ORIGINAL ARTICLE

# Spatial Clustering of Tuberculosis Incidence and its Spatial Association with Population Density and Primary Health Care Distribution in Semarang City, Indonesia

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## Abstract

**Background:** While tuberculosis persists as a public health threat in urban Indonesia, the spread of the disease is uneven. It is believed that rapid urbanization and unequal access to medical services have led to varying disease burdens across regions.

**Objective:** To examine the spatial distribution and clustering of tuberculosis incidence and its association with population density and primary health care distribution in Semarang City.

**Methods:** An ecological study was conducted using a spatial analysis approach based on secondary data on TB cases, population, and health facilities in Semarang City for the years 2022-2023. Both global and local spatial autocorrelation analyses were conducted to examine clustering, followed by bivariate analyses to test their relationships with other variables.

**Results:** Significant spatial clustering of TB incidence was observed in both years (Moran's I = 0.339 in 2022 and 0.465 in 2023; $p < 0.001$). High-incidence clusters were mainly located in the central and eastern urban areas. Population density showed a significant positive spatial association with TB incidence (Moran's I=0.415 in 2022 and 0.522 in 2023; p=0.001), whereas no significant association was found for PHC distribution.

**Conclusion:** Tuberculosis incidence in Semarang City exhibited a clustered spatial pattern, particularly in densely populated areas. These findings support geographically targeted TB control strategies. However, because the analysis was based on aggregated ecological data, the results should not be interpreted at the individual level.

**Keywords:** *Tuberculosis, spatial analysis, population density, primary health care, spatial clustering.*

## INTRODUCTION

Tuberculosis (TB) is still one of the most dangerous infectious diseases that public health officials around the world have to deal with in the twenty-first century. Mycobacterium tuberculosis causes the disease, which still kills millions of people every year, even though there are good ways to diagnose and treat it [1, 2]. The World Health Organization (WHO) says that TB is one of the deadliest infectious diseases in the world. In the past few years, only COVID-19 has killed more people [3]. More than 10.6 million people around the world got tuberculosis in 2022, and about 1.3 million of them died from it. This shows that tuberculosis continues to harm people and healthcare systems [4].

Along with India and China, Indonesia has one of the highest rates of TB in the world. It is always in the top three countries with the highest rates [4]. In 2022, Indonesia had more than 969,000 new cases of TB and more than 93,000 deaths from the disease. This is a major contributor to the world's TB burden [5]. Indonesia has many different kinds of land. There are more than 17,000 islands, and more than 270 million people live in big cities, small cities, and huge rural areas [6]. This makes it hard to stop the spread of TB. Healthcare services are not uniform across the archipelago, and the shift to district-level health management has led to significant differences in the quality and number of TB programs at the local level.

In Central Java Province, Semarang City is recognized as one of the areas with the highest tuberculosis burden and is included among priority districts for TB control. Previous research revealed that Semarang City recorded the highest number of TB cases in Central Java Province and was a high-burden area nationally in Indonesia. Data from the Semarang City Health Office showed a significant increase in cases, from 1,920 in 2020 to 5,125 in 2023 [7]. This ongoing upward trend indicates continued transmission and also an increase in the quality and quantity of early detection and reporting of TB cases. As a fast-growing urban center, the city exhibits considerable variability in population density, socioeconomic conditions, and the environment [8]. The aforementioned factors might contribute to the

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uneven distribution of TB cases in the city. There are approximately 38 primary health care centers providing primary medical assistance within the framework of their administration zones. These facilities form the backbone of tuberculosis prevention and management, serving as the first point of contact where patients undergo screening, are diagnosed, and receive treatment. Thus, differences in the geographical locations and operational capabilities of those institutions, together with socioeconomic inequalities, can affect the distribution of TB cases in the region [9].

Primary health care (PHC) is the primary gateway through which tuberculosis services are delivered in Indonesia, as most patients seek screening, diagnosis, initiation of treatment, and follow-up through this route [10-12]. Despite gains in PHC coverage, access disparities persist due to geographic, socioeconomic, and social barriers [13]. Late diagnosis and treatment of the disease occur in various settings and may lead to continued transmission in the community.

