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Distribution of Diphtheria Cases by Population Density and Access to Health Centers in East Java Province, 2022–2024

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Abstract

Diphtheria remains a re-emerging public health threat in Indonesia, with East Java Province consistently reporting the highest national case burden. This study aimed to describe the spatial distribution of diphtheria cases in relation to population density and healthy home coverage across all 38 districts and cities of East Java Province from 2022 to 2024. An ecological study design with a temporal-spatial approach was employed using secondary data sourced from the East Java Provincial Health Profile for the period 2022–2024. Data were analyzed and visualized using Quantum GIS version 3.34.3 through choropleth and spatial overlay mapping techniques. A total of 909 diphtheria cases were recorded over the study period, with annual increases culminating in 397 cases in 2024. Sidoarjo Regency (74 cases), Surabaya City (68 cases), and Blitar Regency (66 cases) recorded the highest cumulative case counts. Spatial overlay analysis revealed that districts and cities classified with high population density tended to exhibit higher diphtheria case burdens, while areas with low healthy home coverage most notably Bangkalan Regency also showed elevated case counts. Conversely, Madiun City, which had the highest healthy home coverage, recorded only 7 cases throughout the study period. These findings indicate that population density and healthy home access are associated with the geographic distribution of diphtheria incidence, underscoring the need for territory-based, multi-sectoral prevention and control strategies in high-risk districts.

Keywords: Diphtheria Distribution, Geographic Information System, Healthy Home Coverage, Population Density, Spatial Analysis

INTRODUCTION

Global Phenomenon

Diphtheria remains one of the most persistent vaccine-preventable diseases (VPDs) threatening public health in low- and middle-income countries, particularly across Southeast Asia and Sub-Saharan Africa. Globally, the World Health Organization (WHO) recorded a significant resurgence in diphtheria cases in recent years, with 8,819 cases reported worldwide, driven largely by disruptions in routine immunization services during and after the COVID-19 pandemic (WHO, 2024). Regional disparities in disease burden are particularly pronounced: while Europe and North America have achieved near-elimination through sustained immunization programs with DTP3 coverage exceeding 90%, Southeast Asia and parts of Africa continue to report ongoing transmission, with DTP3 coverage falling below 70% in several high-burden areas (Openpublichealthjournal, 2025). The resurgence of diphtheria following the pandemic underscores the fragility of herd immunity and the critical consequences of interrupted vaccination programs on the epidemiology of re-emerging infectious diseases. Risk factors associated with diphtheria transmission include overcrowding, poor sanitation and hygiene, incomplete immunization, and large-scale population movement (NIH/StatPearls, 2024).

National and Regional Phenomenon

Indonesia stands as one of the countries with the highest diphtheria burden in the WHO South-East Asia Region, with 2,969 cases reported between 2017 and 2021 (Karyanti, 2022). Following a nationwide outbreak in 2017, which recorded 954 cases and 44 deaths resulting in a Case Fatality Rate (CFR) of 4.61% (Pracoyo, 2020), the country continued to grapple with persistent transmission. According to the WHO/UNICEF Joint Reporting Form on Immunization (JRF), cases surged from 235 in 2021 to 956 in 2023, before slightly declining to 943 in 2024 (WHO, 2024). Within this national landscape, East Java (East Java) Province has consistently emerged as the province contributing the

highest number of diphtheria cases in Indonesia from 2021 through 2024, accounting for 339 reported cases over this period. A multi-year clinical study further confirmed that the five districts with the highest case burden — Surabaya, Sidoarjo, Blitar Regency, Malang City, and Malang Regency — have shown consistently high incidence over more than a decade, with the eleven-year CFR reaching 2.36% among pediatric patients (Mustikasari et al., 2024). This persistent endemicity reflects deeply embedded structural vulnerabilities that warrant urgent geospatial investigation.

State of the Art: Previous Research Findings

A growing body of research has explored the determinants of diphtheria transmission using ecological and spatial approaches. Anggraini and Hendrati (2023) demonstrated that population density is significantly associated with diphtheria transmission speed in Surabaya, with densely populated areas acting as amplifiers of droplet-based infection. Similarly, Suciptawati, Susilawati, and Endarta (2024) applied spatial regression modeling to East Java diphtheria data and identified that housing conditions — particularly floor type and ventilation quality — significantly influence the spatial distribution of cases. A spatial analysis conducted in Lampung Province also found that diphtheria tends to concentrate in areas with low coverage of healthy homes, even when immunization rates are relatively high, pointing to the critical mediating role of environmental living conditions (Kamilla, Utama & Noviani, 2024). At the district level, Putri and Mahmudah (2025) confirmed that population density is significantly correlated with diphtheria case counts in Sampang Regency ($r = 0.768$; $p = 0.001$), further reinforcing the spatial dimension of transmission risk (Putri & Mahmudah, 2025).

