SRSD
Spatial Review for Sustainable Development
SRSD 3(1): 71–86
ISSN 3062-8229

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Environmental determinants of leprosy: A spatial analysis

Aisyah Noer Auliyah Madani Pertiwi[1,*]
[1] *Global Fund to Fight AIDS, Tuberculosis, and Malaria (GF-ATM), Manado, North Sulawesi 95127, Indonesia.*
*Correspondence: aisyahnoerauliyahmadanipertiwi@gmail.com

Received Date: December 18, 2025 Revised Date: February 17, 2026 Accepted Date: February 24, 2026

ABSTRACT

Background: Leprosy, or *Morbus Hansen*, remains one of the neglected tropical diseases (NTDs) that continues to pose major public health challenges in Indonesia. This study aims to analyze the spatial relationship between handwashing behavior with soap, access to healthy housing, and indoor air quality with leprosy incidence in East Java Province in 2022. **Methods:** An ecological study design was employed using secondary data obtained from the East Java Provincial Health Office. Spatial analysis was conducted using Moran's I and Local Indicators of Spatial Association (LISA) through the GeoDa software to identify both global and local spatial autocorrelation patterns. **Findings:** The results revealed a negative spatial autocorrelation between household handwashing behavior and access to healthy housing with leprosy incidence ($p < 0.05$). This indicates that areas with lower handwashing practices and limited access to healthy housing tend to have higher leprosy case clusters. Meanwhile, indoor air quality showed no significant spatial association ($p > 0.05$). High-risk clusters were identified in Bangkalan, Pamekasan, and Sampang, while low-risk clusters were found in Magetan, Ponorogo, and Tulungagung. **Conclusion:** These findings highlight the need to integrate behavioral and environmental factors into leprosy prevention strategies, particularly through geographically targeted hygiene promotion and housing improvement programs in high-risk districts. Strengthening sanitation infrastructure and aligning leprosy control efforts with local development policies may help reduce spatial disparities in transmission. Future research should employ longitudinal data and incorporate broader social and biological determinants to better understand leprosy dynamics and inform more precise, evidence-based interventions. **Novelty/Originality of this article:** This study introduces a spatial-environmental framework that links household hygiene behavior, healthy housing access, and indoor air quality to leprosy distribution. This research approach offers new insights into environmental pathways of leprosy transmission and supports geographically targeted public health interventions.

KEYWORDS: environmental; geoda; leprosy; moran's I; spatial analysis.

1. Introduction

Mycobacterium leprae, the causative agent of leprosy or *Morbus Hansen*, is a chronic infectious bacterium with a notably long incubation period, averaging around five years or even longer (World Health Organization, 2020). Leprosy is classified as one of the Neglected Tropical Diseases (NTDs), a group of infectious diseases that are often overlooked by society and receive limited attention within health systems. Although NTDs generally have low mortality rates, they contribute significantly to global morbidity and disability, leading to substantial social and economic burdens (Owa et al., 2025). The complexity of leprosy as a public health issue extends beyond the biomedical dimension; it affects productivity, mental well being, and community relations due to the persistent stigma surrounding the disease (Adrianto & Yuwono, 2018).

Cite This Article:
Pertiwi, A. N. A. M. (2026). Environmental determinants of leprosy: A spatial analysis. *Spatial Review for Sustainable Development*, *3*(1), 71-86. https://doi.org/10.61511/srsd.v3i1.2026.2594

Copyright: © 2026 by the author. This article is distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Globally, the registered prevalence rate of leprosy is approximately 16.9 per one million population. In 2021, a total of 140,594 new leprosy cases were reported worldwide, corresponding to a case detection rate of 17.83 per one million population, an increase of 10.2% compared to 2020 (128,405 cases). Reports from 143 countries indicated varying levels of transmission: 36 countries reported zero new cases, 58 reported fewer than 100 cases, 36 reported between 101 and 1,000 cases, and 10 countries reported between 1,001 and 10,000 cases. Among the 23 global priority countries identified by the World Health Organization (WHO), Brazil, India, and Indonesia each recorded more than 10,000 new cases in 2021, underscoring the persistent endemicity of leprosy in these nations (World Health Organization, 2022).

Neglected tropical diseases, including leprosy, are predominantly found in rural, remote, and conflict-affected areas with limited access to healthcare services. These diseases thrive in regions with inadequate access to clean water, poor sanitation, and limited hygiene infrastructure (Qian et al., 2025). The association between leprosy and socioeconomic inequality has long been recognized, with poverty, overcrowding, and poor living conditions identified as key determinants of transmission (Hasker et al., 2025). In developing countries, limited national capacity to deliver adequate health, education, and social welfare services has contributed to the persistence of leprosy as a public health concern (Ihsan et al., 2025). Previous studies have confirmed that leprosy is more prevalent in low-income regions characterized by inadequate hygiene and substandard housing, where environmental and social factors converge to sustain the chain of transmission (da Conceição et al., 2022). Additionally, the environmental conditions of households are often shaped by structural factors such as the availability of public infrastructure, housing improvement programs, and local construction regulations. In some regions, housing quality improvement initiatives have demonstrated positive impacts on ventilation, lighting, and the structural condition of walls and floors, ultimately reducing the risk of environmentally associated diseases such as leprosy.

Communities with lower socioeconomic status are especially vulnerable to leprosy due to a combination of environmental, behavioral, and structural factors. Poor hygiene practices, limited awareness of disease prevention, and low quality housing environments increase the risk of transmission and prolong the disease chain within communities (Putri et al., 2026). In many rural and peri urban areas, people living in poverty are forced to inhabit overcrowded and poorly ventilated dwellings, often lacking access to clean water and sanitation. Such environments facilitate the survival and spread of *Mycobacterium leprae* from one individual to another through prolonged contact (Mishra et al., 2017). Environmental determinants such as household sanitation, access to healthy housing, and air quality are therefore critical components in understanding leprosy transmission dynamics (Effendy et al., 2025). Exposure to smoke from traditional stoves, commonly used in rural settings, can impair lung function and cause chronic inflammation, potentially increasing susceptibility to bacterial infections, including leprosy. The cultural reliance on firewood or biomass as cooking fuel in certain communities further emphasizes the relevance of indoor air quality as an environmental determinant worth examining. Moreover, handwashing with soap is strongly influenced by water availability, distance to water sources, and affordability of hygiene supplies (Soleman & Agustiningtyas, 2025). Among low-income households, the use of soap is often not a priority, indicating that public health interventions should address the provision of enabling facilities in addition to behavioral education (Lages et al., 2025).

From a spatial perspective, the geographic distribution of leprosy is rarely uniform. It tends to form clusters in areas where environmental and behavioral risk factors coexist. Spatial analysis, as part of geographic epidemiology, plays an essential role in identifying such patterns, revealing how environmental determinants and health behaviors contribute to disease transmission (Lages et al., 2025). Framed within a spatial-environmental perspective, variations in environmental hygiene conditions may shape the geographic concentration and clustering of leprosy incidence at the district level. Spatial approaches also enable the identification of *spillover* patterns across neighboring administrative areas,

where high-incidence districts may influence surrounding regions. This allows interventions to be designed at a regional cluster level rather than focusing solely on smaller administrative units, thereby increasing program efficiency. Through spatial epidemiological approaches, public health officials can better identify high risk zones, prioritize resource allocation, and develop geographically tailored interventions. This approach not only enhances the understanding of disease ecology but also supports more efficient and equitable health strategies (Khundi, 2023). Spatial analysis can also integrate health data with socio-economic information, land-use characteristics, and other environmental attributes. For instance, the presence of slum settlements, industrial zones, or high-density agricultural areas may correlate with the spatial distribution of leprosy . The diverse geographic landscape of East Java, ranging from coastal and lowland regions to mountainous and industrial zones, makes the province particularly suitable for such integrative spatial approaches.

