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Implementation of Moran Index-Based Geographic Information System on Tuberculosis Case Distribution: Case Study at Batujajar and Bayongbong Community Health Centers, Indonesia

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ABSTRACT

This study examines the spatial distribution of tuberculosis (TB) cases using the Global Moran's I Index in two regions: Batujajar and Bayongbong Community Health Centers, West Java, Indonesia. Using a correlational design and secondary data (2023–2024), TB cases were analyzed with Geographic Information System (GIS). Results show significant spatial clustering in Batujajar (Moran's I = 0.329; z = 4.038; p < 0.01), with cases concentrated near industrial areas and water bodies, indicating environmental and demographic influences. In contrast, Bayongbong shows no significant spatial autocorrelation (Moran's I = -0.131; p = 0.982), suggesting random distribution. These findings highlight the need for targeted interventions in clustered areas and broader strategies in dispersed regions, supporting improved TB control and resource allocation.

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1. INTRODUCTION

Tuberculosis (TB) remains a serious global health threat, even after more than a century of being recognized and addressed by various global health systems. Data from the World Health Organization (WHO) in 2023 shows that 1.25 million people died from TB, including 161,000 who were also infected with HIV (World Health Organization, 2025). This fact underscores that TB has likely re-emerged as the leading cause of death from a single infectious agent worldwide, replacing COVID-19, which dominated in the past three years. Furthermore, TB is the leading cause of death among people living with HIV and one of the major contributors to deaths related to antimicrobial resistance, a phenomenon that is increasingly gaining attention in global public health. The WHO estimates that in the same year, 10.8 million people worldwide were infected with TB, comprising 6 million men, 3.6 million women, and 1.3 million children, indicating that the disease affects all age groups and all countries (World Health Organization, 2025). Although TB is a preventable and curable disease, the reality is that multidrug-resistant tuberculosis (MDR-TB) remains an acute public health crisis and a threat to global health security. Only 2 out of 5 people with MDR-TB received treatment in 2023, highlighting the significant gaps in healthcare services and early detection of this disease (World Health Organization, 2025).

Indonesia has a large caseload and widespread distribution across various regions. Data on TB case notifications based on health facility categories during the period 2020 to 2024 shows dynamics that reflect increasingly massive early detection efforts as well as new challenges emerging in the health system. Over four years, there has been a significant increase in the number of cases successfully detected, from 393,323 cases in 2020 to 443,235 cases in 2021, then a sharp rise to 724,309 in 2022, and reaching a peak in 2023 with a total of 821,200 cases (Ministry of Health of the Republic of Indonesia, 2024). This increase can be seen as a result of the expansion of detection and reporting services, particularly in community health centers, government hospitals, and private hospitals, which are the main contributors to the national TB notification system. However, a striking phenomenon occurred in 2024, when the number of reported cases dropped sharply to 241,471 cases (Ministry of Health of the Republic of Indonesia, 2024).

Tuberculosis is an infectious disease caused by the infectious agent *Mycobacterium tuberculosis*, which generally attacks the lungs in humans (Malik et al., 2022; Debnath et al., 2022; Kanabalan et al., 2021). Tuberculosis is transmitted by individuals with positive sputum smear results, who spread the infection through droplets expelled when coughing or sneezing (Verma et al., 2024; Long et al., 2022). The bacteria in the air can be inhaled by healthy individuals, leading to infection. *Mycobacterium tuberculosis* is an obligate aerobic bacterium (a bacterium that requires free oxygen to survive), does not form endospores, and has a rod-shaped cell structure (Nagaraja, 2022; Barletta and Steffen, 2022; Roy et al., 2021).