Spatial access to health care has been recognized as vital to tuberculosis control. However, relatively scant empirical literature exists on whether the spatial distribution of PHC centers matches that of tuberculosis incidence in the urban setting in Indonesia [14]. The majority of studies conducted in Semarang and other Indonesian cities have focused on identifying disease hotspots or investigating environmental factors that contribute to transmission [1]. Therefore, little is known about the relationship between population density and the spatial distribution of PHC centers with respect to TB burden. Semarang is a suitable urban setting for studying this relationship, as population density, access to health services, and TB burden vary greatly across its sub-districts. Studying these spatial relationships can contribute to a better understanding of how the TB burden is distributed across urban communities. The present study investigated the geographic distribution of tuberculosis incidence across the 16 sub-districts of Semarang City during 2022-2023. The analysis focused on identifying spatial clustering of tuberculosis and examining its spatial association with population density and the distribution of primary health care facilities.

## METHODS

An ecological framework was adopted, with spatial analytical techniques applied to evaluate geographic variation in tuberculosis incidence. The study was conducted in Semarang City, Central Java Province, Indonesia, encompassing 16 sub-districts. The sub-district was used as the unit of analysis. Analyses were performed at the sub-district level (kecamatan) using aggregated annual tuberculosis notifications obtained from the Tuberculosis Information System (SITB) and did not include individual-level patient records. Cases included all notified tuberculosis patients recorded in the SITB and assigned to their respective sub-districts of residence during 2022 and 2023. Annual incidence rates were calculated separately for each year by dividing the number of reported TB cases by the corresponding sub-district population and expressed per 100,000 population. Before analysis, the dataset was reviewed for completeness and consistency, and only validated annual case reports from the Semarang City Health Office were included.

Secondary data on tuberculosis patients were extracted from the Tuberculosis Information System (SITB) (https://sitb.kemkes.go.id/) managed by the Semarang City Health Office. A retrospective ecological study was conducted from January to June 2024, during which data were retrieved, processed, and analyzed. Additional information on the number and geographic locations of primary health care centers (Puskesmas) within each sub-district was obtained from the Semarang City Health Office.

The dependent variable in the study is the annual incidence rate of TB, defined as the ratio of the total number of reported TB cases in a year to the population of the respective subdistrict, calculated per 100,000 population. The independent variables are the number of PHCs in each subdistrict, an indicator of the availability of health care services, and population density (PD), the number of residents per square kilometer. Spatial units were determined according to the administrative boundaries of the subdistricts.

Spatial analyses were conducted using ArcGIS and GeoDa. Choropleth maps were produced to visually represent geographic variations in TB incidence rates and population density. Global spatial autocorrelation was estimated to assess the spatial pattern of TB incidence rates using Moran's I statistic in ArcGIS. For estimating global spatial autocorrelation, a distance-based spatial weighting matrix was applied using the inverse distance method, with weights assigned to geographically proximate subdistricts being higher [15].

$$I = \frac{n \sum_i \sum_j w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{S_0 \sum_i (x_i - \bar{x})^2}$$

Local spatial autocorrelation and hot spot analysis were estimated using the Local Indicators of Spatial Association (LISA) to identify local clusters by comparing actual and random values within the respective spatial units. Four subdistrict types were identified according to LISA based on similarity of values in a spatial unit with the neighboring subdistricts' values: high-high (HH) - spatial units with high values surrounded by high values (hotspots); low-low (LL) - subdistricts with low values surrounded by low values (cold spots); high-low (HL); low-high (LH). Statistical significance was determined at $p < 0.05$ [16]. Bivariate spatial autocorrelation analysis was conducted in GeoDa using a contiguity-based spatial weights matrix (queen contiguity), where neighboring subdistricts share common boundaries or

vertices. Bivariate Moran's I and BiLISA cluster maps were used to assess the spatial relationship between tuberculosis incidence and population density, as well as between TB incidence and the distribution of primary health centers.

$$I_{xy} = \frac{n \sum_i \sum_j w_{ij} (x_i - \bar{x})(y_j - \bar{y})}{S_0 \sqrt{\sum_i (x_i - \bar{x})^2 \sum_j (y_j - \bar{y})^2}}$$

This study received ethical approval from the Health Research Ethics Committee, Faculty of Public Health, Diponegoro University. The study used aggregated secondary data without individual identifiers; therefore, no direct participant involvement or informed consent was required.

