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MORALITY BEFORE KNOWLEDGE

Spatial autocorrelation analysis of tuberculosis incidence: Identifying geographical clusters and socio-environmental risk factors

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ABSTRACT

Background: Indonesia ranks second as the country with the highest number of tuberculosis cases in the world. The three most populous provinces on the island of Java (West Java, East Java, and Central Java) contribute the most TB cases in Indonesia. The Provincial Health Offices of West Java, East Java, and Central Java have data on tuberculosis incidence and influencing risk factors, but most of the data is processed manually and presented in tables and graphs. Spatial and mapping approaches can be used to visualize the distribution of tuberculosis incidence and its risk factors. **Method:** This study used an ecological study design with a spatial approach. The population in this study consisted of 100 districts/cities in the provinces of West Java, East Java, and Central Java. The data used were aggregated from annual publications issued by the health offices and the central statistics agencies of the three provinces for the period 2024. **Findings:** The tuberculosis case notification rate distribution in the three regions of Java Island exhibited positive spatial autocorrelation. Three independent variables had negative spatial autocorrelation with the TB CNR, namely the percentage of poor people, the percentage of households with access to proper sanitation, and the percentage of livable houses. Meanwhile, population density is the only variable that has positive spatial autocorrelation with TB CNR. **Conclusion:** TB prevention, case finding, and intervention can adopt and modify the policy implications of these spatial analysis results by considering the conditions of each region. **Novelty/Originality of this article:** This study applies spatial analysis using Moran's Index and LISA approaches in the regions of West Java, East Java, and Central Java, as well as its use of variables such as BPJS Health insurance ownership, access to proper sanitation, and livable housing, which have not been widely studied in previous research.

KEYWORDS: case notification rate; spatial analysis; tuberculosis determinants.

1. Introduction

Tuberculosis (TB) is an infectious disease that mostly affects the lungs. It is caused by the bacterium Mycobacterium tuberculosis. Transmission occurs through the air when someone with TB coughs, sneezes, laughs, or speaks (Derakhshan-Nezhad, 2023). In 2023, TB is estimated to be the second leading cause of death worldwide from a single infectious agent, after COVID-19. Approximately a quarter of the global population is also estimated to have been infected with TB.

To address the significant global impact of TB described above, various strategies have been implemented to end the TB epidemic. Since 2014–2015, the WHO and the UN have

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committed to the End TB Strategy, which sets milestones (2020 and 2025) and long-term targets (2030 and 2035) to significantly reduce incidence rates (new cases per 100,000 population per year), TB deaths, and the financial burden borne by patients and their families. WHO also aims to eliminate TB by reducing the incidence to <1 case per 1 million population by 2050. Globally, there are an estimated 10.8 million TB cases in 2023, with an incidence rate of 134 per 100,000 population (95% UI: 125–145). This data shows a slight increase (0.2%) compared to 2022.

Approximately 87% of global cases originate from 30 countries with a high TB burden. The five countries with the largest contribution to the global total are India (26%), Indonesia (10%), China (6.8%), the Philippines (6.8%), and Pakistan (6.3%) (WHO, 2024). Indonesia ranks second as the country with the highest number of TB cases in the world. The number of TB cases continues to increase every year, reaching 724,309 in 2022, 821,200 in 2023, and 889,000 in 2024. The government targets a case detection rate of 90%, a treatment initiation rate of 100%, and a treatment success rate above 80% by 2025 (Ministry of Health, 2025).

Presidential Regulation No. 67 of 2021 concerning Tuberculosis Control also targets the elimination of TB by 2030, with a reduction in incidence to 65 cases per 100,000 population and a reduction in mortality to 6 per 100,000 population (Peraturan Presiden Republik Indonesia Nomor 67 Tahun 2021 Tentang Penanggulangan Tuberkulosis, 2021). The three most populous provinces on the island of Java (West Java, East Java, and Central Java) contribute the most TB cases. Data from the health profiles of each province shows that in 2024, the number of reported TB cases in West Java reached 229,683, East Java 90,863, and Central Java 87,706. The number of cases in these three provinces is still far from the national TB elimination target for 2030.

Numerous studies have been conducted on factors associated with tuberculosis incidence. Previous research using ecological studies with a spatial approach showed that population density, average age at diagnosis, average altitude, average temperature, and average humidity have a spatial interaction with the proportion of TB cases (Pamadi et al., 2023). Other variables, such as the number of poor people, the number of unemployed people, and temperature, also have a significant correlation with the number of pulmonary TB cases (Silva Diba et al., 2024). Other studies show variations in TB CNR between provinces in Indonesia, which are related to the percentage of children who have received complete immunization, the ratio of basic health services per 100,000 population, and the percentage of villages that have received complete basic immunization (Nurjannah & I, 2021). Economic factors such as per capita savings and per capita medical expenditure are also closely related to TB incidence (Zhang et al., 2020). Furthermore, behavioral and environmental factors such as BCG immunization for infants, suitability of public spaces, smoking habits among adolescents, sex ratio, and access to adequate sanitation significantly affect TB incidence (Ningrum et al., 2022).

The Health Departments of West Java, East Java, and Central Java provinces have data on tuberculosis incidence and the risk factors that influence it, but most of this data is processed manually and presented in the form of tables and graphs. However, tuberculosis incidence can be influenced by the regional conditions of the local community. One alternative that can be used to see the distribution of tuberculosis incidence and its risk factors is by using a spatial approach and mapping. Understanding the characteristics of the spatial distribution of TB and its risk factors is key to planning the prevention and control of this disease. Spatial analysis plays an important role in optimizing resource allocation, supporting early diagnosis, and suppressing TB transmission (Bai & Ameyaw, 2024). This approach is also part of area-based disease management, which utilizes Geographic Information Systems (GIS) to monitor disease distribution patterns geographically (Septiani, 2024). Based on this background, this study aims to analyze the spatial relationship between TB case distribution and its risk factors in three provinces on the island of Java (West Java, East Java, and Central Java) in 2024. The results of this analysis are expected to serve as a basis for decision-making in efforts to accelerate the reduction of tuberculosis cases in Indonesia.

2. Methods

This study employs an ecological study design with a spatial approach. The population in this study consists of 100 districts/cities in the provinces of West Java, East Java, and Central Java. The sampling technique used in this study is total sampling. This study used aggregate data from annual publications issued by the West Java, East Java, and Central Java Provincial Health Offices in the form of Health Profiles of the three provinces for 2024 and the Central Statistics Agency (*Badan Pusat Statistik*) for each province in the form of West Java, East Java, and Central Java Provinces in Figures 2024. The dependent and independent variables are presented in Table 1.