This situation poses a threat to various countries, including Indonesia, and it is essential to strengthen their detection, reporting, and intervention systems in a systematic and evidence-based manner. One relevant approach in this context is the integration of a Geographic Information System (GIS) based on spatial autocorrelation indices (Moran's I). The Moran's Index method plays a significant role in revealing the spatial distribution patterns of diseases. This was demonstrated in a study by (Iryanto et al., 2022), which analyzed the distribution of environmental sanitation factors as determinants of diarrhea incidence among children in

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Padang City (Iryanto et al., 2022). A similar approach was applied in a study conducted in Semarang City, which evaluated the spatial autocorrelation of diarrhea, typhoid, and leptospirosis cases (Fikri et al., 2021). In Bandung City, a study conducted in 2024 utilized autocorrelation analysis to identify the spatial distribution patterns of dengue fever cases based on the classification of disease types (Firmansyah et al., 2024). With this approach, we not only look at case numbers but also at geographical distribution patterns that enable the identification of clusters or hotspots of TB cases. This is crucial for supporting more targeted and precise interventions, particularly in areas with high population density, limited access to services, or undetected latent case burdens (Alvarez et al., 2021).

This study focuses on two public health center (puskesmas) working areas, namely the Bayongbong Puskesmas in Garut District with 109 cases in 2024, and the Batujajar Puskesmas in West Bandung District with 189 cases in 2023, both of which are located in West Java Province and are known to have diverse geographical and socioeconomic characteristics. By utilizing the Global Moran's I approach, this study aims to identify whether there are spatial autocorrelation patterns in the distribution of tuberculosis cases in both areas, meaning to determine whether tuberculosis cases tend to cluster in a particular area or are randomly distributed. The results of this analysis are expected to strengthen the TB risk mapping system and contribute to national efforts to achieve the target of ending the TB epidemic by 2030, as outlined in the Sustainable Development Goals (SDGs).

2. METHODS

2.1 Type and Design of Research

This study is a correlational study that utilizes secondary data to identify patterns of the spread of tuberculosis in the working area of the Batujajar and Bayongbong Community Health Center. The research design used is retrospective, as the researchers traced tuberculosis cases over a full year, based on data from 2023 at the Batujajar Community Health Center and data from 2024 at the Bayongbong Community Health Center.

2.2 Population and Sample of Research

The population in this study includes two groups: 189 tuberculosis cases recorded in the medical records of the Batujajar Community Health Center in 2023 and 109 tuberculosis patients from the Bayongbong Community Health Center in 2024. All samples were taken using total sampling techniques. The inclusion criteria for this study were all patient data with diagnosis codes A15-A16 from the DOTS/TB clinic entered into the SI TB application and medical records of patients with tuberculosis in the working areas of the Batujajar Community Health Center in 2023 and the Bayongbong Community Health Center in 2024.

2.3 Data Analysis of Research

Data analysis was performed using a geographic information system (GIS) approach. The Moran index was used in spatial statistics to examine the distribution pattern of TB cases. The Moran index is mostly used to measure the similarity of outcome variables between regions defined as spatially related and to measure global spatial autocorrelation. Such applications can detect the onset of spatial randomness. The emergence of spatial randomness indicates the formation of spatial patterns, such as clustering or trends.

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2.4 Ethical Clearances

The research ethics statement was issued by the Tasikmalaya Ministry of Health Polytechnic with the number DP.04.03/F.XXVI.20/KEPK/51/2025.

2.5 Study Area Description

This study was conducted in two sub-districts in West Java, Indonesia: Batujajar Subdistrict in West Bandung Regency, and Bayongbong Subdistrict in Garut Regency. Batujajar is an area characterized by industrial activity and proximity to water bodies, while Bayongbong represents a rural area with agricultural dominance. The contrast between these two regions allows for a comparative analysis of tuberculosis distribution in different environmental settings.

3. RESULTS AND DISCUSSION

Conservation of the forest relies on cumulative effects, specifically the degree of negative impacts resulting from human behavior. Conservation within the Admine Forest is manifested through a "secondary nature" of protective measures (Salo et al., 2013). This concept, previously mentioned but reserved for later discussion, is derived from expansionist economics, which is an absolute trend. Under the current system, all intensive uses of Admine are justified, yet this system encounters comprehensive conservation challenges for two admins. From another perspective, the environmental balance is nearly lost due to the expanded agricultural economy (Msanda et al., 2021). Our most recent findings indicate a conflict in the Souss Plain over water resources: in recent months, underground farm water has been depleted, particularly in the agricultural estates in the far southern part of the Admine Forest and the Souss Plain, due to illegal management practices occurring at night (as reported by field witnesses).