## RESULTS

Table **1** presents the descriptive statistics of the study variables across the 16 sub-districts of Semarang City. The mean TB incidence rate increased slightly from 278.34 per 100,000 population in 2022 to 288.45 per 100,000 population in 2023. Population density also increased modestly, from 6,875.88 to 6,998.38 persons/km². The number of primary health centers varied across sub-districts, ranging from 1 to 4, with an average of 2.38 PHCs per sub-district.

As shown in Table **2**, the mean TB incidence rate increased by 10.11 cases per 100,000 population between 2022 and 2023. Nonetheless, this change was not statistically significant (p = 0.278). By comparison, population density increased significantly during the same period, with a mean difference of 122.50 persons/km² (95% CI: 93.46-151.53; p < 0.001).

The distribution of tuberculosis (TB) incidence across all sub-districts in Semarang City in 2022 and 2023, along with the locations of primary health care centers, is shown in Fig. **(1)**. The map shows that the central and eastern areas of the city tend to have higher TB incidence rates compared to outlying areas such as Mijen and Gunung Pati, which consistently showed lower rates throughout the study period. Over the two years, this pattern has not changed significantly. Several sub-districts in urban areas continue to show high, even very high, TB incidence rates. Meanwhile, most primary healthcare facilities are located in densely populated central areas. This likely contributes to the high number of cases detected and reported in these areas. In general, the results of this study indicate that the distribution of TB cases in Semarang City is not random, but rather forms a clustering pattern, particularly in the central sub-districts.

**Table 1:** Descriptive statistics of study variables 2022-2023.

| No. | Subdistrict | Number of Primary Health Centers | *TB Incidence Rate 2022 | *TB Incidence Rate 2023 |
|---|---|---|---|---|
| 1 | Candisari | 1 | 331.7 | 331.36 |
| 2 | Tugu | 2 | 202.13 | 162.36 |
| 3 | Semarang Timur | 3 | 369.69 | 426.43 |
| 4 | Ngaliyan | 3 | 231.02 | 203.34 |
| 5 | Pedurungan | 4 | 202.07 | 237.02 |
| 6 | Gunung Pati | 2 | 229.48 | 195.67 |
| 7 | Tembalang | 3 | 282.04 | 324.95 |
| 8 | Mijen | 2 | 178.69 | 197.05 |
| 9 | Gajah Mungkur | 1 | 323.88 | 325.57 |
| 10 | Semarang Selatan | 3 | 309.16 | 347.21 |
| 11 | Semarang Utara | 3 | 343.61 | 362.92 |
| 12 | Semarang Tengah | 1 | 314.01 | 288.24 |
| 13 | Gayamsari | 1 | 328.11 | 329.7 |
| 14 | Genuk | 2 | 311.31 | 330.44 |
| 15 | Semarang Barat | 3 | 300.61 | 272.27 |
| 16 | Banyumanik | 4 | 195.9 | 280.65 |

*Tuberculosis incidence rate is expressed per 100,000 population.

