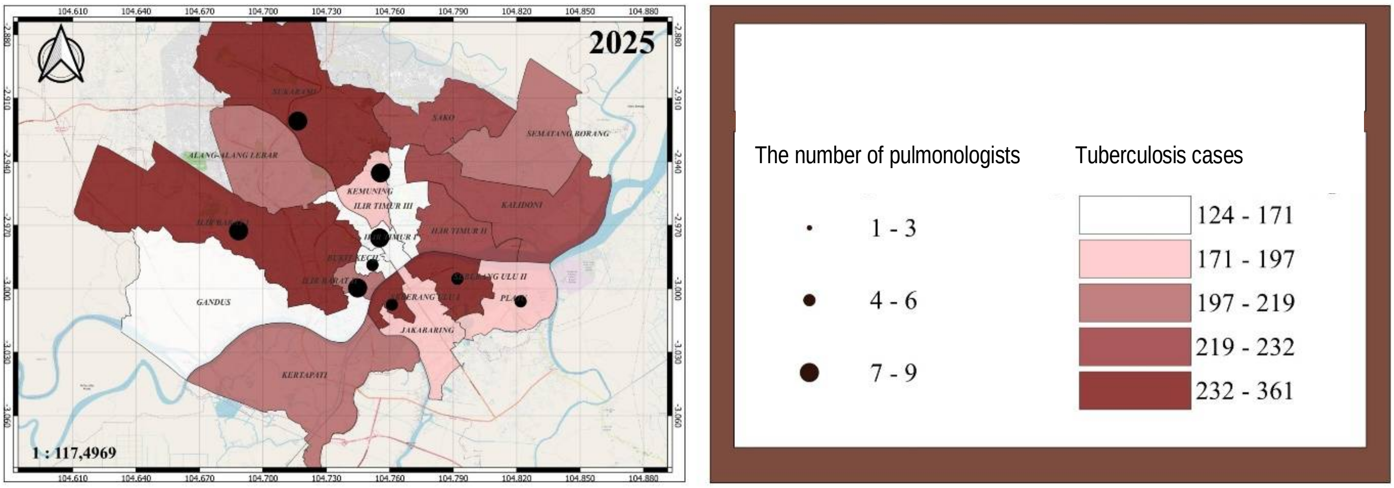

Figure 13. Spatial map of pulmonologists' availability and pulmonary tuberculosis cases in Palembang City in 2025.

DISCUSSION

This study found that the temporal pattern of climate variability in Palembang City during January 2020–October 2025 did not exhibit a consistent or linear relationship with monthly fluctuations in adult pulmonary tuberculosis cases, suggesting that the influence of meteorological variables on tuberculosis incidence at a monthly temporal scale is inherently complex, nonlinear, and not uniformly deterministic [10,11]. This finding aligns with the broader scientific literature, which has repeatedly demonstrated that climatic effects on tuberculosis transmission vary across geographical settings, population structures, and temporal windows. For instance, a meta-analysis by Qin et al. (2022) reported that only rainfall showed a statistically significant positive association with tuberculosis risk, whereas temperature, humidity, and other meteorological indicators did not demonstrate significant effects [9]. In contrast, a spatial–temporal investigation conducted in China identified relative risks (RR) greater than 1 for humidity, rainfall, and sunshine duration; indicating a positive association while average temperature showed an RR below 1, suggesting a protective or negative effect, and wind speed exhibited no significant influence [12].

Further evidence from a longitudinal study in northern China confirmed that the relationship between climate and tuberculosis is both nonlinear and lagged, meaning that climatic exposures may influence tuberculosis risk only after a certain delay. For example, tuberculosis risk was found to decrease as daily temperature increased but rose with higher wind speed, illustrating the multifaceted and sometimes counterintuitive nature of climatic impacts on airborne infectious diseases [13,14]. Several physiological and behavioral mechanisms may underlie these patterns. Humidity, for instance, can modulate the survival and aerosol stability of *Mycobacterium tuberculosis* in the environment, while extreme weather conditions may alter human mobility, indoor crowding, and exposure patterns in ways that influence transmission dynamics [9,15].

However, in Palembang, temporal consistency was not observed. Periods of elevated humidity or temperature were occasionally followed by increases in tuberculosis cases, but these patterns did not recur reliably across years. This inconsistency reinforces the notion that intermediary determinants, such as socioeconomic conditions, healthcare accessibility, behavioral patterns, and host immunological resilience interact with climatic factors to shape tuberculosis incidence trends [6,9,15,16]. Thus, climate alone cannot fully explain temporal variations in tuberculosis burden in this setting.