3.1 Distribution of Tuberculosis Cases at the Batujajar Community Health Center

The prevalence rate of cases in the Batujajar Community Health Center working area was calculated using the prevalence rate period, a statistical measure that describes the number of individuals exposed to TB. The health center covers the villages of Panguban, Batujajar Timur, Cangkorah, Selacau, Giriasih, Batujajar Barat, and Galanggang. This data was taken from the number of new and old cases of TB at the Batujajar Community Health Center. The complete results are presented in **Table 1** below,

Table 1. Tuberculosis Prevalence Results in the Batujajar Community Health Center Working Area for the period January-December 2024

Villages	Cases Total	Community Total	Prevalance Rate (per 10.000 population)	Rank
Panguban	37	14,719	25	1
Batujajar Timur	31	15,806	20	2
Cangkorah	22	12,431	18	3
Selacau	20	13,436	15	4
Giriasih	20	14,578	14	5

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Batujajar Barat	25	18,728	13	6
Galanggang	27	22,659	12	7

Based on the data in **Table 1**, the prevalence of disease cases in the Batujajar Community Health Center working area during the period January-December 2024 shows that Panguban Village has the highest prevalence rate, namely 25 people per 14,719 residents, placing it in first place. Following closely behind is Batujajar Timur in second place with a prevalence of 20 people out of 15,806 residents, and Cangkorah in third place with a prevalence of 18 people out of 12,431 residents. Meanwhile, the village with the lowest prevalence rate is Galanggang, with 12 people out of 22,659 residents, ranking seventh. Batujajar Barat and Giriasih also have lower prevalence rates compared to other areas, with 13 and 14 cases respectively. **Figure 1** below shows the distribution of TB cases in the working area of the Batujajar Community Health Center.