Indonesia, one of the WHO designated priority countries for leprosy elimination, continues to face challenges in controlling transmission, particularly in East Java Province. East Java has consistently reported one of the highest numbers of leprosy cases in the country, reflecting both persistent transmission and potential underreporting in certain districts (Hidayah, 2024). The province's diverse geography, varying socioeconomic conditions, and disparities in sanitation and housing quality create complex spatial patterns of disease occurrence. These factors make East Java an appropriate region for spatial epidemiological studies aimed at uncovering environmental influences on leprosy incidence (Prameswari, 2024).

Several previous studies in Indonesia have examined individual-level factors related to leprosy, such as personal hygiene, nutrition, and socioeconomic status. However, research exploring the spatial environmental dimension of leprosy at the district or sub-district level remains limited. This study analyzed three key household environmental variables: Households practicing handwashing with soap, access to healthy housing, and indoor air quality management. These variables represent modifiable environmental and behavioral determinants that can be addressed through public health interventions (Rahmah et al., 2018). Handwashing behavior serves as a proxy for hygiene awareness and sanitation practices, while access to healthy housing reflects the structural and environmental quality of living conditions. Indoor air quality, although less frequently studied in relation to leprosy, represents an emerging environmental health concern that may influence immune vulnerability and household-level disease exposure (Chastonay & Chastonay, 2022).

Spatial epidemiological approaches offer several advantages over traditional analyses. They enable visualization of disease patterns, identification of spatial clusters, and statistical testing of spatial relationships between health outcomes and environmental determinants (Oliveira et al., 2025). Accordingly, this study analyzes the spatial association between environmental hygiene conditions and district-level leprosy incidence in East Java Province, positing that poorer conditions are linked to higher spatial clustering of cases. By identifying geographic concentrations of risk, this approach provides an empirical basis for prioritizing high-risk districts and guiding geographically targeted public health interventions. Ultimately, integrating spatial statistics with environmental health indicators strengthens the ecological understanding of leprosy transmission in East Java Province.

2. Methods

This study employed an analytical research design with an ecological study approach, in which the population served as the unit of analysis. The unit of analysis was defined at the administrative level of districts and municipalities within East Java Province, comprising a total of 38 regions. The ecological design was chosen because it allows for the assessment of relationships between variables at the population level and provides an overview of disease distribution within a broader geographical context. In public health research, this approach is highly relevant since health interventions and policies are

generally implemented at the community or administrative level rather than at the individual level.

The ecological approach used in this study aligns with the theoretical framework of the epidemiological triangle, which explains the interaction between the agent, host, and environment in influencing disease occurrence. In the context of leprosy, *Mycobacterium leprae* as the agent cannot spread independently without environmental conditions that facilitate transmission. The environmental factors examined in this study: Access to healthy housing, handwashing with soap, and indoor air quality, represent key components of the "environment" element within the epidemiological triangle. Poor housing conditions, limited hygiene practices, and inadequate indoor air quality may collectively create settings that support prolonged contact and exposure, thereby increasing the likelihood of transmission at the population level. By recognizing the interaction between the agent and these environmental determinants, this study employs spatial analysis to identify areas where environmental conditions may contribute to higher leprosy incidence.

The study utilized secondary data derived from the 2023 East Java Provincial Health Profile published by the East Java Provincial Health Office. The dataset included the number of recorded leprosy cases, the percentage of households with access to healthy housing, the percentage of households practicing handwashing with soap, and indicators of indoor air quality management. All variables were processed into proportions at the district or municipal level to ensure comparability across regions. Before conducting spatial analysis, all data underwent a quality control process to verify completeness and consistency. This procedure ensured that there were no recording errors, outliers, or missing values that might bias the results. If inconsistencies were identified, data adjustments were made based on logical checks and official data records.

Spatial statistical analysis was conducted using GeoDa software, employing two primary techniques: Moran's I and Local Indicators of Spatial Association (LISA). Moran's I measures the degree of global spatial autocorrelation, that is, the extent to which similar values cluster across geographic areas. The index ranges from –1 to +1, where positive values (approaching +1) indicate a strong spatial clustering, values near 0 suggest random spatial distribution (no spatial autocorrelation), and negative values (approaching –1) denote spatial dispersion or dissimilarity among neighboring areas. The statistical significance of Moran's I was assessed by comparing the observed value (I) with the expected value (E[I]). When I > E[I], it indicates positive spatial autocorrelation; when I = E[I], there is no spatial dependence; and when I < E[I], it reflects negative spatial autocorrelation.

Subsequently, a univariate LISA analysis was performed to identify the local spatial patterns of each variable independently. This analysis aimed to determine which districts or municipalities exhibited statistically significant spatial relationships with their neighbors. Areas with $p < 0.05$ were considered to have significant local clustering. Districts that showed significant clustering were then analyzed further through a bivariate LISA, which explored the spatial association between leprosy incidence and each environmental and behavioral determinant (healthy housing access and handwashing with soap).

The LISA results were visualized through Moran significance maps and cluster maps, illustrating the spatial distribution of significant associations. The maps classify regions into four main quadrants:

2.1 High-High (HH) : Districts with high values surrounded by high-value neighbors,
2.2 Low-Low (LL) : Districts with low values surrounded by low-value neighbors,
2.3 High-Low (HL) : Districts with high values surrounded by low-value neighbors, and
2.4 Low-High (LH) : Districts with low values surrounded by high-value neighbors.

The analytical process was carried out systematically, beginning with secondary data collection, data cleaning and standardization, descriptive spatial analysis, global autocorrelation testing (Moran's I), and local cluster detection using LISA. Each stage of analysis was followed by interpretation within an epidemiological framework to understand the spatial interactions between behavioral and environmental risk factors and

the distribution of leprosy. This methodological approach provided a comprehensive spatial understanding of the relationship between contextual determinants and leprosy incidence at the district and municipal levels across East Java Province.

3. Results and Discussion

3.1 Characteristic of leprosy incidence in East Java Province

The spatial distribution map of leprosy cases in East Java Province shows a clear geographic variation in the distribution of the disease across districts and municipalities. Areas with the highest number of leprosy cases (indicated in dark brown) ranged between 100 and 249 cases and were concentrated in nine regions: Sumenep, Pamekasan, Sampang, Bangkalan, Surabaya City, Tuban, Pasuruan, Probolinggo, and Jember. Districts categorized as having a moderate number of cases (light brown) ranged from 40 to 95 cases and were distributed across ten areas, namely Banyuwangi, Bondowoso, Situbondo, Lumajang, Malang, Gresik, Sidoarjo, Jombang, Lamongan, and Bojonegoro. Meanwhile, districts with relatively low case counts (pale brown) ranging from 13 to 29 cases were identified in ten regions, including Ngawi, Magetan, Ponorogo, Trenggalek, Tulungagung, Kediri, Mojokerto, Nganjuk, Probolinggo City, and Pasuruan City. In contrast, districts with the fewest cases (pale yellow) ranging from 0 to 12 cases were found in nine areas, namely Pacitan, Blitar, Madiun, Kediri City, Blitar City, Malang City, Mojokerto City, Madiun City, and Batu City (Figure 1).