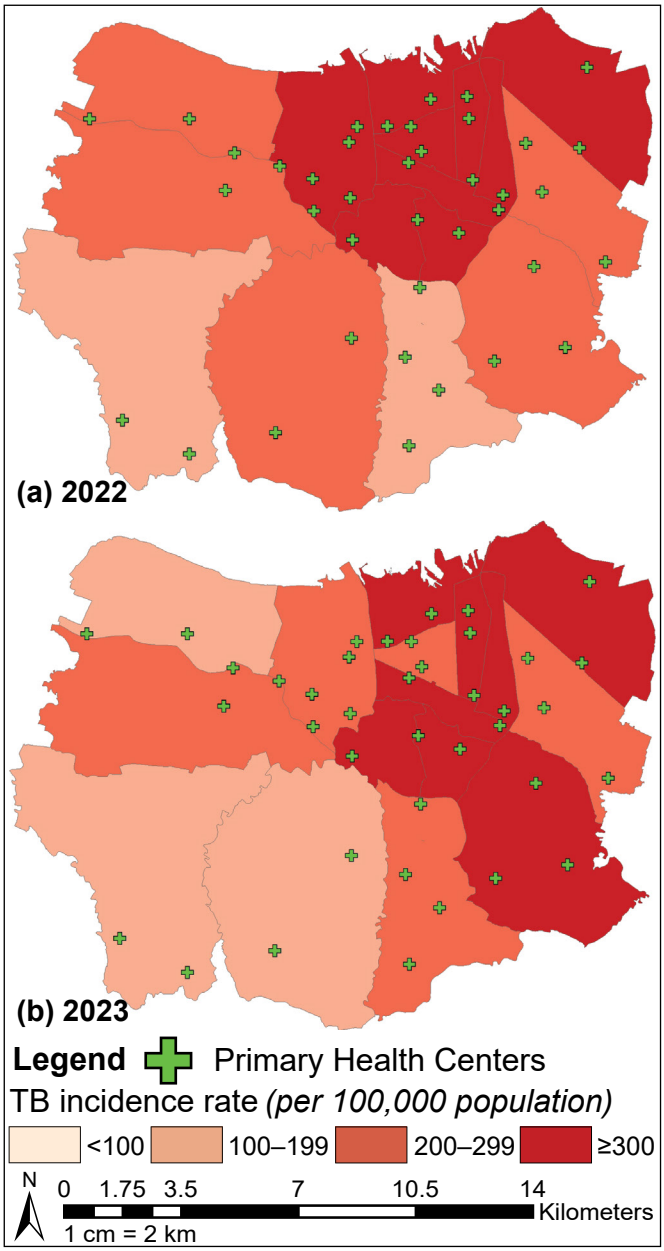



**Fig. (1):** Spatial distribution of tuberculosis incidence rates and primary health center locations in Semarang City: **(a)** 2022 and **(b)** 2023.

**Table 2:** Comparison of population density and tuberculosis incidence rates between 2022 and 2023.

| Parameters | Mean ± SD | Median | Minimum | Maximum |
|---|---|---|---|---|
| Population density 2022a | 6875.88 ± 3852.01 | 6358.14 | 1176.14 | 12067.24 |
| Population density 2023a | 6998.38 ± 3902.47 | 6459.77 | 1201.59 | 12261.64 |
| Number of PHCs | 2.38 ± 1.02 | 2.50 | 1.00 | 4.00 |
| TB incidence rate 2022b | 278.34 ± 61.54 | 304.89 | 178.69 | 369.69 |
| TB incidence rate 2023b | 288.45 ± 72.63 | 306.60 | 162.36 | 426.43 |

aPopulation density is expressed as persons/km².
bTuberculosis incidence rate is expressed per 100,000 population.
PHCs = Primary Health Centers

This finding is further supported by the results of the global spatial autocorrelation analysis (**Table 3**). In 2022, the Moran's I value was recorded at 0.339 (z = 2.765; p < 0.001), indicating strong positive spatial autocorrelation. A similar pattern was also found in 2023, with a Moran's I value of 0.465 (z = 3.695; p < 0.001).