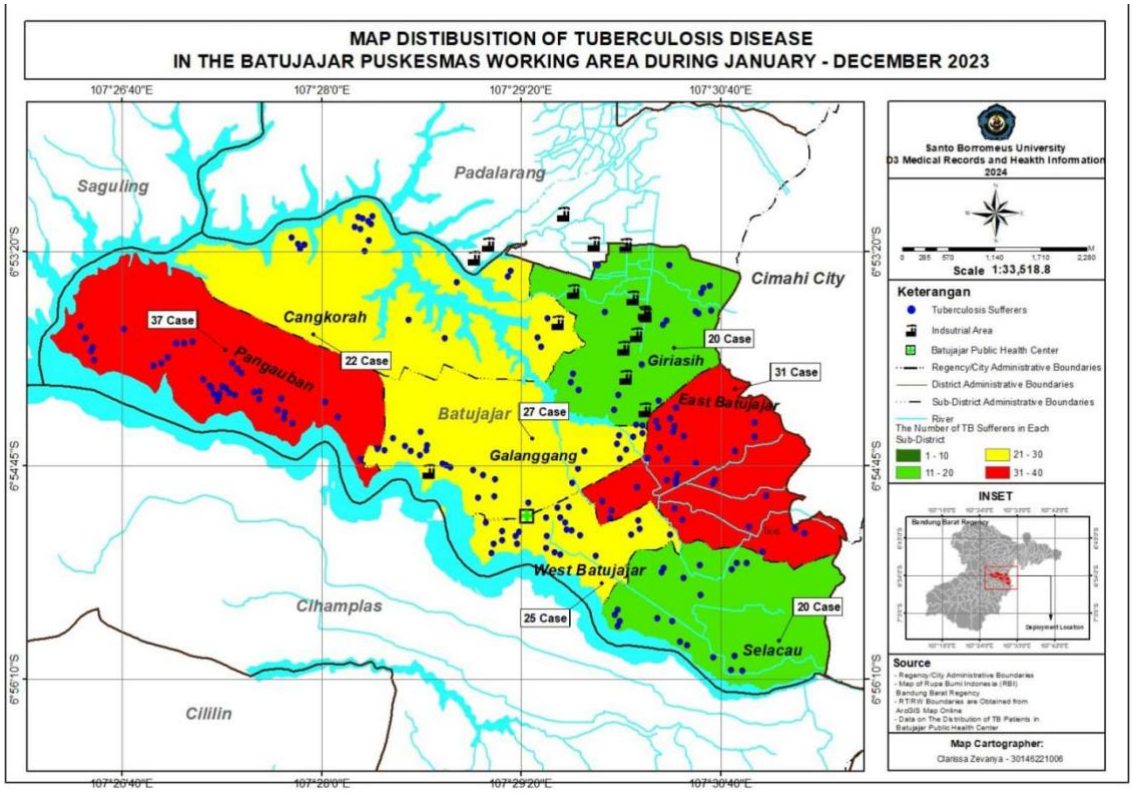

Figure 1. Distribution of Tuberculosis Cases in the Batujajar Community Health Center Working Area in 2023

Figure 1 illustrates the distribution of tuberculosis cases categorized into four levels. The first level is colored dark green with 1-10 cases, light green with 11-20 cases, yellow with 21-30 cases, and red with 31-40 cases. In this case, there are both new and old cases, as seen in the village of Pangauban, which is colored red with a high number of cases, and the distribution of cases is concentrated near water bodies, possibly due to humidity factors. Similarly, in Batujajar Timur, the distribution of cases is also concentrated in areas near industrial zones, which are predominantly colored red. Figure 2 below shows the results of the Moran Index analysis,

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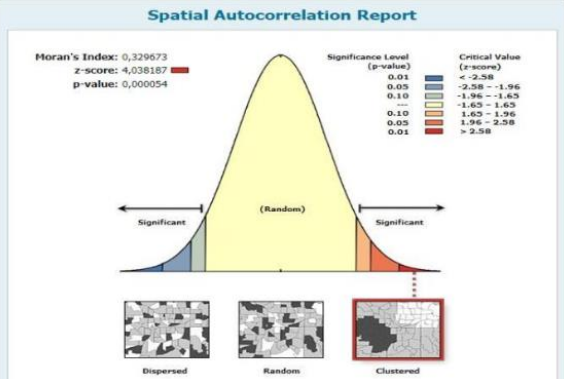

Global Moran's I Summary

Moran's Index:	0,329673
Expected Index:	-0,014493
Variance:	0,007264
z-score:	4,038187
p-value:	0,000054

Dataset Information

Input Feature Class:	SebaranTB
Input Field:	TB
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	1000,1000 Meters
Weights Matrix File:	None
Selection Set:	False

Figure 2. Tuberculosis Distribution Pattern Based on Moran's Index in the Batujajar Community Health Center Working Area in 2023

The second Spatial Autocorrelation Report (**Figure 2**) provides contrasting results to the previous analysis. In this instance, the Global Moran's I Index is 0.329673, with a z-score of 4.038187 and a p-value of 0.000054. These values suggest a statistically significant spatial pattern in the distribution of tuberculosis (TBC) cases within the study area. A positive Moran's I value that is significantly different from zero, as shown here, indicates a strong spatial clustering of TBC cases. The z-score far exceeds the critical value of ±2.58 (which corresponds to a significance level of 0.01), and the very low p-value (less than 0.01) confirms that there is less than a 1% probability that this observed clustering occurred by random chance. Visually, this corresponds to the red zone on the distribution curve, indicating a statistically significant clustering pattern. This analysis used different spatial conceptualization and parameters than the first. Notably, the inverse distance method was applied for spatial relationships, meaning that locations closer together exert more influence on one another than those farther apart. The distance threshold was set to 1000 meters and 1000 meters multiple, which likely allowed the detection of local neighborhood effects that were not captured in the previous analysis.