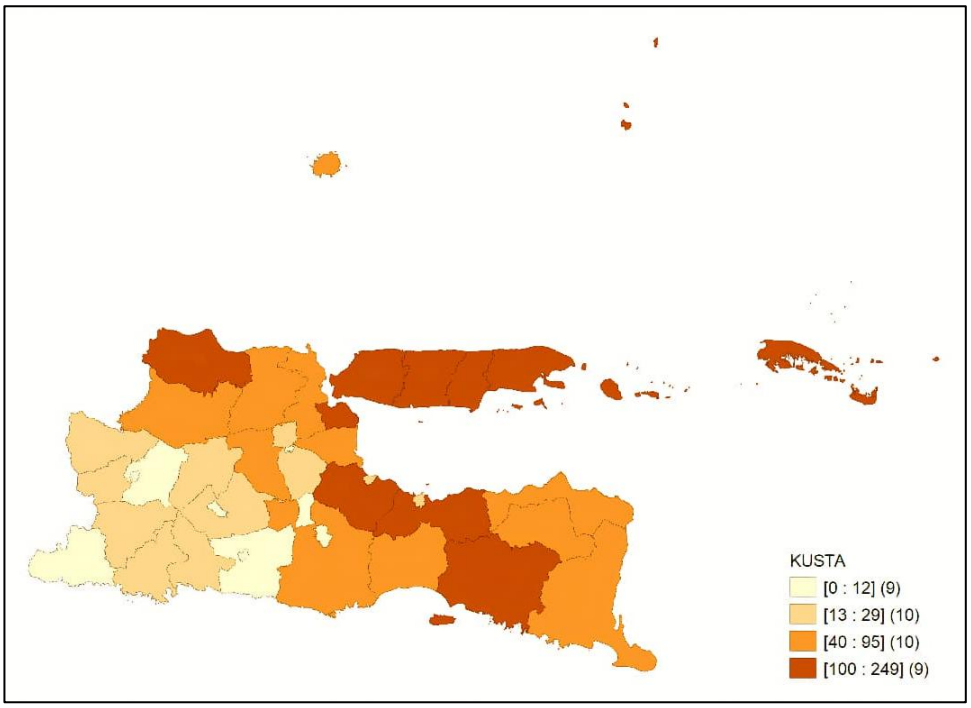


Fig. 1. Distribution of leprosy cases in East Java Province, 2022

Overall, the distribution pattern indicates that leprosy incidence tends to be concentrated in the eastern and northern parts of East Java Province, particularly in the Madura Island region (Sumenep, Pamekasan, Sampang, and Bangkalan). These districts have a relatively high disease burden and are geographically adjacent to one another, forming a cluster of areas with a greater risk of leprosy transmission compared to surrounding districts. On the other hand, the southern and western parts of the province, such as Pacitan, Tulungagung, and Blitar, show a much lower number of cases and do not exhibit a distinct clustering pattern.

The variation in case numbers among districts suggests differences in environmental and household behavioral factors across areas. Districts with a high incidence of leprosy

generally show lower levels of handwashing with soap and poorer housing conditions compared to areas with lower case numbers. These differences may reflect potential spatial associations between environmental factors, hygiene-related behavior, and leprosy incidence. In addition, the spatial distribution pattern reveals that districts with a high number of cases are often located close to other districts with similar characteristics, while areas with lower numbers of cases tend to be scattered more randomly. This indicates the possible existence of spatial autocorrelation, which will be further examined using Moran's I and Local Indicators of Spatial Association (LISA) analyses to determine the degree of spatial relationships among districts and to identify significant clusters that may represent focal points of leprosy transmission in East Java Province.

Furthermore, the concentration of high-incidence districts in northern and eastern East Java suggests the presence of spatial interaction where adjacent regions may share similar environmental vulnerabilities related to household hygiene and housing quality. The proximity of these districts may strengthen the continuity of transmission, especially in areas where practices of handwashing with soap remain consistently low across neighboring regions. In contrast, districts with very low case counts tend to be surrounded by areas with similarly favorable environmental conditions, indicating a more stable pattern of lower transmission risk. The emerging contrast between these spatial groupings highlights the importance of considering local environmental characteristics when interpreting disease patterns. These spatial tendencies also reinforce the need for geographically targeted interventions, as districts forming high–high patterns may require more intensive surveillance and community-level behavioral improvements compared to districts categorized as low–low.

3.2 Result of spatial autocorrelation analysis

The results of the global spatial autocorrelation analysis for the four variables, conducted using GeoDa software, are presented in Figure 2. The obtained Moran's I values were as follows: leprosy cases (0.665), handwashing with soap (0.123), healthy housing (0.133), and indoor air quality (−0.076). The Moran's I values for leprosy cases, handwashing with soap, and healthy housing were higher than the expected value E[I] = −0.0270, indicating a positive spatial autocorrelation across districts and municipalities. This means that these three variables exhibited clustered spatial patterns, where neighboring districts tended to have similar characteristics. In contrast, the Moran's I value for indoor air quality (−0.076) was lower than the expected value, indicating a negative spatial autocorrelation and a dispersed distribution pattern. This finding suggests that districts with higher or lower indoor air quality were not geographically concentrated but rather scattered across different parts of the province.

Overall, these results indicate that leprosy incidence, handwashing behavior, and access to healthy housing display spatial dependence, while indoor air quality does not exhibit a clear spatial clustering pattern in East Java Province. The relatively high Moran's I value for leprosy cases demonstrates that the spatial distribution of this disease is not random but shows a clustered configuration among neighboring districts with similar case levels. A similar, though weaker, trend is observed for handwashing with soap and healthy housing, suggesting that hygiene behavior and housing quality are spatially related and may share geographical similarities in their distribution.

The global analysis indicates that the spatial arrangement of leprosy cases follows a structured pattern, with districts that report high case numbers often situated near other high-incidence areas. Conversely, districts with low case counts tend to be surrounded by other districts with similarly low incidence levels. The variables representing handwashing behavior and healthy housing exhibit the same direction of spatial dependence, indicating a tendency for regions with poor hygiene and housing indicators to cluster geographically.

The results of the local spatial autocorrelation analysis using the univariate LISA test showed a p-value of 0.001 ($p < 0.05$), as illustrated in Figure 3. This value indicates that several districts demonstrated statistically significant local spatial clustering of leprosy

cases. The significant clustering suggests that certain areas exhibit concentrated patterns of leprosy incidence, which may help identify high-risk districts for targeted public health interventions. The LISA analysis identified areas where the relationship between each district and its neighbors contributed significantly to the overall spatial pattern observed at the provincial level. In some regions, the degree of local spatial association was stronger, while in others it was weaker or non-significant, suggesting variability in spatial concentration across East Java Province. This variability highlights that while some districts form clear clusters, others show dispersed patterns, indicating that environmental, social, and behavioral factors may differently influence leprosy risk across regions.