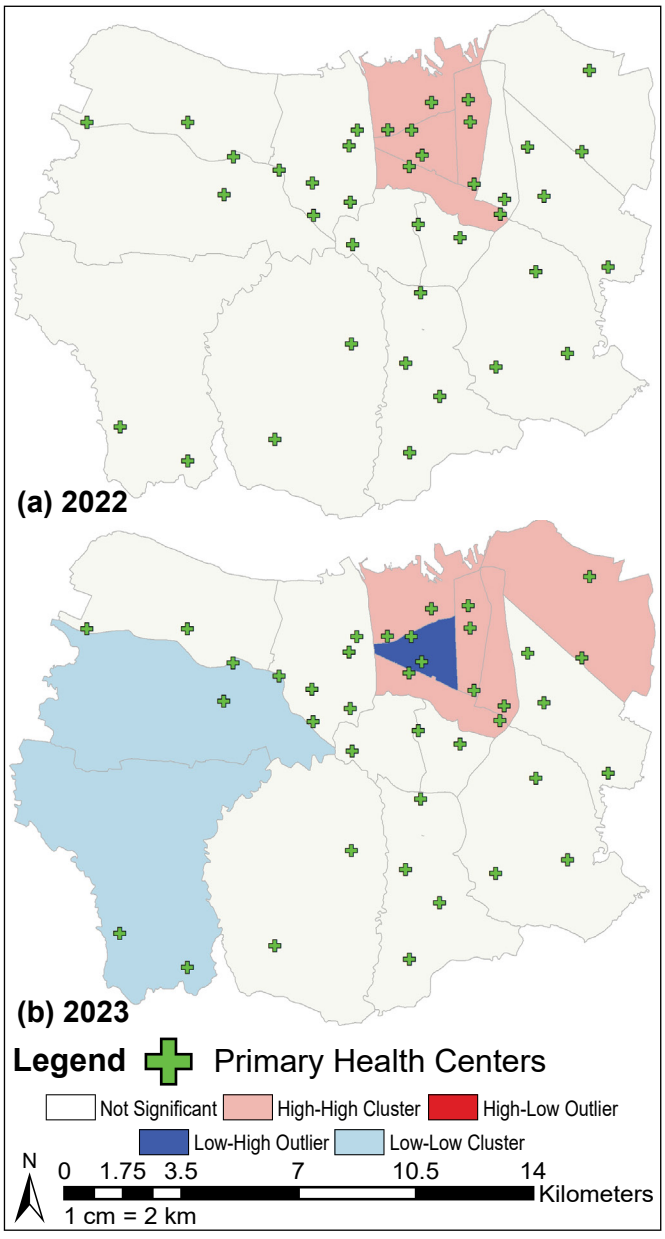



**Fig. (2):** Local spatial clusters of tuberculosis incidence in Semarang City (2022-2023) derived from Anselin Local Moran's I analysis.

**Table 3:** Global spatial autocorrelation of tuberculosis incidence rates in Semarang City, 2022-2023.

| Year | Moran's I | z-score | p-value | Spatial Pattern |
|---|---|---|---|---|
| 2022 | 0.339 | 2.765 | < 0.001 | Clustered |
| 2023 | 0.465 | 3.695 | < 0.001 | Clustered |

**Table 4:** Bivariate spatial autocorrelation between tuberculosis incidence, population density, and primary health care distribution in Semarang City, 2022-2023.

| Parameters | Year | Moran's I | Z-score | p-value |
|---|---|---|---|---|
| TB IR - Population Density | 2022 | 0.415 | 3.503 | 0.001 |
| TB IR - Population Density | 2023 | 0.522 | 4.756 | 0.001 |
| TB IR - PHCs | 2022 | 0.068 | 0.415 | 0.356 |
| TB IR - PHCs | 2023 | -0.005 | -0.057 | 0.460 |

TB IR = Tuberculosis incidence rate
PHCs = Primary Health Centers

Local spatial autocorrelation analysis using the Anselin Local Moran's I method indicates the presence of several significant clusters of TB cases in several sub-districts in Semarang City (**Fig. 2**). In 2022, a High-High cluster was detected in the northern-central part of the city, indicating that sub-districts with high TB incidence were surrounded by neighboring areas with similarly high incidence rates. Most of the remaining sub-districts did not exhibit statistically significant local spatial autocorrelation. In 2023, the spatial clustering of tuberculosis incidence became more clearly defined. High-High clusters remained concentrated in the northern and eastern parts of Semarang City, indicating the persistence of localized areas with elevated TB incidence. Conversely, Low-Low clusters were identified in the western part of the city, suggesting geographic concentrations of comparatively low disease burden. Additionally, a Low-High outlier was observed in the central area, representing a sub-district with relatively low TB incidence, surrounded by neighboring sub-districts with higher incidence rates.