3.2 Distribution of Tuberculosis Cases at the Bayongbong Community Health Center

The prevalence rate of tuberculosis cases in the Bayongbong Community Health Center's service area was determined using the period prevalence rate, a statistical indicator that

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reflects the total number of individuals affected by TB within a specific time frame. This health center serves several villages, including Bayongbong, Banjarsari, Ciburuy, Cinisti, Ciela, Cikedokan, Mulyasari, Mekarsari, and Pamalayan. The data utilized include both new and existing tuberculosis cases recorded at the Batujajar Community Health Center. The detailed findings are displayed in **Table 2** below,

Table 2. Tuberculosis Prevalence Results in the Bayongbong Community Health Center Working Area for the period January-December 2024

Villages	Cases Total	Community Total	Prevalance Rate (per 10.000 population)	Rank
Bayongbong	69	7,733	89	1
Mulyasari	65	7,356	88	2
Mekarsari	41	4,752	86	3
Ciela	43	5,790	74	4
Cinisti	33	5,492	60	5
Pamalayan	30	5,097	59	6
Ciburuy	32	5,756	56	7
Cikedokan	15	5212	29	8
Banjarsari	11	6,256	18	9

Table 2 displays the distribution of tuberculosis (TB) prevalence in the Bayongbong

Community Health Center's working area for the period of January to December 2024. Bayongbong Village recorded the highest prevalence rate, with 69 TB cases among a population of 7,733, resulting in a rate of 89 per 10,000 population and ranking first. Mulyasari followed closely in second place with 65 cases out of 7,356 residents, yielding a prevalence rate of 88. Mekarsari ranked third, reporting 41 cases from a population of 4,752 and a prevalence rate of 86. Ciela ranked fourth with 43 TB cases among 5,790 residents, equating to a rate of 74 per 10,000. Cinisti Village placed fifth with 33 cases from 5,492 residents, producing a prevalence rate of 60. Pamalayan came in sixth with 30 cases among 5,097 people and a prevalence rate of 59. Ciburuy was ranked seventh with 32 cases from 5,756 individuals, corresponding to a prevalence rate of 56. Cikedokan was in eighth place with 15 cases and a population of 5,212, resulting in a prevalence rate of 29. Finally, Banjarsari had the lowest prevalence rate of 18 per 10,000 population, with 11 cases recorded among 6,256 residents. These findings reveal notable disparities in TB prevalence across the different villages served by the health center. Figure 3 below shows the distribution of TB cases in the working area of the Bayongbong Community Health Center.