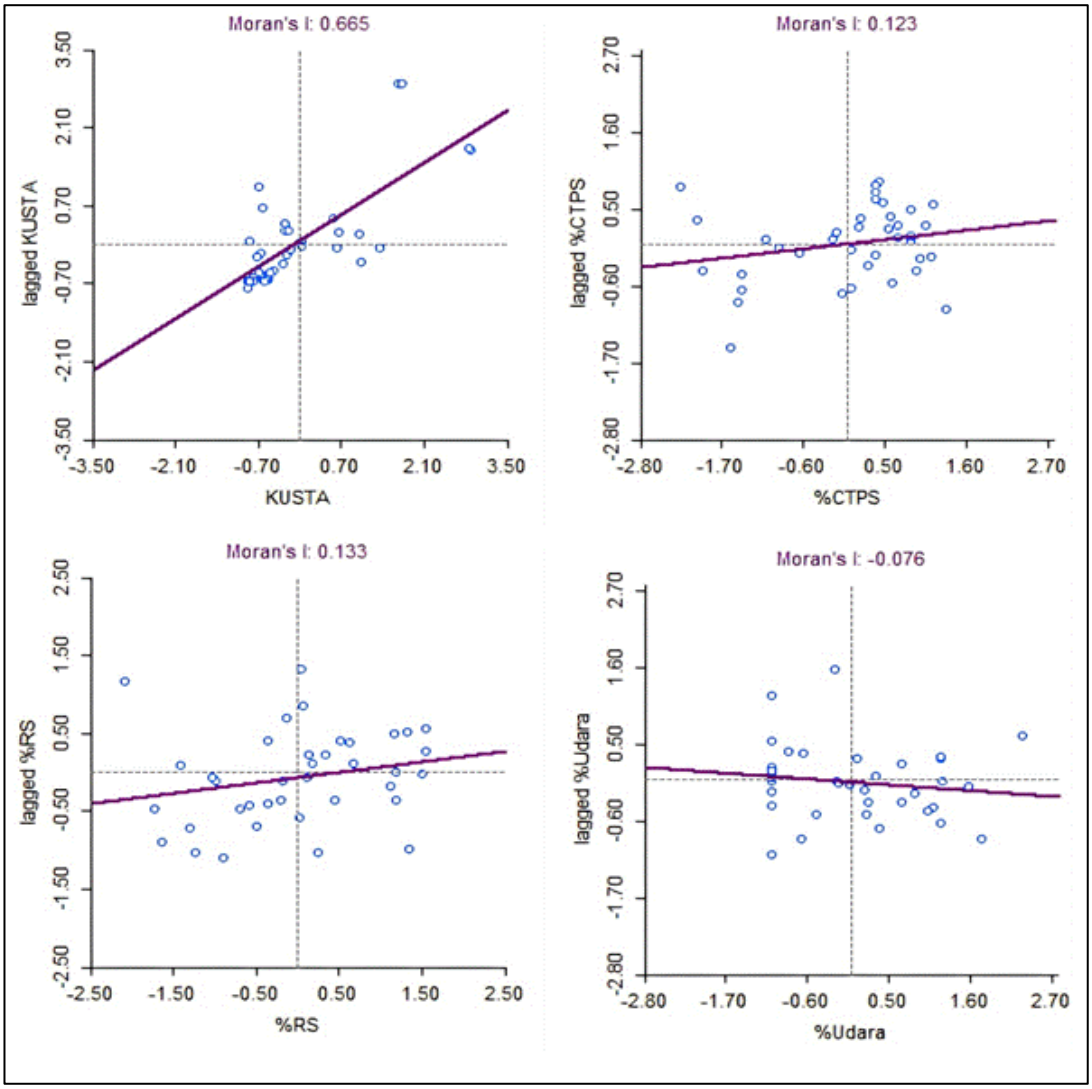


Fig. 2. Global Moran's I scatterplots of district-level leprosy incidence, access to healthy housing, household handwashing practices, and indoor air quality in East Java Province, 2022

The findings from both global and local analyses provide consistent evidence of spatial association in the distribution of leprosy and related environmental variables. Such consistency reinforces the importance of spatial statistical methods, like Moran's I and LISA, for planning and prioritizing interventions in districts with higher disease burden. The presence of significant local clustering implies that certain areas share similar spatial patterns, whereas others show more dispersed or isolated values. Identifying these clusters can assist health authorities in allocating resources effectively, conducting focused community education, and improving surveillance where leprosy cases are concentrated. Comparable observations were reported by Bueno et al. (2023) in Brazil, who found statistically significant clusters of leprosy cases using local spatial statistics such as LISA, demonstrating the usefulness of spatial autocorrelation methods in detecting and

visualizing areas with similar disease patterns. These comparative findings suggest that spatial clustering is a universal phenomenon in leprosy epidemiology, and similar analytical approaches could be applied in different endemic regions to understand transmission dynamics.

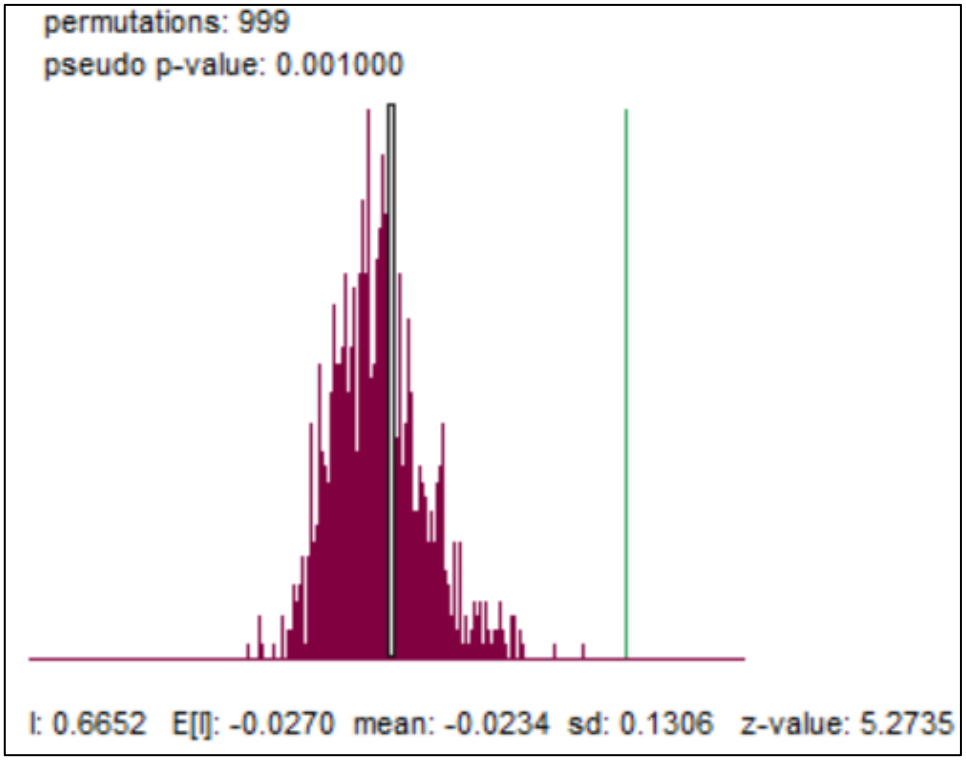


Fig. 3. Local moran's I scatter plot of leprosy cases in East Java Province, 2022 (999 Permutations)

3.3 Result of bivariate analysis using the local indicators of spatial association test

The bivariate LISA analysis was conducted to assess the spatial autocorrelation between handwashing with soap, access to healthy housing, and indoor air quality with leprosy incidence in East Java Province. The results of this analysis are presented in Table 1 below. The results of the bivariate LISA analysis presented in Table 1 indicate statistically significant spatial associations ($p < 0.05$) for two variables handwashing with soap ($p = 0.009$) and access to healthy housing ($p = 0.010$). This finding suggests the presence of spatial autocorrelation between household hygiene behavior, housing conditions, and leprosy incidence. Both handwashing with soap and access to healthy housing exhibited negative spatial autocorrelation with leprosy cases, as indicated by negative Moran's I values. This implies that areas with poor hygiene behavior and unhealthy housing conditions tend to cluster near regions with higher leprosy incidence. These spatial patterns highlight how environmental disadvantages and hygiene-related behaviors can accumulate geographically, creating pockets of vulnerability that may facilitate sustained transmission of leprosy.