The findings from the bivariate spatial autocorrelation test are presented in Table **4**. There existed a significant spatial relationship between the population density and TB incidence. The strength of the relationship increased from 0.415 in Moran's I in 2022 to 0.522 in 2023. The result implies that sub-districts with high population density tended to be located close to regions with high TB incidence, suggesting clustering of disease burden in densely populated regions. On the other hand, there was a weak spatial relationship between TB incidence and the distribution of PHCs in both 2022 (0.068) and 2023 (-0.005).

Fig. **(3)** illustrates the local spatial association between tuberculosis incidence and population density. In 2022, four significant high-high clusters were detected in the northern and central areas of Semarang City, highlighting locations where densely populated sub-districts coincided with elevated TB incidence in neighboring

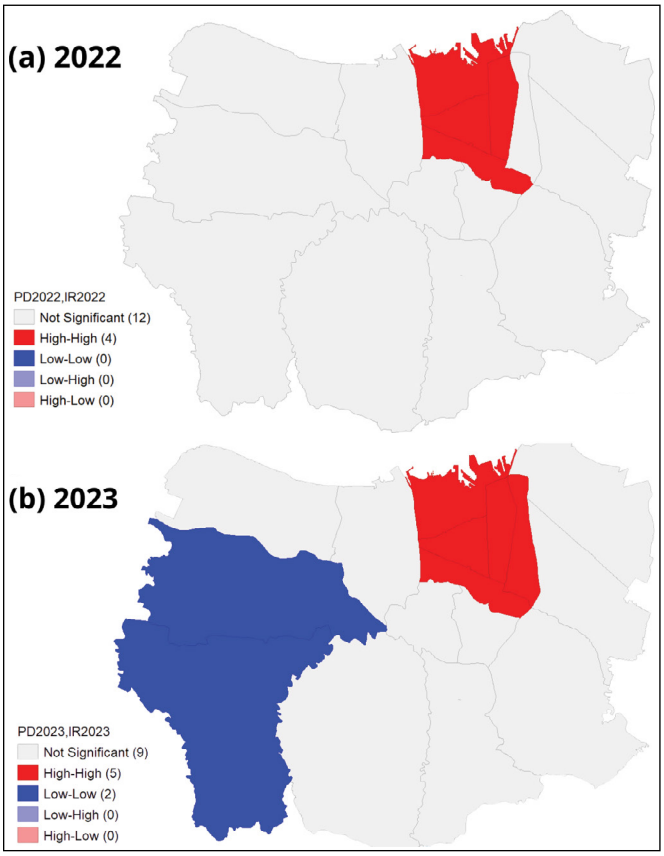



**Fig. (3):** BiLISA cluster maps illustrating the spatial association between tuberculosis incidence and population density in Semarang City: **(a)** 2022 and **(b)** 2023.