The spatial analysis revealed substantial heterogeneity in tuberculosis case distribution across subdistricts, suggesting a potential link to the spatial distribution of general practitioners. Subdistricts with higher availability of general practitioners; such as Ilir Barat I, Ilir Timur I, and Seberang Ulu I tended to report more tuberculosis cases. This pattern is consistent with the concept of detection bias, wherein areas with better healthcare infrastructure and more clinicians are able to conduct more effective active and passive case finding, thereby identifying cases that might remain undetected in underserved regions [17,18]. Conversely, subdistricts with limited numbers of general practitioners face heightened risks of delayed diagnosis, inadequate screening coverage, and under-reporting, which may allow ongoing transmission to persist unnoticed [19,20]. These findings align with previous studies demonstrating that the density of healthcare facilities and health workers is positively associated with tuberculosis detection rates [21,22]. Although some studies in Central Asia have reported a negative correlation between physician density and tuberculosis incidence, possibly reflecting improved treatment access and reduced transmission [23] the present findings underscore that, in the local context of Palembang, the distribution of health workers influences case reporting and programmatic visibility rather than biological incidence alone. Therefore, addressing disparities in healthcare access, including equitable distribution of general practitioners and strengthening the capacity of community health centers, is essential for narrowing the detection gap.

Based on these spatial–temporal patterns, tuberculosis control strategies in Palembang must adopt an integrated and multifaceted approach. First, strengthening primary healthcare is crucial. Enhancing the training, distribution, and retention of health workers can expand routine screening coverage and improve early detection. Second, active case finding (ACF) must be intensified. A study published in *The Lancet Regional Health* emphasizes that ACF strategies must ensure that every tuberculosis patient receives appropriate treatment and continuous support throughout therapy [22]. This aligns with World Health Organization recommendations, which advocate systematic screening of high-risk populations while cautioning that exclusive reliance on high-risk groups may overlook a substantial proportion of cases in the general population [22]. Consequently, the tuberculosis program in Palembang should broaden screening efforts to include communities with high transmission potential, incorporating active contact investigation and mobilizing public health workers to identify latent and early-stage cases.

Third, engagement of the private sector through a public–private mix (PPM) approach is essential for closing the detection gap. The World Health Organization highlights that reaching all healthcare providers, both public and private is critical to identifying the millions of tuberculosis cases that remain undiagnosed each year [21,24]. Strengthening partnerships with private clinics and hospitals in Palembang will ensure that tuberculosis patients who initially seek care outside the public system are appropriately reported and managed. Finally, integrating climate data with health indicators can support early warning systems. For example, if meteorological forecasts predict periods of high humidity or extreme weather, health authorities can intensify targeted case-finding activities during these high-risk intervals. Evidence from high-burden settings indicates that combining service strengthening, ACF, and spatially informed interventions can effectively reduce tuberculosis transmission.

The main limitation of this study lies in its ecological design. Because data were aggregated at the monthly and subdistrict levels, individual-level information was not captured, raising the possibility of ecological fallacy [25]. Important confounding factors, such as socioeconomic status, smoking behavior, housing density, HIV status, and nutritional deficiencies were not measured and therefore could not be controlled for. As a result, the associations observed should be interpreted as population-level patterns rather than direct causal relationships at the individual level. Future research employing cohort or multilevel designs will be necessary to examine causal pathways linking climate exposure and healthcare access to individual tuberculosis risk. Additionally, interventional studies are needed to evaluate the effectiveness of ACF strategies and physician redistribution within the specific context of Palembang.

CONCLUSION

Monthly climate variability in Palembang did not show a consistent association with fluctuations in adult pulmonary TB cases during the period January 2020–October 2025, while spatial patterns pointed to heterogeneity in cases related to the distribution of doctors and case detection capabilities. To reduce the hidden burden of TB and prevent ongoing transmission, city TB programs need to combine equitable health services (including redistribution of medical personnel and strengthening of PPM), active case-finding strategies focused on high-risk clusters, and increased capacity for disruption-resistant reporting systems (e.g., disruptions due to pandemics). Due to ecological and aggregate data limitations, further research using multilevel designs or individual-level data linking climate exposure and health service indicators at the individual level is recommended to test causal hypotheses, along with interventional evaluations to determine the effectiveness of spatial targeting strategies.

Ethical consideration, competing interest and source of funding

-This study was approved by the Health Research Ethics Committee, Faculty of Public Health, Universitas Sriwijaya, No. 936/UN9.FKM/TU.KKE/2025.

-The authors declare that they have no competing interests associated with the material presented in this paper.

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