Table 1. Bivariate LISA analysis of leprosy cases in East Java Province, 2022

Variabel	Moran's I	E[1]	SD	Sig.	Z
Handwashing	-0.2801	-0.0270	0.1058	0.009	-2.7520
Healthy houshing	-0.2725	-0.0270	0.1087	0.010	-2.6123
Air quality	-0.1411	-0.0270	0.1036	0.077	-1.4062

The negative autocorrelation also suggests contrasting spatial conditions between neighboring areas, indicating that disparities in hygiene and housing could be an important signal for targeted public health interventions. In contrast, the variable of indoor air quality

did not show a significant spatial association with leprosy incidence across districts and municipalities (p = 0.077). This result aligns with a recent systematic review reporting that three studies conducted in Indonesia found no significant relationship between household ventilation and the prevalence of leprosy (Pertiwi & Syahrul, 2024). Similarly, a case-control study in Mojokerto Regency examined household physical conditions, including ventilation, humidity, temperature, and occupant density, but also found no statistically significant association between ventilation and leprosy incidence (Fadlila et al., 2022).

These findings suggest that while household hygiene and housing quality demonstrate spatial relevance to leprosy incidence, indoor air quality may not play a major spatial role in influencing disease transmission in East Java Province. This lack of spatial significance indicates that the factors influencing leprosy transmission may be more strongly tied to direct human contact and broader environmental conditions rather than indoor ventilation alone. It also reinforces the idea that ventilation-related factors may vary widely across communities, diluting any detectable spatial pattern when assessed at the district level. Based on the bivariate LISA results, six districts or municipalities in East Java Province were found to have statistically significant spatial relationships between household handwashing behavior, access to healthy housing, and leprosy incidence. The spatial positions of these significant districts are illustrated in the Moran cluster map below:

3.3.1 Moran significance map and cluster map of the relationship between handwashing behavior and leprosy cases

The Moran significance map presented in (Fig. 4a) illustrate the spatial relationship between household handwashing with soap behavior and leprosy incidence in East Java Province. In Quadrant II, three districts were identified Bangkalan (p = 0.001), Pamekasan (p = 0.001), and Sampang (p = 0.05). Meanwhile, Quadrant IV included three districts: Magetan (p = 0.05), Ponorogo (p = 0.05), and Tulungagung (p = 0.05). These findings indicate that areas with low handwashing behavior surrounded by high leprosy incidence (Low-High) were concentrated in the Madura region, while districts with high handwashing behavior surrounded by low leprosy incidence (High-Low) were located in the southwestern part of East Java Province (Fig. 4b). This contrasting distribution highlights the uneven behavioral and environmental conditions that shape the spatial patterns of disease across the province.

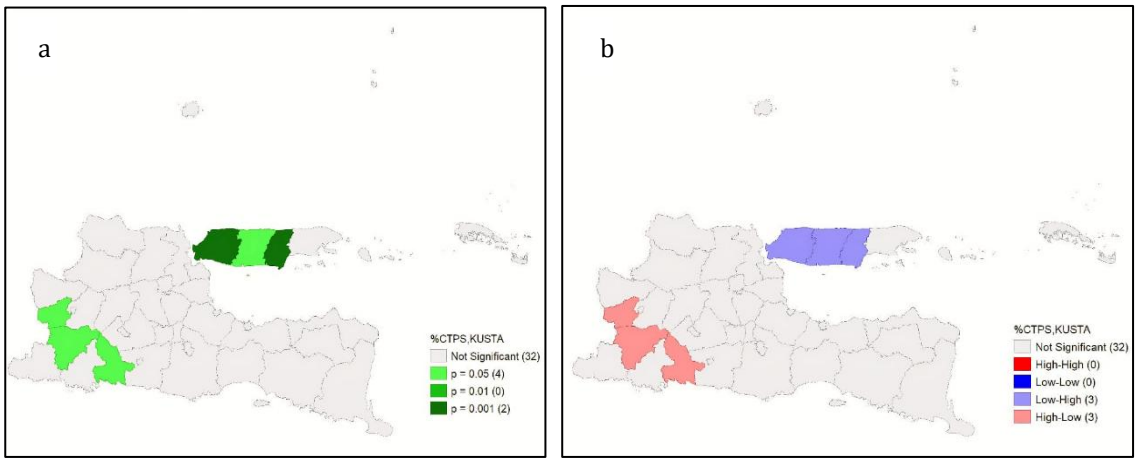


Fig. 4. (a) Moran significance map; (b) Cluster map of the relationship between handwashing with soap behavior and leprosy cases in East Java Province, 2022

The results of the bivariate LISA analysis revealed a negative spatial autocorrelation between household handwashing with soap behavior and leprosy incidence. This finding indicates that lower levels of handwashing behavior within households are associated with higher leprosy incidence, and conversely, higher handwashing behavior corresponds to lower leprosy incidence. A negative spatial autocorrelation value suggests that neighboring

regions tend to display contrasting behavioral and epidemiological characteristics, reinforcing the importance of considering spatial heterogeneity in public health assessments. The negative spatial autocorrelation also suggests that adjacent areas tend to be dissimilar, indicating a dispersed spatial pattern of distribution.

This study identified three districts located in Quadrant II (Low-High) Bangkalan, Pamekasan, and Sampang and three districts in Quadrant IV (High-Low) Magetan, Ponorogo, and Tulungagung. These spatial patterns imply that regions with poor handwashing practices surrounded by areas of high leprosy incidence are concentrated in the Madura region, whereas districts with better hygiene behavior adjacent to areas of lower disease incidence are found in the southwestern part of East Java Province. This spatial polarity suggests that localized interventions must be tailored according to regional behavioral tendencies rather than relying solely on uniform provincial strategies.

The findings of this study are consistent with research conducted in Tangerang City in 2015, which reported that individuals who did not practice proper hand hygiene had a 3.357 times higher risk of contracting leprosy compared to those who regularly washed their hands with soap (Komalaningsih, 2016). Regular handwashing with soap is an essential behavioral measure that can significantly reduce the risk of leprosy transmission. Increased public awareness and consistent implementation of hand hygiene practices are therefore expected to serve as effective preventive strategies to limit the spread of leprosy in the community (Hidayati, 2017). Strengthening community-based hygiene promotion programs may further improve compliance, especially in areas where behavioral practices remain below recommended standards.