Table 1. Research variables

Variable	Description	Unit	Data Source
Y	Tuberculosis Case Notification Rate (CNR)	Cases per 100,000 Population	Provincial Health Office
X_1	Percentage of Poor Population	%	Central Statistics Agency
X_2	Percentage of Population with BPJS Health Insurance	%	Provincial Health Office
X_3	Real Expenditure per Capita	Thousand rupiah/person/year	Central Statistics Agency
X_4	Population Density	(Km^2)	Central Statistics Agency
X_5	Percentage of Households with Access to Proper Sanitation	%	Provincial Health Office
X_6	Percentage of Livable Houses	%	Provincial Health Office

Univariate data analysis was performed on each variable to provide an overview of the research results regarding tuberculosis (TB) risk factors. Spatial analysis was used to determine the presence or absence of spatial autocorrelation between regions that describe the distribution pattern of the TB Case Notification Rate (CNR) and its risk factors per district/city in the three provinces on the island of Java. Mapping analysis was used to determine the distribution of TB CNR per district/city in the three provinces on the island of Java. Spatial analysis was performed using the GeoDa application. Meanwhile, mapping analysis was performed using the Quantum Geographic Information System (QGIS) mapping application. Categories in the mapping were classified with the help of QGIS software.

The spatial pattern analysis used in this study was the Global Moran Index to test spatial autocorrelation in general, followed by Local Autocorrelation (LISA) analysis. The spatial distribution pattern can be determined by comparing the Moran Index I value with its expected value E(I). If the Moran's I value is equal to E(I), then there is no spatial autocorrelation. If the value of Moran's I is greater than E(I), this indicates the presence of positive spatial autocorrelation with a clustered distribution pattern, and if the value of Moran's I is less than E(I), this indicates the presence of negative spatial autocorrelation with a scattered pattern (Abdulhafedh, 2017).

This study uses a significance level of 95%, so that an area is said to have statistically significant spatial autocorrelation if the p-value is <0.05 and the Z value is $> +1.96$ in the Global Moran Index and LISA analysis results. Moran's I values range from -1 to +1. Values close to +1 indicate positive spatial autocorrelation, values close to -1 indicate negative autocorrelation, and values close to 0 indicate no spatial autocorrelation.

The Global Moran Index is used to assess overall autocorrelation, and LISA is used to assess local spatial autocorrelation between regencies/cities. LISA analysis produces several maps, including the BiLISA Cluster Map, BiLISA Significance Map, and Bivariate Moran's (Inggarputri et al., 2023). In addition, LISA also displays a Moran scatter diagram, which divides the data into four quadrants: High-High (Quadrant I), Low-High (Quadrant II), Low-Low (Quadrant III), and High-Low (Quadrant IV) (Saini & Eryando, 2024).

3. Results and Discussion

3.1 Map of tuberculosis (TB) case notification rate (CNR) distribution

Figure 1 shows a visualization of the distribution of TB CNR in districts/cities in the provinces of West Java, East Java, and Central Java in 2024, grouped into three quantiles. Areas with high TB CNR rates, ranging from 315 to 1.195 cases per 100,000 population, are marked in red. Areas with high TB CNR include Bogor Regency (512 cases), Sukabumi (439 cases), Cianjur (472 cases), Bandung (373 cases), Garut (350 cases), Kuningan (333 cases), Cirebon (401 cases), Majalengka (334 cases), Sumedang (331 cases), Indramayu (318 cases), Subang (380 cases), Purwakarta (446 cases), Karawang (527 cases), Bekasi (472 cases), Bogor City (1,059 cases), Sukabumi City (951 cases), Bandung City (737 cases), Cirebon City (1,195 cases), Bekasi City (516 cases), Depok City (389 cases), Cimahi City (754 cases), Tasikmalaya City (625 cases), Banjar City (724 cases), Kediri City (466 cases), Pasuruan City (318 cases), Mojokerto City (551 cases), Madiun City (455 cases), Banyumas (354 cases), Magelang City (925 cases), Surakarta City (469 cases), Salatiga City (582 cases), Semarang City (400 cases), and Tegal City (1,080 cases).

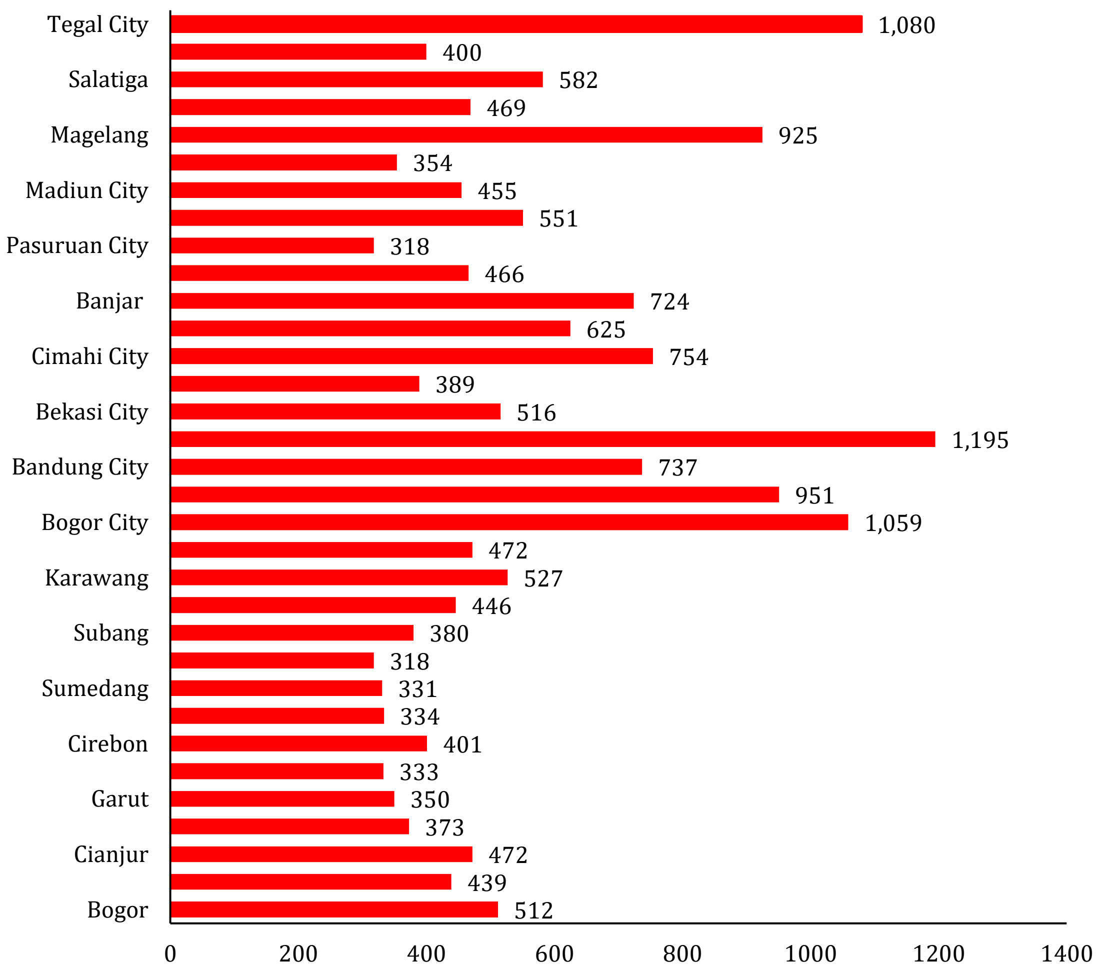

Fig. 1. High TB CNR rates

The areas with medium TB CNR marked in yellow include Tasikmalaya (254 cases), Ciamis (276 cases), West Bandung (242 cases), Pangandaran (223 cases), Lumajang (188 cases), Jember (183 cases), Bondowoso (192 cases), Situbondo (196 cases), Probolinggo

(184 cases), Pasuruan (199 cases), Sidoarjo (249 cases), Mojokerto (174 cases), Tuban (178 cases), Lamongan (234 cases), Gresik (252 cases), Sumenep (197 cases), Blitar City (208 cases), Malang City (301 cases), Probolinggo City (243 cases), Surabaya City (314 cases), Cilacap (205 cases), Purbalingga (230 cases), Kebumen (192 cases), Wonosobo (196 cases), Sukoharjo (183 cases), Rembang (196 cases), Kudus (288 cases), Kendal (197 cases), Pekalongan (200 cases), Pemalang (213 cases), Tegal (286 cases), Brebes (271 cases), and Pekalongan City (310 cases).