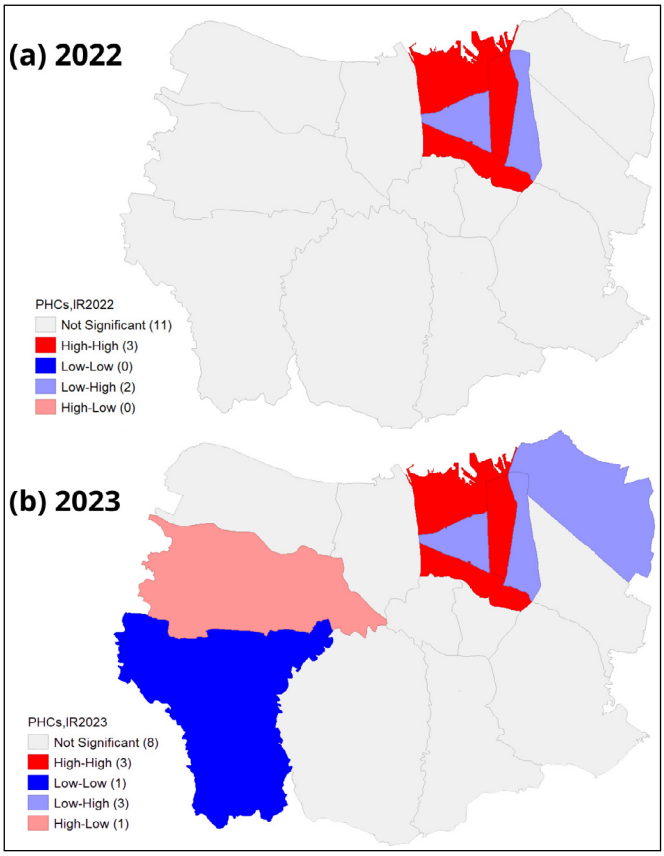



**Fig. (4):** BiLISA cluster maps of the spatial association between tuberculosis incidence and primary health care distribution in Semarang City: **(a)** 2022 and **(b)** 2023.

areas. The pattern became more evident in 2023, with five high-high clusters persisting across the northern urban zone and two low-low clusters appearing in the western part of the city.

Fig. **(4)** presents the local spatial association between tuberculosis incidence and the distribution of primary health care centers. In 2022, three high-high clusters and two low-high outliers were observed in the northern part of the city. In 2023, the spatial pattern became more heterogeneous, comprising three high-high clusters, one low-low cluster, three low-high outliers, and one high-low outlier. The presence of these localized clusters and outliers indicates spatial variability in the relationship between PHC distribution and tuberculosis incidence across sub-districts.

## DISCUSSION

Tuberculosis incidence in Semarang exhibits a non-random spatial distribution with clear clustering. Areas with high-incidence clusters seem concentrated in the central and eastern portions of the city, but surrounding sub-districts consistently have lower-incidence clusters. This is expected, as population density is a major factor in disease transmission intensity in the urban center and eastern portions, which have higher population density than suburbs with lower population density. As for community health centers (Puskesmas), their distribution across sub-districts indicates uneven availability. However, no significant spatial association was observed between PHC distribution and TB incidence, suggesting that the number and location of PHCs alone may not fully explain the observed spatial variation in TB incidence. Similar observations have been reported in previous studies, which highlighted that differences in TB burden are influenced not only by the availability of health facilities but also by factors related to service accessibility, utilization, case-finding activities, and health system performance [17]. Notably, the number of health centers is higher in East Semarang, but TB incidence rates remain relatively high. Conversely, several sub-districts with fewer health centers reported lower TB incidence rates. Although these patterns were not statistically significant, they suggest that factors beyond the mere presence of PHCs may shape variations in TB incidence.

Comparable geographic concentrations of tuberculosis have also been reported in several Indonesian settings, suggesting that the observed clustering is not coincidental but structurally driven, with TB cases concentrated in densely populated urban areas [18, 19]. Evidence from a study in Bandar Lampung suggests that TB cluster formation is closely linked to high population density and easy access to healthcare [20]. Several studies have shown that TB is more common

in dense urban environments, particularly in slums and city centers, where high residential density increases the frequency of close contact between individuals, thus increasing the opportunity for transmission. Other studies have suggested that TB incidence tends to be higher in urban areas than in rural areas, primarily due to higher population density and environmental conditions that favor disease spread [21]. Similar results have been found in other regions with high TB prevalence, where spatial analysis often identifies persistent TB hotspots in densely populated areas [22-24]. Spatial analyses such as those conducted in Mysuru, India, consistently link TB hotspots to densely populated neighborhoods, highlighting the importance of population density [25]. High population density increases interactions and the likelihood of repeated exposures, which can lead to the progression of latent TB to active TB and is often associated with socioeconomic disadvantage. These findings suggest that the number of health facilities alone may be insufficient to explain spatial differences in TB incidence. Existing literature supports this interpretation, emphasizing that while geographic access influences case detection, the quality, accessibility, and integration of services are equally important. Consequently, areas with more health facilities may not necessarily achieve better TB control outcomes if barriers to service utilization persist. Evidence from Lima showed that neighborhoods with poorer pedestrian access to clinics experienced lower tuberculosis screening uptake, suggesting that physical accessibility may influence case detection and contribute to underdiagnosis [26].