These findings are also supported by previous studies emphasizing the importance of WASH (Water, Sanitation, and Hygiene) conditions in leprosy prevention. Poor sanitation facilities, lack of access to clean water, and unavailability of soap can contribute to the persistence of *Mycobacterium leprae* in the environment and increase human exposure (Souza et al., 2025; Wasson et al., 2022). The high proportion of multibacillary leprosy cases may also be influenced by inadequate hygiene practices and limited awareness regarding personal cleanliness. This indicates that improving handwashing behavior alone may not be sufficient without addressing broader structural barriers such as water scarcity, affordability of hygiene supplies, and access to sanitation infrastructure.

However, other studies such as Amsikan et al. (2019) found no statistically significant relationship between personal hygiene practices and leprosy risk. This discrepancy might be due to differences in study settings, population characteristics, and the inclusion of confounding factors such as nutritional status, socioeconomic level, or BCG vaccination history (Pertiwi et al., 2024). In contrast, Prakoeswa et al. (2020) highlighted that the majority of respondents in their study area had good hygiene practices, which might explain the absence of significant associations between hygiene behavior and leprosy incidence. These inconsistencies underscore that leprosy transmission is multifactorial, and hygiene-related factors may vary in importance depending on regional context, environmental exposure, and behavioral norms.

Overall, these results demonstrate that hygiene behavior, especially regular handwashing with soap plays a crucial role in leprosy prevention. Improving WASH access and promoting behavioral change at the household and community levels are essential public health strategies to break the transmission chain of leprosy and achieve the national target of leprosy elimination in Indonesia. Strengthened collaborations between health offices, water supply agencies, and local community leaders may accelerate the adoption of healthy hygiene practices. Future programs should incorporate spatial analysis tools to identify priority intervention zones more precisely, ensuring that high-risk areas receive targeted and effective public health actions.

3.3.2 Moran significance map and cluster map of the relationship between access healthy housing and leprosy cases

The Moran significance and cluster maps presented in Figure 5 illustrate the spatial

relationship between access to healthy housing and leprosy incidence in East Java Province. Based on the bivariate LISA analysis, several districts exhibited spatial associations that highlight how environmental and housing factors may influence disease patterns. These findings also suggest that environmental variables can function as early indicators for identifying high-risk areas before increases in case numbers occur. In Quadrant II (Low-High), three districts were identified: Bangkalan (p = 0.001), Pamekasan (p = 0.001), and Sampang (p = 0.05). In Quadrant III (Low-Low), one district was observed, namely Magetan (p = 0.05). Meanwhile, Quadrant IV (High-Low) included two districts, Ponorogo (p = 0.05) and Tulungagung (p = 0.05).

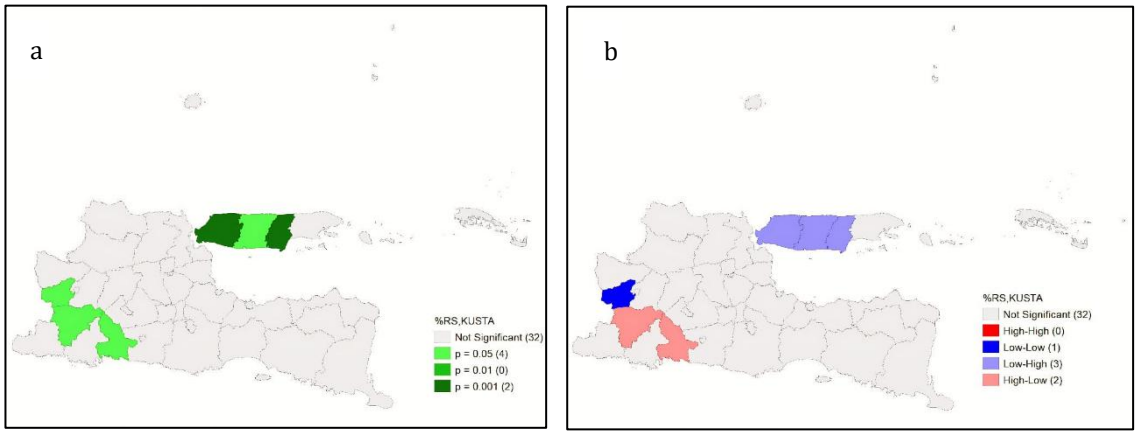


Fig. 5. (a) Moran significance map; (b) Cluster map of the relationship between acces healthy housing and leprosy cases in East Java Province, 2022

The results of the bivariate LISA analysis indicated a negative spatial autocorrelation between access to healthy housing and leprosy incidence. This negative value reflects an inverse spatial relationship areas with low access to healthy housing tend to be adjacent to areas with high leprosy incidence, and conversely, areas with better housing access are surrounded by areas with low disease incidence. This pattern highlights that leprosy transmission is influenced not only by individual-level factors but also by spatial characteristics of surrounding regions that may amplify or suppress risk. This pattern reveals that neighboring areas do not share similar characteristics, implying a dispersed or contrasting spatial configuration rather than clustering of similar attributes.

The identification of three districts in Quadrant II (Low-High) Bangkalan, Pamekasan, and Sampang suggests that these regions, which have relatively poor access to healthy housing, are spatially associated with neighboring regions experiencing higher rates of leprosy. This reinforces the need for area-based prevention strategies that consider disparities in basic infrastructure across districts. These findings are particularly significant as all three districts are located on Madura Island, which is known to have a relatively high burden of leprosy compared to other parts of East Java. Poor housing conditions, limited sanitation infrastructure, and crowded living environments are common features in these areas, potentially exacerbating disease transmission. Social factors such as population mobility and daily living habits may further strengthen the connection between housing conditions and leprosy risk.

In contrast, Ponorogo and Tulungagung, which were identified in Quadrant IV (High-Low), represent areas with higher access to healthy housing surrounded by regions with low leprosy incidence. This suggests that better environmental and housing conditions may contribute to disease prevention, as they provide protective factors that limit opportunities for transmission. This pattern also indicates that physical interventions such as improved ventilation and sanitation, may provide strong protective effects at the community level. The district of Magetan, located in Quadrant III (Low-Low), indicates that both the district and its neighbors have low access to healthy housing and simultaneously low leprosy incidence. This could reflect the influence of other mitigating factors, such as effective public

health programs, community awareness, or stronger surveillance systems that offset environmental disadvantages. This shows that non-environmental determinants also play an important role, especially prompt detection and case management.

The relationship between housing conditions and leprosy has been discussed extensively in prior studies. The present findings are consistent with a study conducted in Sampang District, which found that unhealthy housing conditions were the most dominant factor associated with leprosy cases. Individuals living in unhealthy houses were reported to have a 14.531 times higher risk of developing leprosy compared to those residing in healthy homes (Andinta, 2017). Households with inadequate ventilation, absence of functional windows, high occupancy density, and lack of bedroom separation between leprosy patients and healthy family members showed higher odds of leprosy (Silitonga et al., 2026). Moreover, Adellya et al. (2024) and Pescarini et al. (2018), reported similar findings, indicating that limited access to healthy housing, including overcrowded living conditions and inadequate ventilation, was significantly associated with the persistence of leprosy in endemic areas. Their studies highlighted that high household density facilitates close and prolonged contact among family members, increasing the likelihood of Mycobacterium leprae transmission. Poor housing quality, characterized by damp walls, insufficient sunlight, and poor airflow, creates conditions that indirectly favor bacterial survival and reduce personal hygiene practices.