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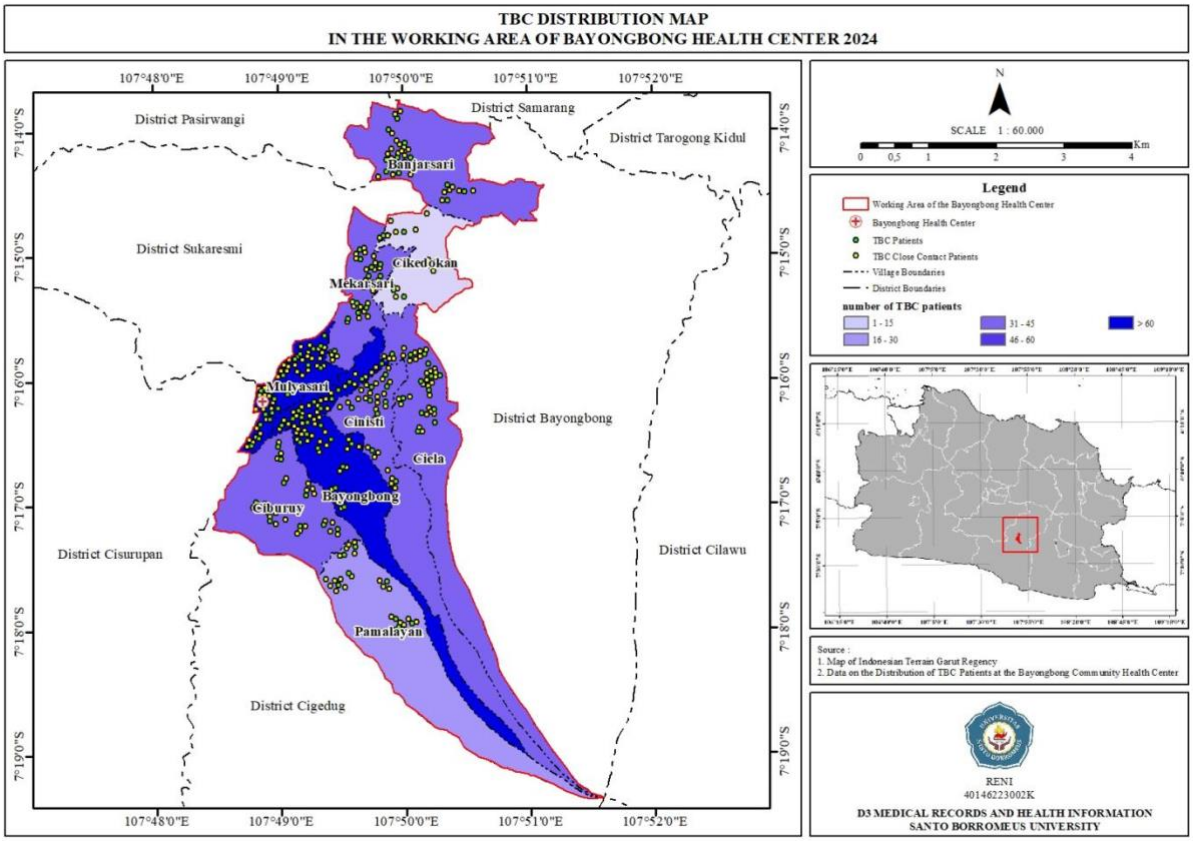

Figure 3. Distribution of Tuberculosis Cases in the Bayongbong Community Health Center Working Area in 2024

Figure 3 illustrates the distribution of tuberculosis cases categorized into five levels. The first level has 1-15 cases, the second has 16-30 cases, the third has 31-45 cases, the fourth has 46-60 cases, and the fifth has more than 60 cases. Interpretation of the data reveals that the villages of Bayongbong, Mulyasari, and Mekarsari are the epicenters of tuberculosis transmission, indicated by the dominance of dark blue and purple shading and the dense clustering of green dots, which each represent individual TBC patients. These visual cues are consistent with the numerical data presented previously, where Bayongbong reported 69 cases, Mulyasari 65 cases, and Mekarsari 41 cases. **Figure 4** below shows the results of the Moran Index analysis.

The Spatial Autocorrelation Report (**Figure 4**) using the Global Moran's I Index provides an analysis of the spatial pattern of tuberculosis (TBC) cases in the Bayongbong Community Health Center's working area. The computed Moran's Index is -0.131574, with a z-score of -0.022045 and a p-value of 0.982412. These values are critical in interpreting the degree of spatial clustering or dispersion of TBC cases. The Moran's I Index ranges from -1 to +1. A value close to +1 indicates strong spatial clustering, while a value close to -1 suggests strong dispersion. A value near 0 indicates a random spatial pattern. In this analysis, Moran's I value is negative but very close to 0, and the z-score is also near zero, falling well within the nonsignificant (yellow) zone of the normal distribution curve. This is further confirmed by the high p-value (0.982412), which is well above the typical significance thresholds (e.g., 0.05 or 0.01). Based on this statistical output, we can conclude that the spatial distribution of tuberculosis cases in the Bayongbong Health Center's working area does not exhibit a

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statistically significant spatial pattern. In simpler terms, the observed TBC case distribution appears to be random, with no evidence of clustering or spatial autocorrelation. This finding suggests that tuberculosis cases are not concentrated in specific hotspots nor dispersed consistently across the study area.