In Indonesia, the role of primary healthcare in tuberculosis management is also limited by challenges in service delivery. Many patients are referred to hospitals rather than managed at the primary healthcare level. Evidence from one study reported that 81% of 782 tuberculosis-related visits resulted in referrals [27]. This variance directly stems from PHC capacity limitations, including inadequate diagnostic tools, a lack of dedicated TB treatment rooms, and incentive mechanisms that favor secondary care. Such conditions can delay diagnosis and treatment interventions and hinder the progression to cure, ultimately undermining TB control efforts. These findings have important implications for TB control in Semarang and similar urban settings. The identified hotspots in densely populated areas may represent priority locations for targeted TB control interventions. Strategies such as active case finding through house-to-house screening, deployment of mobile X-ray or GeneXpert units, and focused outreach in densely populated areas are potentially more effective in these areas [28]. Concrete interventions can also include improving housing conditions, including reducing overcrowding and improving ventilation, as well as increasing public awareness of TB, which is also crucial for limiting transmission [29]. At the same time, strengthening primary care should focus more on improving facility capacity and performance rather than expanding the number of facilities. These findings suggest that factors beyond the mere presence of health facilities, including diagnostic capacity, service accessibility, health worker competency, and the organization of TB services, may contribute to variations in TB detection and management [30]. As a result, strengthening PHC performance through improved diagnostic capabilities, reliable bacteriological testing, adequate workforce training, and better integration of TB services may enhance the effectiveness of TB control efforts.

## STUDY LIMITATIONS

Several limitations should be considered when interpreting the findings of this study. Firstly, the ecological approach implies that all results were obtained using aggregated information at the sub-district level; hence, no conclusions about individuals can be drawn. As a consequence, there is a possibility of an ecological fallacy if the relationships found in the study are interpreted as individual-level risk factors between population density, primary health care services, and incidence of tuberculosis. Secondly, the current research used only 16 sub-districts with data for a short time frame - 2022-2023. Even though this dataset was sufficient to identify spatial patterns, it may have reduced sensitivity to detecting more detailed spatial and temporal patterns of tuberculosis cases. Finally, many important determinants of tuberculosis could not be included in the analysis due to a lack of data, including socioeconomic factors, environmental factors, housing, mobility, and accessibility of health care services.

## CONCLUSION

This study demonstrates that tuberculosis incidence in Semarang City exhibits a clustered spatial pattern, particularly within densely populated urban areas. Population density showed a significant spatial association with tuberculosis incidence, whereas the distribution of primary health care facilities was not spatially correlated with the disease burden. These findings suggest that population concentration remains an important contextual factor influencing the geographic distribution of tuberculosis. Therefore, tuberculosis control strategies should prioritize high-burden hotspots through targeted interventions, while simultaneously improving the accessibility, coverage, and effectiveness of primary health care services. Strengthening place-based public health approaches may contribute to more efficient resource allocation and enhanced tuberculosis control in urban settings.

## LIST OF ABBREVIATIONS

TB : Tuberculosis
PHC : Primary Health Care
IR : Incidence Rate
LISA : Local Indicators of Spatial Association
SITB : Tuberculosis Information System
PD : Population Density

## ETHICS APPROVAL

This study received ethical approval from the Health Research Ethics Committee, Faculty of Public Health, Diponegoro University. All procedures performed in studies involving human participants followed the ethical standards of the institutional and/or national research committee and the Declaration of Helsinki.

## CONSENT FOR PUBLICATION

Not applicable.

## AVAILABILITY OF DATA

Secondary data on tuberculosis patients were extracted from the Tuberculosis Information System (SITB) (https://sitb.kemkes.go.id/) managed by the Semarang City Health Office. The data used in this study are available from the corresponding author upon reasonable request and subject to approval from the Semarang City Health Office.

## FUNDING

None.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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All authors have read and approved the final manuscript.

## GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

AI-assisted tools were used solely for language editing. All scientific content, analyses, and conclusions were developed and approved by the authors.

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