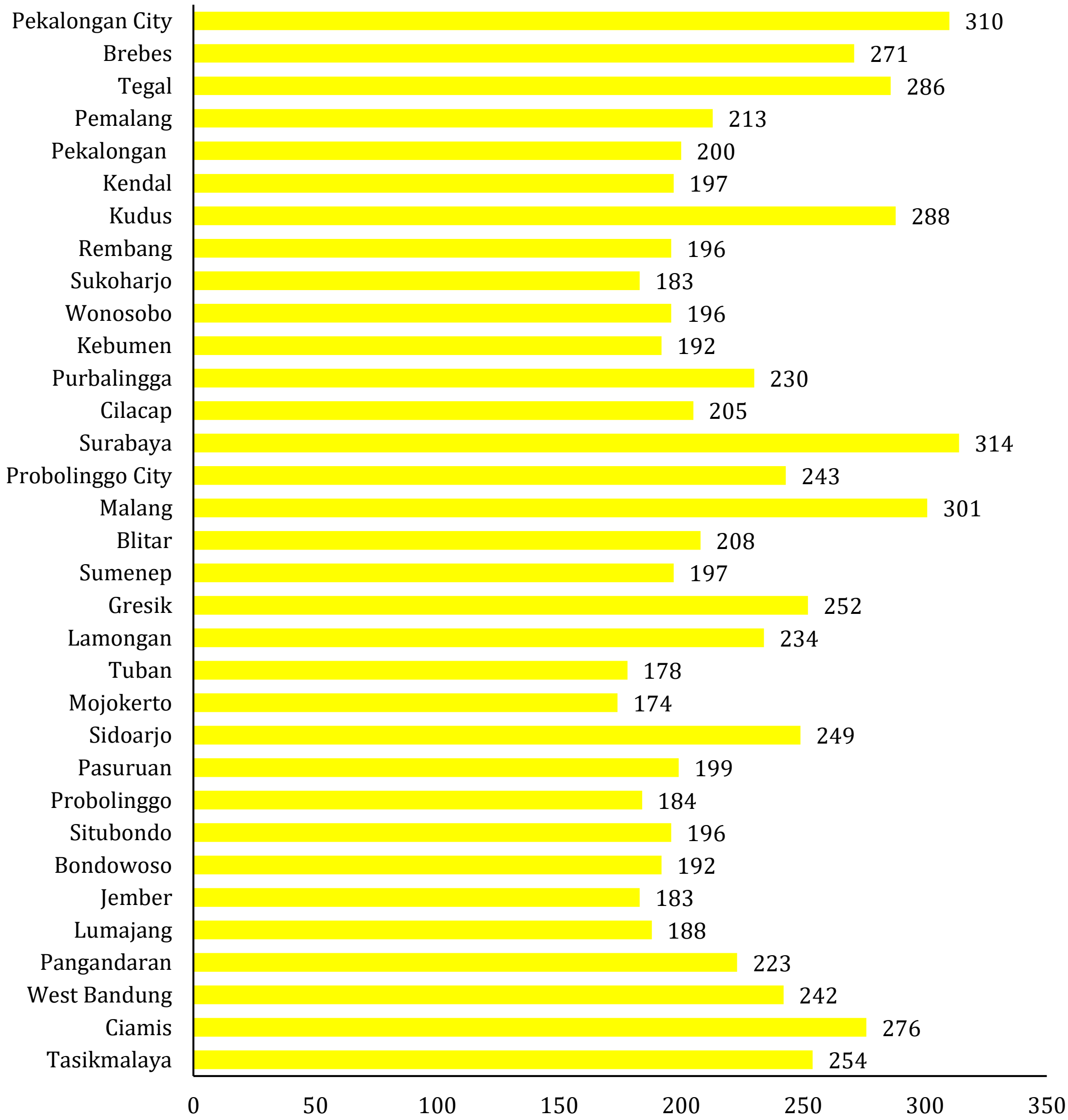

Fig. 2. Medium TB CNR rates

Areas with low TB CNR are marked in green, including Pacitan (75 cases), Ponorogo (136 cases), Trenggalek (68 cases), Tulungagung (133 cases), Blitar (87 cases), Kediri (139 cases), Malang (116 cases), Banyuwangi (155 cases), Jombang (166 cases), Nganjuk (129 cases), Madiun (128 cases), Magetan (136 cases), Ngawi (152 cases), Bojonegoro (170 cases), Bangkalan (161 cases), Sampang (147 cases), Pamekasan (127 cases), Batu City (152 cases), Banjarnegara (132 cases), Purworejo (119 cases), Magelang (76 cases), Boyolali (119 cases), Klaten (138 cases), Wonogiri (137 cases), Karanganyar (107 cases), Sragen (124 cases), Grobogan (149 cases), Blora (147 cases), Jepara (137 cases), Demak (154 cases), Semarang (83 cases), Temanggung (102 cases), Batang (169 cases), and Pati (170 cases).