Conversely, Fadlila et al. (2022) found no significant association between housing conditions and leprosy incidence, suggesting that other factors such as socioeconomic status, nutritional status, and access to early diagnosis, may have stronger direct effects in certain settings. The inconsistency across studies indicates that leprosy risk factors are context-specific and vary with social and demographic dynamics. This discrepancy underscores the multifactorial nature of leprosy transmission, where environmental, biological, and social factors interact in complex ways. Overall, the findings confirm that access to healthy housing is a crucial spatial determinant of leprosy distribution in East Java. The observed negative spatial autocorrelation indicates that poor housing access tends to coincide with high disease incidence, forming distinct spatial contrasts across districts. Spatial tools such as LISA therefore play an essential role in mapping priority areas more precisely. The persistence of leprosy in areas with poor housing underscores the need for multi-sectoral interventions targeting environmental health, infrastructure, and community behavior simultaneously. Cross-sector collaboration between health, housing, and regional development is critical for reducing disparities and accelerating elimination efforts. Despite these valuable findings, this study has several limitations. The use of secondary data may not capture all relevant environmental and behavioral variables, and the ecological design does not allow for causal inference. Other social, biological, and health service factors may also influence disease distribution. Future research should incorporate longitudinal data, include additional social and biological determinants, and assess the effectiveness of targeted interventions over time. Such efforts would provide a more comprehensive understanding of leprosy dynamics and support evidence-based policymaking.

4. Conclusions

This study provides important insights into the spatial dynamics of leprosy transmission in East Java Province by integrating environmental and household behavioral factors. The findings indicate that low levels of handwashing with soap and limited access to healthy housing are spatially associated with higher leprosy incidence, particularly in areas such as Madura Island. In contrast, regions in southern East Java generally exhibit better environmental and behavioral conditions and lower disease incidence. These spatial patterns suggest that differences in the physical home environment, including inadequate ventilation and sanitation, contribute to clusters of leprosy cases, while areas with more favorable environmental conditions tend to have lower risk. The bivariate LISA analysis further supports the evidence that environmental and behavioral determinants play a

significant spatial role in disease distribution, highlighting the utility of spatial mapping for identifying high-risk areas.

The findings carry important implications for leprosy control strategies. Strengthening handwashing with soap and improving access to healthy housing should be prioritized as public health interventions and components of social welfare. Spatially informed policies can help identify priority districts for focused interventions, optimize resource allocation, and guide integrated strategies involving public health education, infrastructure improvement, and community engagement. Through these approaches, the geographical concentration of leprosy cases can be sustainably reduced, supporting long-term disease elimination goals in East Java Province.

Acknowledgement

The author would like to express sincere appreciation to the East Java Provincial Health Office for making available the East Java Provincial Health Profile 2023, which served as the secondary data source for this study.

Author Contribution

Conceptualization, methodology, data curation, formal analysis, visualization, writing original draft preparation, review, editing, revised, and project administration were all performed by A.N.A.M. Pertiwi. The author has read and approved the final version of the manuscript.

Funding

This research received no external funding.

Ethical Review Board Statement

Ethical review and approval were waived for this study because it used publicly available secondary data from the East Java Provincial Health Profile 2023 and did not involve any human participants, animals, or identifiable personal information.

Informed Consent Statement

Not available. This study did not involve human participants, as it used publicly available secondary data aggregated at the district and provincial levels from the East Java Provincial Health Profile 2023.

Data Availability Statement

The data used in this study are publicly available from the East Java Provincial Health Office through the East Java Provincial Health Profile 2023. No new data were created or generated during this study. The dataset can be accessed through the official website of the East Java Provincial Health Office: https://dinkes.jatimprov.go.id

Conflicts of Interest

The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Declaration of Generative AI Use

During the preparation of this work, the author used ChatGPT (OpenAI) to assist in improving the grammar, clarity, and overall readability of the manuscript. After using this tool, the author thoroughly reviewed and edited the content as needed and takes full responsibility for the accuracy and integrity of the final publication.

Open Access

©2026. The author. This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: http://creativecommons.org/licenses/by/4.0/

References

Adellya, D. V., Narwati, N., Anggraeni, S., & Thohari, I. (2024). Physical house condition and individual characteristics influence the incidence of leprosy. *International Journal of Advanced Health Science and Technology*, *4*(5), 378-384. https://doi.org/10.35882/ijahst.v4i5.409

Adrianto, H., & Yuwono, N. (2018). *Pengantar blok penyakit tropis: Dari zaman kuno hingga abad 21 terkini*. Pustaka Abadi.

Amsikan, N. S., Riwu, Y. R., & Tira, D. S. (2019). Hubungan faktor risiko dengan kejadian penyakit kusta di Kota Kupang tahun 2018. *Lontar: Journal of Community Health*, *1*(1), 7-15. https://doi.org/10.35508/ljch.v1i1.2152

Andita, U. (2017). *Hubungan rumah sehat dan karakteristik individu dengan kasus kusta di wilayah kerja Puskesmas Kedungdung Kecamatan Kedungdung Kabupaten Sampang.* (Doctoral dissertation, Universitas Airlangga). https://repository.unair.ac.id/59177/

Chastonay, A. H., & Chastonay, O. J. (2022). Housing risk factors of four tropical neglected diseases: A brief review of the recent literature. *Tropical Medicine and Infectious Disease*, *7*(7), 143. https://doi.org/10.3390/tropicalmed7070143

da Conceição, J. R., Lopes, C. P. G., Ferreira, E. I., Epiphanio, S., & Giarolla, J. (2022). Neglected tropical diseases and systemic racism especially in Brazil: From socio-economic aspects to the development of new drugs. *Acta tropica*, *235*, 106654. https://doi.org/10.1016/j.actatropica.2022.106654

Effendy, D. S., Jamal, T. M., & Lakawa, S. R. (2025). Risk factor analysis of leprosy incidence in coastal areas: A review. *Journal of Health Science and Pharmacy*, *2*(1), 112-124. https://stikbar.org/ycabpublisher/index.php/jhsp/article/view/1179

Fadlila, A., Nurzila, U., & Adriyani, R. (2022). The relationship between physical conditions of house and sanitation with leprosy case in patients at Sumberglagah Mojokerto Hospital. *The Indonesian Journal of Public Health*, *17*(3), 395. https://doi.org/10.20473/ijph.v17i3.2022.395-405

Hasker, E., Cambau, E., Geluk, A., de Jong, B. C., Barreto, J., van Brakel, W., ... & Vollset, M. (2025). Interrupting transmission of Mycobacterium leprae: Synthesis of new evidence and research recommendations. *Leprosy Review*, *96*(2), e2025034. https://doi.org/10.47276/lr.96.2.2025034

Hidayah, A. N. (2024). *Penerapan metode fuzzy geographically weighted clustering pada pengelompokan Kabupaten/Kota di Provinsi Jawa Timur berdasarkan kasus penyakit.* (Doctoral dissertation, Universitas Islam Negeri Maulana Malik Ibrahim). http://etheses.uin-malang.ac.id/65340/

Hidayati, S. (2017). Sanitasi rumah dan personal hygiene dengan kejadian penyakit kusta tipe multi basiler (Studi di Kecamatan Sumberbaru Kabupaten Jember Tahun 2016). (Skripsi, Universitas Jember). https://repository.unej.ac.id/handle/123456789/85626