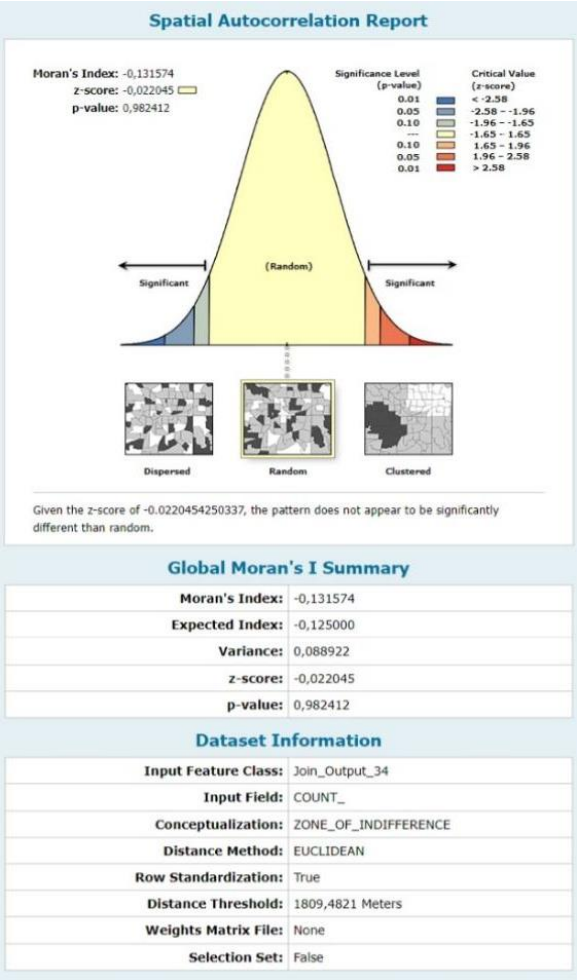

Figure 4. Tuberculosis Distribution Pattern Based on Moran's Index in the Bayongbong Community Health Center Working Area in 2024

The spatial analysis of tuberculosis (TB) case distribution in the working areas of Batujajar and Bayongbong Community Health Centers revealed significant differences in spatial patterns. In Batujajar, the Global Moran's I index was calculated at 0.329 with a z-score of 4.038 and a p-value of 0.000. These values are statistically significant and indicate a strong clustering pattern of TB cases. In other words, TB cases in this area are not randomly distributed but tend to be concentrated in specific locations. This clustering is visually supported by the distribution map, which highlights red zones in villages such as Panguban and Batujajar Timur areas located near industrial zones and water bodies. Environmental factors such as humidity, population density, and socioeconomic conditions likely contribute to the formation of these clusters (Mohidem et al., 2021; Xia et al., 2024; Liyew et al., 2024). The use of the inverse distance method in spatial analysis further strengthens this finding, as proximity between locations influences the similarity in TB case numbers. These results underscore the importance of spatially targeted interventions, particularly in high-risk areas, to effectively control TB transmission.

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In contrast, the spatial analysis of TB cases in the Bayongbong Community Health Center area yielded different results. The Global Moran's I index was -0.131 with a z-score of -0.022 and a p-value of 0.982, indicating no statistically significant spatial pattern. This suggests that TB cases in Bayongbong are randomly distributed across the area, with no evidence of spatial clustering. Although some villages such as Bayongbong, Mulyasari, and Mekarsari reported relatively high prevalence rates, the spatial distribution of cases did not form consistent clusters. This implies that TB transmission in Bayongbong may be more influenced by non-spatial factors such as individual health behavior, health service access, or reporting inconsistencies (Khorshid et al., 2025; Khundi, 2023; Adewole, 2021). Therefore, a more effective approach in this region may involve household or individual-based outreach and equitable health education rather than spatial zoning strategies.