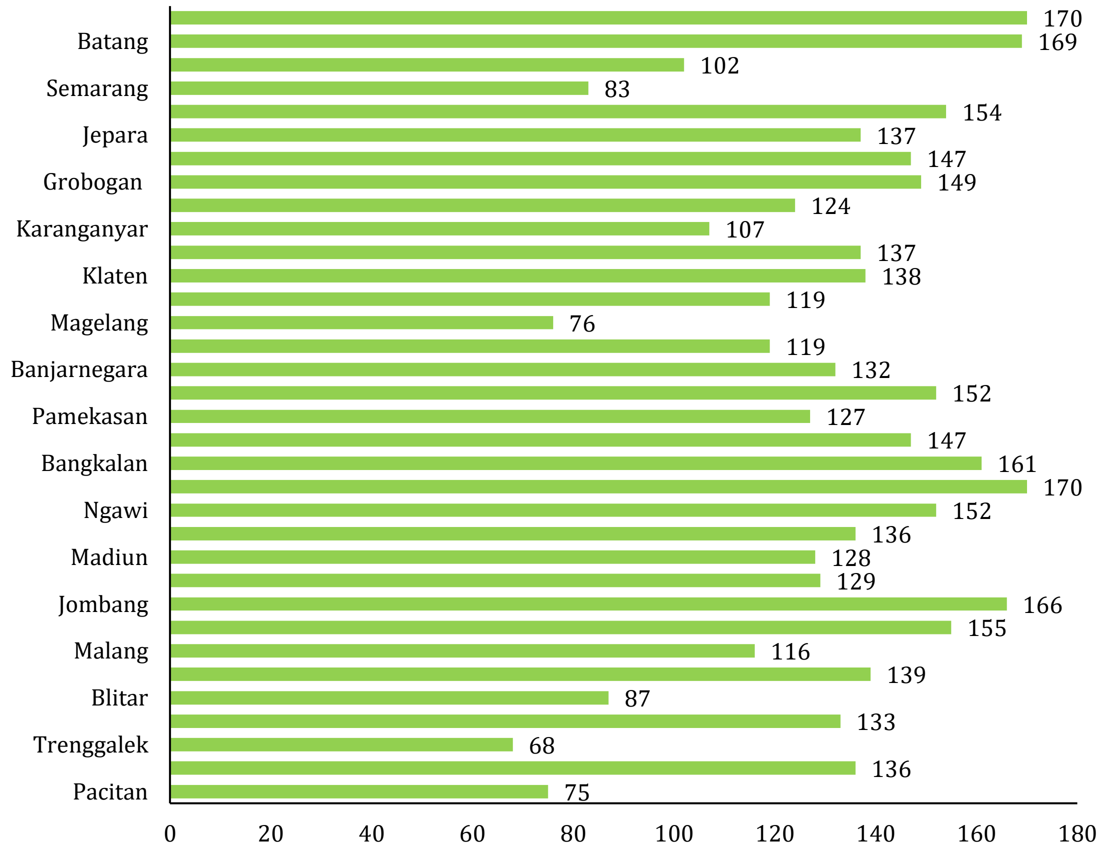

Fig. 3. Low TB CNR rates

3.2 Univariate analysis results

Table 2. Shows the distribution of research variables that are normally distributed and not normally distributed. There are two variables that are normally distributed, namely the percentage of poor people and the percentage of people who have BPJS health insurance, with average values of 9,43% and 70,76%. These two variables have less varied data distribution, because the standard deviation value is smaller than the average.

Table 2. Results of univariate analysis of dependent and independent variables (N=100)

Variable (Normally Distributed)	Measures of Central Tendency			Dispersion Measure	
	Mean	Median	Mode	Standard Deviation	Variance
Percentage of Poor Population (X_1)	9.43	9.14	2.34	3.58	12.8
Percentage of Population with BPJS Health Insurance (X_2)	70.76	70.60	57.88	13.53	182.9
Variable (Non-Normal Distribution)					
Tuberculosis Case Notification Rate (CNR) (Y)	207	68	68	1.195	1.128
Real Expenditure per Capita (X_3)	11,881	10,926	8,965	19,666	10,701
Population Density (X_4)	1,064.50	872	303.40	15,175.96	14,872.6
Percentage of Households with Access to Proper Sanitation (X_5)	86.91	83.25	45.88	99	53.2
Percentage of Livable Houses (X_6)	72.3	69.11	32.8	94.4	61.5

Meanwhile, the remaining variables are not normally distributed. The tuberculosis CNR variable ranges from 68 per 100,000 population in Trenggalek Regency to 1,195 per

100,000 population in Cirebon City. The lowest real expenditure per capita is IDR 8.965 in Tasikmalaya Regency and the highest is IDR 19.666 in Surabaya City. The lowest population density is 303,40 people per square kilometer in Banyuwangi Regency and the highest is 15.175,96 people per square kilometer in Bandung City. The lowest percentage of households with access to proper sanitation is 45,88% in Sukabumi City, while the highest is 99,1% in Bekasi City. The lowest percentage of livable houses is 32,83% in Sukabumi Regency, while the highest is 94,4%.

Based on Table 3, it is known that the Moran's I value for the TB CNR variable (I= 0.2661), the percentage of poor people (I= 0.4131), the percentage of people who have BPJS Health Insurance (I=0.1313), real per capita expenditure (I= 0.2831), population density (I= 0.1942), the percentage of households with access to proper sanitation (I=0.4756), and the percentage of livable houses (I= 0.4996) have an I value greater than E[I], which is -0.0101. This indicates that all variables have a clustered distribution pattern, so that locations with high (or low) values tend to be close to locations with similar values. In addition, all variables have statistically significant spatial autocorrelation (|z-value| $>z_{\alpha/2}$) and P < 0.05. Thus, all variables meet the requirements to proceed to the spatial bivariate test to see the spatial relationship between the dependent and independent variables.

Table 3. Univariate Global Moran's I results

Variable	N	Moran's I	E[I]	Z-Value	P-Value
Tuberculosis Case Notification Rate (CNR) (Y)	100	0.2661	-0.0101	3.9839	0.02
Percentage of Poor Population (X_1)	100	0.4131	-0.0101	5.1321	0.01
Percentage of Population with Health Insurance (X_2)	100	0.1313	-0.0101	2.0246	0.04
Real Expenditure per Capita (X_3)	100	0.2831	-0.0101	3.8025	0.01
Population Density (X_4)	100	0.1942	-0.0101	2.9283	0.02
Percentage of Households with Access to Proper Sanitation (X_5)	100	0.4756	-0.0101	5.9123	0.01
Percentage of Livable Houses (X_6)	100	0.4996	-0.0101	6.1053	0.01

* Note: |Z-value| $>Z_{\alpha/2}$ (0.025) = 1.96

3.3 Results of the LISA bivariate analysis

Table 4. Shows the results of the LISA bivariate test (Local Indicator Spatial Autocorrelation) between the TB CNR variable (Y) and the independent variables ($X_{1,2,3,4,5,6}$). For the variable percentage of the population with BPJS health insurance (X_2) and the variable real expenditure per capita (thousand rupiah/person/year) (X_3), the p-value is >0.05 and the calculated Z value is less than (|z-value| $>z_{\alpha/2}$) = 1.96. This indicates that there is no spatial autocorrelation between neighboring locations.

Table 4. Bivariate Results of TB CNR and Global Moran's I independent variable

Variable	N	Moran's I	E[I]	Z-Value	P-Value
Percentage of Poor Population (X_1)	100	-0.2034	-0.0101	-3.1447	0.01*
Percentage of Population with BPJS Health Insurance (X_2)	100	-0.0092	-0.0101	-0.0725	0.48
Real Expenditure per Capita (X_3)	100	-0.0649	-0.0101	-0.9882	0.15
Population Density (X_4)	100	0.1088	-0.0101	2.1249	0.03*
Percentage of Households with Access to Proper Sanitation (X_5)	100	-0.2222	-0.0101	-3.5203	0.01*
Percentage of Livable Houses (X_6)	100	-0.2622	-0.0101	-4.4781	0.01*

* Note: P-Value <0.05

The results of the bivariate LISA (Local Indicator Spatial Autocorrelation) test on the TB CNR (Y) variable and the percentage of poor population (X_1) obtained a z value of -3.1447 and a p-value <0.05. This means that there is negative spatial autocorrelation between the percentage of poor population and TB CNR in the regencies/cities of West Java, East Java, and Central Java provinces. The Moran's I index value for this variable is -0.2034, which is smaller than the estimated I value (E[I]) of -0.0101, so the relationship pattern between the percentage of poor people and TB CNR between regencies/cities in West Java, East Java, and Central Java provinces is scattered/random. This means that regions with high TB CNR tend to be close to regions with low poverty rates, and vice versa.