Ihsan, S. W., Fauziah, S., Inayah, S. Z., & Pabutung, S. M. (2025). Demographic Distribution of leprosy cases in South Sumatra Province: An analysis of health profile data, 2019–2023. *Journal of Epidemiology and Health Science*, *2*(3), 82-91. https://doi.org/10.36685/jehs.v2i3.1440

Khundi, M. (2023). *Towards a framework for improved targeting of tuberculosis interventions: a spatial analysis of patient notification and prevalence survey data from urban Blantyre, Malawi.* (Doctoral dissertation, London School of Hygiene & Tropical Medicine). https://doi.org/10.17037/PUBS.04670919

Komalaningsih, S. (2016). Hubungan personal hygiene dengan kejadian penyakit kusta di Rumah Sakit Khusus Kusta Dr Sitanala Kota Tangerang tahun 2015. *Jurnal Sehat Masada*, *10*(2), 20-32. https://ejurnal.stikesdhb.ac.id/index.php/Jsm/article/view/18

Lages, D. dos S., Maciel, I. C. L., Vidal, S. L., & Lana, F. C. F. (2025). Spatial, social and serological factors in the prevalence and risk of leprosy in areas of high endemicity: An integrative review. *Infectious Disease Reports*, *17*(3), 1–11. https://doi.org/10.3390/idr17030057

Mishra, S. R., Dhimal, M., Bhandari, P. M., & Adhikari, B. (2017). Sanitation for all: The global opportunity to increase transgenerational health gains and better understand the link between NCDs and NTDs, a scoping review. *Tropical Diseases, Travel Medicine and Vaccines*, *3*(1), 1–7. https://doi.org/10.1186/s40794-017-0051-3

Oliveira, N. G. de, Bortolomai, B. E., Bogado, A. C., & Dias-Baptista, I. M. F. (2025). Factors associated with the spatial distribution of leprosy: A systematic review of the published literature. *Geospatial health*, *20*(2). https://doi.org/10.4081/gh.2025.1394

Owa, K., Wahyuni, S., Ismayanti, G., & Kaswi, N. (2025). *Kesehatan lingkungan dalam pengelolaan penyakit tropis*. PT Optimal Untuk Negeri.

Pertiwi, A. N. A. M., Martini, S., & Nasr, N. M. G. (2024). Relationship between BCG vaccination history and the incidence of leprosy in children: A literature review. *PERIODIC Epidemiology Journal*, *12*(1), 1–8. https://doi.org/10.20473/jbe.v12i12024.1

Pertiwi, A. N. A. M., & Syahrul, F. (2024). Risk factors for leprosy: A systematic review. *Indonesian Journal of Public Health*, *19*(3), 575–589. https://doi.org/10.20473/ijph.v19i3.2024.575-589

Pescarini, J. M., Strina, A., Nery, J. S., Skalinski, L. M., Andrade, K. V. F. de, Penna, M. L. F., Brickley, E. B., Rodrigues, L. C., Barreto, M. L., & Penna, G. O. (2018). Socioeconomic risk markers of leprosy in high-burden countries: A systematic review and meta-analysis. *PLoS Neglected Tropical Diseases*, *12*(7). https://doi.org/10.1371/JOURNAL.PNTD.0006622

Prakoeswa, F. R. S., Ilhami, A. Z., Luthfia, R., Putri, A. S., Soebono, H., Husada, D., ... & Prakoeswa, C. R. S. (2020). Correlation analysis between household hygiene and sanitation and nutritional status and female leprosy in Gresik regency. *Dermatology Research and Practice*, *2020*(1), 4379825. https://doi.org/10.1155/2020/4379825

Prameswari, A. (2024). Gambaran epidemiologi penyakit kusta di Provinsi Jawa Timur tahun 2022. *The Indonesian Journal of Health Promotion*, *7*(6), 1495–1499. https://doi.org/10.56338/mppki.v7i6.5119

Putri, D. A., Widia, Y., Alinda, M. D., & Romadhon, P. Z. (2026). The role of environmental factors in supporting the spread of leprosy in Dr Soetomo Hospital. *International Journal of Health Science & Medical Research*, *5*(1), 29–44. https://www.leprosy-information.org/resource/role-environmental-factors-supporting-spread-leprosy-dr-soetomo-hospital

Qian, J., Ma, Y., Wei, Y., Peng, Z., Li, W., Zhang, T., Yin, F., & Shui, T. (2025). Socioeconomic determinants of the leprosy risk in Yunnan Province, China : A county-level spatiotemporal study. *Frontiers in Public Health*, *April*, 1–10. https://doi.org/10.3389/fpubh.2025.1427319

Rahmah, A. H., Dharmawan, R., & Rahardjo, S. S. (2018). Socioeconomic, environmental, and behavioral determinants of leprosy in Kediri, East Java. *Journal of Epidemiology and Public Health*, *03*(02), 253–262. https://doi.org/10.26911/jepublichealth.2018.03.02.05

Silitonga, I., Nurjazuli, Sulistiyani, Budiyono, & Suhartono. (2026). Association between home physical environment, individual characteristics and personal hygiene and the incidence of leprosy in Cirebon Regency. *Scientific Periodical of Public Health and Coastal Health*, *8*(1), 15–23. https://jurnal.uinsu.ac.id/index.php/contagion/article/view/27397

Soleman, S. R., & Agusningtyas, I. (2025). Analysis of water, sanitation, and hygiene programs' impact on leprosy incidence in Indonesia: A secondary data analysis from the WHO Global Health Observatory. *Medical Technology and Public Health Journal*, *9*(2), 141-150. https://doi.org/10.33086/mtphj.v9i2.6522

Souza, G., Santos, C., & Lisboa, É. (2025). Water, sanitation, and hygiene in urban areas: A review. *Water (Switzerland)*, *17*(17), 1–22. https://doi.org/10.3390/w17172634

Wasson, M. K., Whitson, C., Miller, B., Abebe, W., Tessema, B., Emerson, L. E., Anantharam, P., Tesfaye, A. B., & Fairley, J. K. (2022). Potential drivers of leprosy infection: A case–control study of parasitic coinfection and water, sanitation, and hygiene in North Gondar, Ethiopia. *Frontiers in Tropical Diseases*, *3*, 1–14. https://doi.org/10.3389/fitd.2022.934030

World Health Organization. (2020). *Ending the neglect to attain the sustainable development goals: a road map for neglected tropical diseases 2021–2030.* World Health Organization. https://www.who.int/publications/i/item/9789240010352

World Health Organization. (2022). Global leprosy (Hansen disease) update, 2021: Moving towards interruption of transmission. In *Weekly Epidemiological Record*. World Health Organization. https://www.who.int/publications/i/item/who-wer9736-429-450

Biographies of Author

Aisyah Noer Auliyah Madani Pertiwi, Global Fund to Fight AIDS, Tuberculosis, and Malaria (GF-ATM), Manado, North Sulawesi 95127, Indonesia.

- Email: aisyahnoerauliyahmadanipertiwi@gmail.com
- ORCID: 0009-0008-2529-7521
- Web of Science ResearcherID:
- Scopus Author ID: 58885405700
- Homepage: https://scholar.google.com/citations?user=hp-PTWwAAAAJ