This finding is consistent with (Xue et al., 2023), who found that in certain rural and inland areas of China, TB distribution showed low or no spatial clustering over time, particularly when basic healthcare access and environmental conditions were relatively uniform (Xue et al., 2023). They argued that spatial randomness can emerge when health interventions, social environments, and transmission dynamics do not concentrate geographically, even in high-incidence regions. Supporting this view, (Cabral et al., 2024) analyzed the distribution of TB–diabetes comorbidity in Brazil and found that the absence of spatial clusters in some municipalities was due to evenly distributed risk factors and homogeneity in health service availability (Cabral et al., 2024). (Likewise, Kiani et al., 2021), in a study covering a decade in Iran, noted that spatio-temporal randomness in TB cases may reflect systemic efforts in nationwide control measures, reducing the spatial gaps between regions (Kiani et al., 2021). Furthermore, (Bai and Ameyaw, 2024) emphasized that global reductions in TB incidence are not only driven by geographic interventions but also by macro-level socioeconomic factors, improved diagnostics, and treatment availability, which may mask spatial effects in certain contexts (Bai and Ameyaw, 2024). Overall, the findings confirm that the application of Geographic Information Systems (GIS) and Moran's Index can provide valuable insights into TB risk mapping and help design more targeted intervention strategies. In areas with evident clustering patterns like Batujajar, hotspot identification, and localized intervention are critical. Conversely, in areas with random distribution such as Bayongbong, efforts should focus on widespread and equitable screening, early case detection, and behavioral interventions. These findings support national efforts to eliminate TB by 2030, in alignment with the Sustainable Development Goals (SDGs).

However, this study has several limitations that should be considered when interpreting the results. First, the data used were secondary and reliant on the accuracy and completeness of case reporting within the health centers' information systems, which could be affected by underreporting or misclassification. Second, the spatial analysis did not directly incorporate environmental or socioeconomic variables, such as sanitation, housing density, nutritional status, or population mobility, which are important determinants of TB distribution. Third, the choice of distance parameters in Moran's I calculation may influence the sensitivity of the clustering detection and could miss more localized spatial variations. Therefore, further studies that integrate environmental and socioeconomic data with higher spatial resolution are recommended to strengthen these findings and improve the effectiveness of field interventions.

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4. CONCLUSIONS

Based on the findings of this study, it can be concluded that there are notable differences in the spatial distribution patterns of tuberculosis (TB) cases between Batujajar and Bayongbong Community Health Centers. The Batujajar region demonstrated a statistically significant spatial clustering pattern of TB cases, particularly concentrated in areas near industrial zones and water bodies, as confirmed by a positive Moran's I value (0.329) and significant z-score (4.038; $p < 0.01$). This indicates that TB transmission in Batujajar may be strongly influenced by environmental and demographic factors, requiring geographically targeted interventions to mitigate the spread.

In contrast, the Bayongbong region showed a random distribution of TB cases, as evidenced by a Moran's I value of -0.131 with a non-significant p-value (0.982), suggesting that TB cases are more evenly spread without any discernible clustering. This implies that TB transmission in Bayongbong may be influenced by household-level or behavioral factors rather than spatial proximity. These findings affirm the importance of incorporating spatial analysis tools such as Moran's Index into routine tuberculosis surveillance, as they provide a valuable foundation for tailoring control strategies according to local spatial characteristics and public health priorities.

5. RECOMMENDATIONS

Based on the findings of this study, we recommend that public health authorities and policymakers integrate spatial analysis tools such as Moran's Index into routine surveillance systems to identify TB hotspots and deploy resources efficiently. In regions like Batujajar, with clear clustering, intensified surveillance and environmental health interventions should be prioritized in high-prevalence zones. In contrast, in areas such as Bayongbong, where cases are randomly distributed, broad-based approaches such as improved public awareness, early screening, and equitable healthcare access are more appropriate. Future research should aim to integrate environmental, demographic, and socioeconomic variables to better understand the determinants of spatial variation in TB transmission. Additionally, enhancing data quality and completeness at the health facility level will be critical to ensuring more accurate spatial assessments and improving disease response planning.

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