The results of the LISA (Local Indicator Spatial Autocorrelation) bivariate test on the TB CNR (Y) and population density (X_4) variables resulted in z-value of 2.1249 and p-value of <0.05. This means that there is positive spatial autocorrelation between population density and TB CNR in the regencies/cities of West Java, East Java, and Central Java provinces. The Moran's I index value for this variable is 0.1088, which is greater than the estimated I value (E[I]) of -0.0101, so the relationship pattern between population density and TB CNR between regencies/cities in West Java, East Java, and Central Java provinces is clustered. This means that areas with high TB CNR are adjacent to areas with high population density, and vice versa.

The results of the LISA (Local Indicator Spatial Autocorrelation) bivariate test on the TB CNR (Y) variable and the percentage of households with access to proper sanitation (X_5) obtained a Z value of -3.5203 and a p-value <0.05. This means that there is negative spatial autocorrelation between the percentage of households with access to proper sanitation and the TB CNR in the regencies/cities of West Java, East Java, and Central Java provinces. The Moran's I index value for this variable is -0.2222, which is smaller than the estimated I value (E[I]) of -0.0101, so the relationship pattern between the percentage of households with access to proper sanitation and TB CNR between regencies/cities in West Java, East Java, and Central Java provinces is scattered/random. This means that regions with high TB CNR are surrounded by regions with low percentages of households with access to proper sanitation, and vice versa.

The results of the LISA (Local Indicator Spatial Autocorrelation) bivariate test on the TB CNR (Y) variable and the percentage of livable houses (X_6) obtained a z value of -4.4781 and a p-value <0.05. This means that there is negative spatial autocorrelation between the percentage of livable houses and TB CNR in the regencies/cities of West Java, East Java, and Central Java provinces. The Moran's I index value for this variable is -0.2622, which is smaller than the estimated I value (E[I]) of -0.0101, so the relationship pattern between the percentage of livable houses and TB CNR between regencies/cities in West Java, East Java, and Central Java provinces is scattered/random. This means that regions with high TB CNR are surrounded by low percentages of livable houses, and vice versa.

3.4 Bivariate LISA cluster map results

The LISA analysis map of the relationship between TB CNR (Y) and the percentage of poor population (X_1) identifies statistically significant spatial associations, categorized into four quadrants. High-High areas (red) represent areas with high TB CNR surrounded by high poor population, located in Banyumas Regency. Low-Low areas (dark blue) represent areas with low TB CNR surrounded by low poor population, are located in Bandung Barat Regency. Low-High areas (light blue) represent areas with low TB CNR surrounded by high poor population, which are located in Purbalingga Regency, Banjarnegara Regency, Kebumen Regency, Purworejo Regency, Blora Regency, Tuban Regency, Bangkalan Regency, Sampang Regency, Pamekasan Regency, and Probolinggo City. High-Low areas (pink) represent areas with high TB CNR surrounded by low poor population, are located in Bogor Regency, Bekasi Regency, Bekasi City, and Depok City.

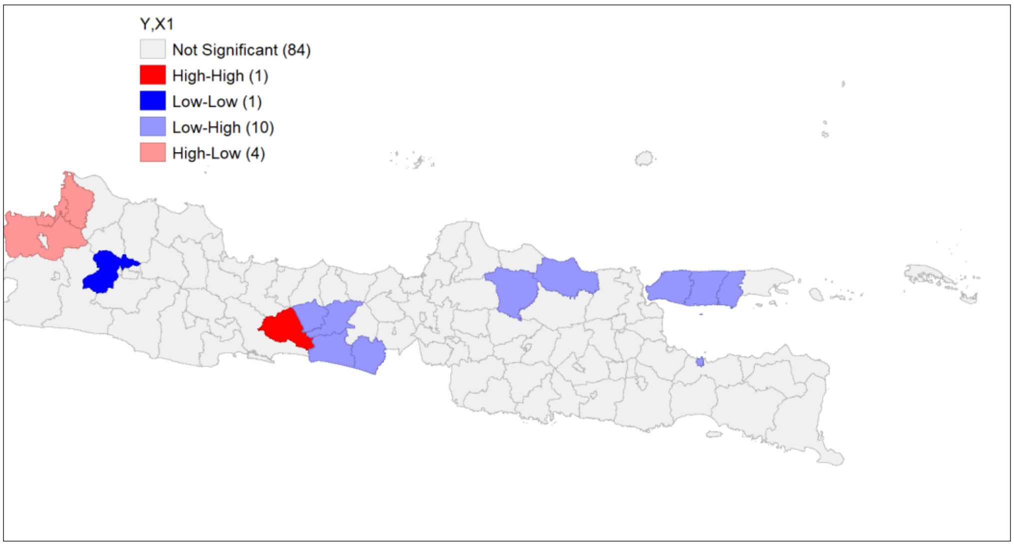

Fig. 4. Bivariate LISA map of TB CNR (Y) and percentage of poor population (X_1)

The LISA analysis map of the relationship between TB CNR (Y) and population density (X_4) identifies statistically significant spatial associations, categorized into four quadrants. High-High areas (red) represent regions with high TB CNR surrounded by high population density, located in Bogor Regency, Bandung Regency, and Cimahi City. Low-Low areas (dark blue) represent areas with low TB CNR surrounded by low population density, and are located in Blora Regency, Rembang Regency, Pacitan Regency, Ponorogo Regency, Trenggalek Regency, Tulungagung Regency, Jember Regency, Banyuwangi Regency, Bondowoso Regency, Situbondo Regency, Nganjuk Regency, Ngawi Regency, Bojonegoro Regency, and Tuban Regency. Low-High areas (light blue) where low TB CNR is surrounded by high population density are located in Bandung Barat Regency. No High-Low clusters were observed.

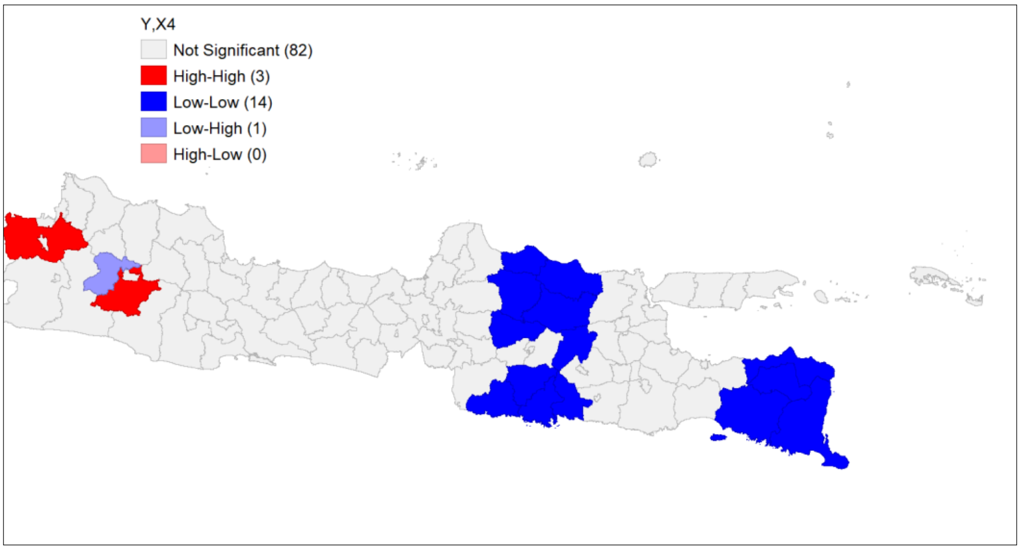

Fig. 5. Bivariate LISA map of TB CNR (Y) and population density (X_4)

The LISA analysis map of the relationship between TB CNR (Y) and the percentage of households with access to proper sanitation (X_5) identifies areas with statistically significant spatial associations, categorized into four quadrants. No High-High clusters (red) were observed. Low-Low areas (dark blue) represent areas with low TB CNR surrounded by regions with low access to proper sanitation are located in Tasikmalaya Regency, Bandung Barat Regency, Banyuwangi Regency, Bondowoso Regency, and Sampang Regency. Low-High areas (light blue), which areas with low TB CNR surrounded by regions with high access to proper sanitation, are located in Boyolali Regency, Sukoharjo Regency, Grobogan Regency, Jepara Regency, Mojoerto Regency, Jombang Regency, Nganjuk Regency, Magetan Regency, Ngawi Regency, Tuban Regency, Lamongan Regency, and Gresik Regency. High-Low areas (pink) represent areas with high TB CNR surrounded by regions with low access to proper sanitation are located in Sukabumi Regency, Cianjur Regency, Bandung Regency, Garut Regency, Sumedang Regency, Purwakarta Regency, Sukabumi City, Bandung City, and Cimahi City.

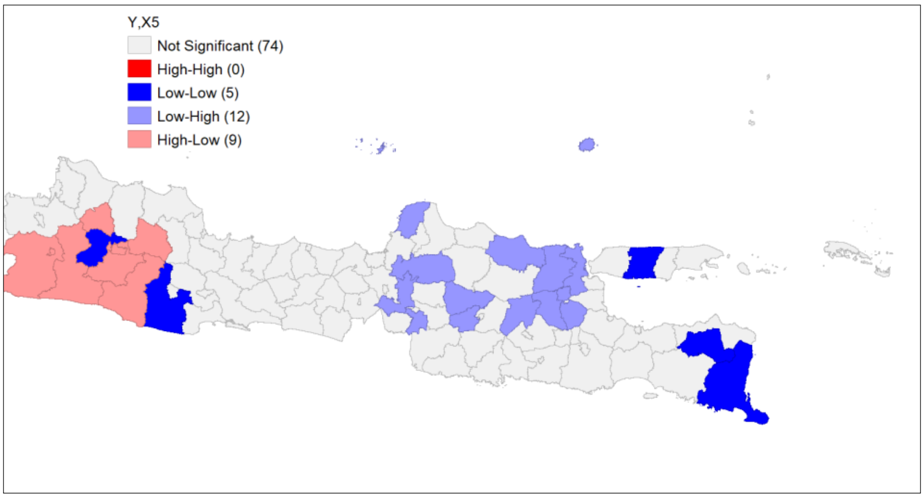

Fig. 6. Bivariate LISA map of TB CNR (Y) and percentage of households with access to proper sanitation (X_5)

The LISA analysis map of the relationship between TB CNR (Y) and the percentage of livable houses (X_6) identifies areas with statistically significant spatial associations, categorized into four quadrants. High-High areas (red) represent regions with high TB CNR surrounded by high percentages of livable houses, located in Surakarta City. Low-Low areas (dark blue) represent regions with low TB CNR surrounded by low percentages of livable houses, such as Tasikmalaya Regency, Bandung Barat Regency, and Kebumen Regency. Low-High areas (light blue) represent regions with low TB CNR surrounded by high percentages of livable houses, which are located in Boyolali Regency, Sukoharjo Regency, Wonogiri Regency, Karanganyar Regency, Jepara Regency, Ponorogo Regency, Tulungagung Regency, Blitar Regency, Kediri Regency, Malang Regency, Pasuruan Regency, Mojokerto Regency, Madiun Regency, and Magetan Regency. High-Low areas (pink) represent regions with high TB CNR surrounded by low percentages of livable houses, such as Bogor Regency, Sukabumi Regency, Cianjur Regency, Bandung Regency, Garut Regency, Purwakarta Regency, Sukabumi City, Bandung City, Bekasi City, and Cimahi City.

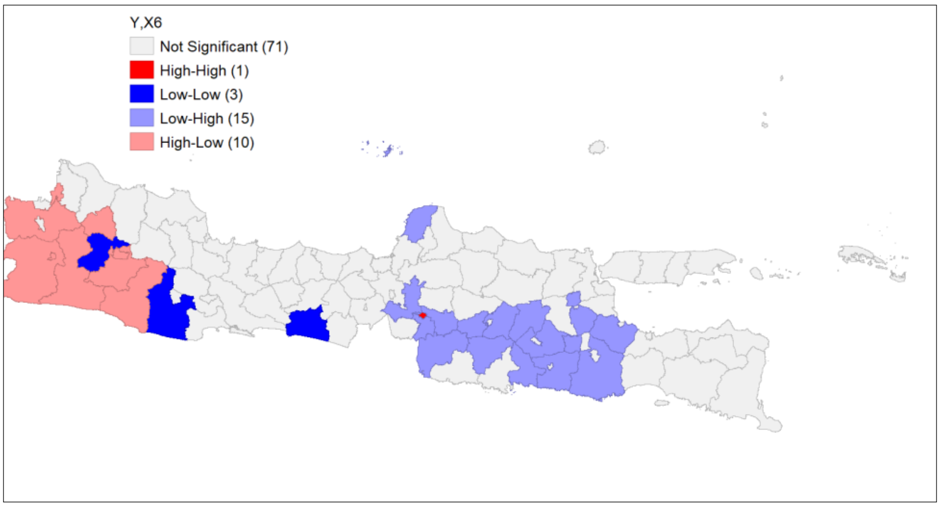

Fig. 7. Bivariate LISA map of TB CNR (Y) and percentage of livable houses (X_6)

3.5 Spatial autocorrelation of TB CNR (Y) and percentage of poor population (X_1)

The bivariate LISA results show that there is negative spatial autocorrelation between TB CNR and the percentage of poor population. The results of this study are in line with the studies Carrasco-Escobar et al. (2020), Silva Diba et al. (2024), Santi et al. (2020), and Saputra et al. (2020) which state that there is spatial autocorrelation, although there are differences in direction (positive). These findings are inconsistent with the study (Nahak et al., 2024), which states that there is no spatial autocorrelation between the number of poor people and the number of pulmonary TB cases. These findings are also inconsistent with the study Karim & Utomo (2024). These differences in results may be due to differences in the study areas.

Poor people tend to pay less attention to their living conditions, such as living in crowded and poorly ventilated houses, delayed diagnosis, and increased vulnerability due to malnutrition and/or HIV infection (Wanahari et al., 2022). Poverty is also associated with poor health knowledge and a lack of awareness about healthy living, which can increase the risk of exposure to TB (Riznawati et al., 2024). However, poverty can be an indirect cause of pulmonary TB transmission in the community. High rates of pulmonary TB transmission can also occur in areas with low poverty levels. This is because pulmonary TB is not caused by a single factor, but can be influenced by other factors that contribute to the disease (Maulana et al., 2024).

3.6 Spatial autocorrelation of TB CNR (Y) and percentage of population with health Insurance (X_2)

The bivariate LISA results show that there is no spatial autocorrelation between TB CNR and the percentage of the population with BPJS Health Insurance. These results are in line with the study (Im & Kim, 2021) which found that health insurance participation is negatively correlated with TB incidence. Health insurance is more directly related to successful treatment than the TB Case Notification Rate (CNR). Other studies have found that health insurance is considered to increase the chances of successful treatment for TB patients. Additionally, in Indonesia, there may be discrepancies in the recording and reporting of TB cases, particularly among TB patients using BPJS health insurance, resulting in unreported cases (Putra & Pradnyani, 2022).

3.7 Spatial autocorrelation of TB CNR (Y) and real per capita expenditure (X_3)

The bivariate LISA results show that there is no spatial autocorrelation between TB CNR and Real Per Capita Expenditure. This finding differs from the study (Santi et al., 2025) which states that per capita expenditure affects the spread of tuberculosis in West Java. This difference may be due to differences in the analysis area. Furthermore, the per capita expenditure indicator covers all household expenditures (food, non-food, and other services), not specifically reflecting health expenditures. Thus, high per capita expenditure does not always indicate that the community is healthy or has better access to health services. Furthermore, low-income households tend to allocate a larger portion of their expenditure to food, leaving only a small amount for health. As a result, expenditure on access to health services, including TB diagnosis and treatment, decreases (Zhang et al., 2020).

3.8 Spatial autocorrelation of TB CNR (Y) and population density (X_4)

The bivariate LISA results show that there is positive spatial autocorrelation between TB CNR and population density. These results are in line with the studies Rao & Johnson (2021), Silva Diba et al. (2024), Inggarputri et al. (2023), and Daniel et al. (2022) which state that there is positive spatial autocorrelation between the number of TB cases and population density. These results are not in line with the study Nurjannah & I (2021) which shows no correlation between population density and TB CNR, and the study Septiani (2024) which shows no spatial autocorrelation between population density and pulmonary tuberculosis cases in Central Java Province.

Tuberculosis is a disease that can be transmitted through the air/droplets when coughing, sneezing, or talking, with population density increasing the risk of this disease. High population density can increase the likelihood of human interaction or exposure, thereby facilitating the spread of Mycobacterium TB bacteria. High population density is also often accompanied by unhealthy environmental conditions such as inadequate ventilation, poor sanitation, and poor indoor air circulation. These conditions increase the risk and facilitate the transmission of disease (Cahyaningrum & Setiyadi, 2024).

In addition, high population density is also related to the density of outdoor living experienced in urban areas, especially in urban slums and informal settlements characterized by a lack of basic sanitation, poor housing, excessive population density, high levels of traffic congestion, and urban air pollution resulting from increased vehicle movement, industrial pollution, waste from power plants, and the burning of household fuels. This situation can contribute to an increase in TB (Daniel et al., 2022). In the context of prevention and response, densely populated areas put pressure on the healthcare system, making it challenging for individuals infected with tuberculosis in these areas to access quality healthcare services (Silva Diba et al., 2024).

3.9 Spatial autocorrelation of TB CNR (Y) and percentage of households with access to proper sanitation (X_5)

The bivariate LISA results show that there is negative spatial autocorrelation between TB CNR and the percentage of households with access to proper sanitation. These findings are consistent with the study Falefi et al. (2023), which states that access to proper sanitation has a negative impact on tuberculosis incidence, indicating that higher levels of access to proper sanitation are associated with lower tuberculosis incidence. The studies Seran Berek et al. (2025) and Kusuma et al. (2022) also state that the percentage of households with access to proper sanitation has a significant effect on the number of TB cases. Access to proper sanitation plays an important role in reducing the transmission of tuberculosis. Adequate sanitation facilities, such as effective waste management and clean human waste disposal, can help prevent the spread of TB bacteria by minimizing environmental contamination. Households with access to proper sanitation can avoid environments that may be contaminated with TB bacteria (Falefi et al., 2023). Homes are places that should protect and improve the health status of the community, so homes with good sanitation access need to be improved (Yuliawati et al., 2024).

3.10 Spatial autocorrelation of TB CNR (Y) and percentage of livable houses (X_6)

The bivariate LISA results show that there is negative spatial autocorrelation between TB CNR and the percentage of livable houses. These results are in line with the research Prameswari & Hendrati (2024) which states that the relationship between the percentage of livable houses and the incidence of childhood TB shows a negative direction in 2020 and 2022. A livable house is a house that meets safety requirements, building requirements, and minimum space requirements of 29 square meters, as well as the health requirements of its occupants. The assessment of livable housing is obtained through composite indicators from seven related indicators, namely access to clean water, access to proper sanitation, sufficient living area (floor space per capita > 7.2 m2), type of walls, type of roof, type of flooring, and electric lighting (Usrina et al., 2025). Housing quality significantly influences the development and management of tuberculosis (TB) through factors such as population density, ventilation, sunlight exposure, and humidity levels, which are influenced by the condition of the roof, floor, and walls. All eligible studies emphasize the importance of housing affordability and quality in TB prevention, early detection, treatment, and management. This study defines substandard housing as unaffordable and poor-quality housing (Lee et al., 2022).

3.11 Policy implications

The results of Geographic Information System (GIS) analysis, in the form of spatial autocorrelation analysis and mapping used in this study, can be used to measure the distribution of TB CNR in three provinces on the island of Java, assist in spatial understanding of the relationship between TB CNR and its risk factors, and track TB CNR so that health interventions can be planned, implemented, and monitored to prevent and control TB cases, especially those related to the environment. GIS can also be used to model alternative actions based on disease risk predictions (Nayak et al., 2021). Based on these findings, several policy implications that can help resolve TB problems and their risk factors can be seen in the following table. Policy implications that can be used to resolve TB CNR issues with the percentage of poor population at the regency/city level can be seen in Table 5.

Table 5. Policy Implications for TB CNR and the percentage of the poor population

Quadrant	Relationship Pattern	Region	Policy Implications
High-High	High TB CNR - High Poor Population	Banyumas Regency	Strengthening of dual interventions in the form of TB screening and social assistance or treatment.
Low-Low	Low TB CNR - Low Poor Population	Bandung Barat Regency.	• Maintain achievements, monitoring, and TB surveillance. • Promote health to prevent transmission, detect disease early, and maintain healthy living behaviors.
Low-High	Low TB CNR – High Poor Population	Purbalingga Regency, Banjarnegara Regency, Kebumen Regency, Purworejo Regency, Blora Regency, Tuban Regency, Bangkalan Regency, Sampang Regency, Pamekasan Regency, and Probolinggo City.	• Investigate underreporting of TB. • Strengthen coordination with health facilities and partnerships. • Promote health to prevent transmission, detect disease early, and maintain healthy living behaviors.
High-Low	High TB CNR – Low Poor Population	Bogor Regency, Bekasi Regency, Bekasi City, and Depok City.	• Facilitate access to health facilities. • Monitor mobility. • Increase public awareness of tuberculosis and encourage proactive seeking of healthcare services.

Policy implications that can be used to resolve TB CNR issues with population density at the regency/city level can be seen in Table 6.

Table 6. Policy implications for TB CNR and population density

Quadrant	Relationship Pattern	Region	Policy Implications
High-High	High TB CNR – High Population Density	Bogor Regency, Bandung Regency, Cimahi City.	• Improvement of healthy housing. • Improvement of human resources for TB investigation, tracking, and reporting. • Health promotion to avoid close contact with TB patients at home. • Encouraging the community not to discriminate against suspected TB cases and TB patients. • Procurement, construction, development, and maintenance of health facilities that can be used as places for prevention, promotion, and early detection of suspected TB cases, such as health centers, integrated health service posts, and village health posts/community health centers.
Low-Low	Low TB CNR – Low Population Density	Blora Regency, Rembang Regency, Pacitan Regency, Ponorogo Regency, Trenggalek Regency, Tulungagung Regency, Jember Regency, Banyuwangi Regency, Bondowoso Regency, Situbondo Regency, Nganjuk Regency, Ngawi Regency, Bojonegoro Regency, and Tuban Regency.	• Healthy home monitoring. • Promote health to prevent transmission, detect diseases early, and maintain clean and healthy living behaviors.
Low-High	Low TB CNR – High Population Density	Bandung Barat Regency.	• Investigate underreporting of TB. • Strengthen coordination with health facilities and partnerships for TB tracking, reporting, and treatment. • Health Promotion to prevent transmission, detect disease early,

			and maintain clean and healthy living behaviors.
High-Low	High TB CNR – Low Population Density	---	---

Policy implications that can be used to resolve TB CNR issues with the percentage of households that have access to proper sanitation at the regency/city level can be seen in Table 7.

Table 7. Policy implications of TB CNR and percentage of households with access to proper sanitation

Quadrant	Relationship Pattern	Region	Policy Implications
High-High	High TB CNR – High Percentage of Households with Access to Proper Sanitation	---	---
Low-Low	Low TB CNR – Low Percentage of Households with Access to Proper Sanitation	Tasikmalaya Regency, West Bandung Regency, Banyuwangi Regency, Bondowoso Regency, and Sampang Regency.	• Improved access to adequate sanitation. • Promote health to prevent transmission and detect diseases early. • Promote a clean and healthy environment and lifestyle.
Low-High	Low TB CNR – High Percentage of Households with Access to Proper Sanitation	Boyolali Regency, Sukoharjo Regency, Grobogan Regency, Jepara Regency, Mojokerto Regency, Jombang Regency, Nganjuk Regency, Magetan Regency, Ngawi Regency, Tuban Regency, Lamongan Regency, and Gresik Regency.	• Maintain sanitation achievements. • Strengthen TB monitoring and surveillance systems.
High-Low	High TB CNR – Low Percentage of Households with Access to Proper Sanitation	Sukabumi Regency, Cianjur Regency, Bandung Regency, Garut Regency, Sumedang Regency, Purwakarta Regency, Sukabumi City, Bandung City, and Cimahi City.	• Improve access to and quality of proper sanitation facilities. • Health promotion to prevent transmission and detect disease early. • Promote a clean and healthy living environment and behavior. • Ensuring support for individuals with TB symptoms and patients undergoing treatment.

Policy implications that can be used to resolve TB CNR issues with the percentage of livable houses at the regency/city level can be seen in Table 8.

Table 8. Policy implications for TB CNR and percentage of livable houses

Quadrant	Relationship Pattern	Region	Policy Implications
High-High	High TB CNR – High Percentage of Livable Houses	Surakarta City	• Ensuring support for people with TB symptoms and patients undergoing treatment. • Evaluating other factors such as population density, mobility, or treatment adherence. • Enhancing collaboration with healthcare networks for active screening. • Promoting an environment where homeowners are advised to open windows and let light in. • Promoting clean and healthy living behaviors.
Low-Low	Low TB CNR – Low Percentage of Livable Houses	Tasikmalaya Regency, West Bandung Regency, and Kebumen Regency.	• Environmental monitoring and TB prevention education. • Gradual rehabilitation of houses. • Integration with the healthy home program.
Low-High	Low TB CNR – High Percentage of Livable Houses	Boyolali Regency, Sukoharjo Regency, Wonogiri Regency, Karanganyar Regency, Jepara Regency, Ponorogo Regency, Tulungagung Regency, Blitar Regency, Kediri Regency, Malang Regency, Pasuruan Regency, Mojokerto Regency, Nganjuk Regency, Madiun Regency, and Magetan Regency.	• Maintain the quality of livable and healthy homes. • Strengthen the TB surveillance and early detection system. • Promote the environment as an effort to maintain healthy homes.
High-Low	High TB CNR – Low Percentage of Livable Homes	Bogor Regency, Sukabumi Regency, Cianjur Regency, Bandung Regency, Garut Regency, Purwakarta Regency, Sukabumi City, Bandung City, Bekasi City, and Cimahi City.	• Rehabilitate uninhabitable homes. • Integration of TB programs with housing and healthy environment programs. • Promotion of healthy living practices and TB prevention education. • Monitoring and support for individuals with TB symptoms and TB patients.

3.12 Limitation and recommendations

The study has several limitations, including the use of secondary data, where not all risk factors associated with tuberculosis incidence are available. This study also used an ecological approach where the unit of analysis was based on region, so the results cannot be generalized to individuals. In addition, this study has the potential to encounter problems with changes in the unit of analysis (Modifiable Areal Unit Problem/MAUP), where the results of the analysis may differ depending on the spatial level or boundaries used, such as village, sub-district, regency/city, or province. Future researchers are encouraged to investigate other risk factors related to tuberculosis, such as climate/weather factors, and to use advanced spatial methods such as spatial regression. Provincial health offices and regency/city health offices in West Java, East Java, and Central Java are advised to improve early detection and active surveillance and to adopt policy implications that can be modified by each provincial health office.

4. Conclusion

The distribution of the Tuberculosis Case Notification Rate (CNR) in regencies and cities of West Java, East Java, and Central Java provinces shows positive spatial autocorrelation. This means the TB CNR distribution pattern is clustered, so that areas with high or low TB CNR values tend to be close to areas with similar values. LISA bivariate analysis found three independent variables with negative spatial autocorrelation to TB CNR. These variables, the percentage of poor people, the percentage of households with access to proper sanitation, and the percentage of livable houses, show a scattered or random pattern. Meanwhile, population density is the only variable that has positive spatial autocorrelation with a clustered pattern. Each region has different geographical characteristics, so the risk factors for TB also vary between regions. Therefore, TB prevention, case detection, and intervention can adopt policy implications from the results of this spatial analysis by considering the local conditions of each region.

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Author Contribution

The author was solely responsible for the conceptualization, data collection, analysis, and writing of the manuscript.

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The dataset used in this research is available at:
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https://dinkes.jatimprov.go.id/index.php?r=site/file_list&id_file=10&id_berita=8
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Conflict of Interest

The author declares no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the author used Grammarly to help improve the grammar and clarity of the manuscript. After using this tool, the author reviewed and edited the content as needed and is fully responsible for the content of the publication.

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