Inconsistencies and Limitations of Prior Studies

Despite these contributions, existing studies present notable inconsistencies and methodological gaps. Putri and Mahmudah (2025) found that the percentage of unhealthy homes did not reach statistical significance in correlation testing, which contrasts with findings by Kamilla, Utama, and Noviani (2024) where healthy home coverage emerged as a meaningful spatial predictor of diphtheria. Similarly, immunization coverage — long considered the primary determinant of diphtheria incidence — was found to have no statistically significant association with confirmed cases in East Java in a 2023 spatial study (Unair Journal, 2024), suggesting that environmental and structural factors may exert greater influence than commonly assumed. Moreover, most prior spatial studies in Indonesia have been conducted within single districts or provinces with limited temporal scope, making it difficult to discern longitudinal trends in the distributional shift of cases. The heavy reliance on univariate analysis or simple choropleth mapping without integration of multiple overlapping risk layers further limits the analytical depth of current evidence.

Research Gap and Problem Statement

A critical research gap remains in the simultaneous spatial visualization of multiple epidemiological risk factors — namely population density and healthy home coverage — overlaid with diphtheria case distribution across all 38 districts and cities of East Java Province over a three-year period (2022–2024). While temporal analyzes have captured year-to-year fluctuations and individual spatial analyzes have analyzed single risk factors in isolation, no study to date has produced a comprehensive multi-layered spatial map that tracks the co-distribution of these variables across the full territorial extent of East Java during the post-pandemic recovery period. Given that the post-COVID-19 era has introduced significant disruptions to surveillance systems and immunization delivery — which may have altered the spatial clustering patterns of diphtheria — it is imperative to re-examine the geographic distribution of cases in this context (Fitriani et al., 2024; Salsabila, Handayani & Qudrotin, 2024). The absence of such a district-level temporal spatial analysis constitutes both a scientific gap and a practical limitation for public health authorities seeking evidence-based, area-targeted interventions.

Objectives, Urgency, and Novelty

This study aims to describe and analyze the spatial distribution of diphtheria cases in East Java Province from 2022 to 2024 in relation to population density and healthy home coverage at the district

and city level, using QGIS version 3.34.3. The urgency of this research is underscored by the continued escalation of diphtheria cases in East Java — which has been the highest-burden province in Indonesia for four consecutive years — and by the need for geographically targeted control strategies in the post-pandemic era (Mustikasari et al., 2024; WHO, 2024). The novelty of this study lies in its integration of a three-year longitudinal temporal framework with multi-variable overlay spatial analysis, combining two distinct environmental risk factors — population density and healthy home access — simultaneously mapped against diphtheria case distribution across all 38 districts and cities of East Java. Unlike previous studies that have examined these variables in isolation or within narrower geographic scopes, this research provides a comprehensive ecological-spatial perspective that contributes both theoretically — by expanding the evidence base for environmental determinants of diphtheria — and practically, by generating actionable geographic intelligence to guide district-level disease prevention and health equity interventions.

RESEARCH METHODE

Research Design and Type

This study employed a quantitative ecological study design with a temporal-spatial approach, examining the distribution of diphtheria cases in relation to population density and healthy homes (healthy homes) coverage across all districts and cities of East Java Province, Indonesia, from 2022 to 2024. An ecological study design is appropriate when the unit of analysis is a population or group rather than an individual, allowing researchers to examine patterns of disease distribution in relation to environmental and demographic factors at the aggregate level (Sugiyono, 2022). This design is widely adopted in epidemiological research on communicable diseases, particularly when the objective is to describe geographic variation and identify potential determinants of disease clustering across administrative units (Kamilla et al., 2024; Suciptawati et al., 2024). The temporal dimension of this design enabled the research team to capture longitudinal trends in diphtheria incidence over a three-year observation window, which is essential for understanding post-pandemic shifts in disease distribution patterns (Fitriani et al., 2024). The spatial approach was operationalized through Geographic Information System (GIS) analysis, which has been increasingly recognized as a valuable epidemiological tool for visualizing, mapping, and analyzing the geographic distribution of infectious diseases (Anggraini & Hendrati, 2023).

Population and Sample

The study population encompassed all 38 districts and cities (regencies/cities) within East Java Province, encompassing an estimated total population of 41.9 million inhabitants with an average population density of approximately 872.32 persons per square kilometer (BPS East Java, 2024). Because this study adopted a population-level ecological design, total population sampling (saturated sampling) was applied, meaning all 38 administrative units were included as units of analysis without exclusion. This technique is justified when the total number of analytical units is manageable and complete coverage ensures the elimination of sampling bias, thus enhancing the representativeness and reliability of spatial pattern analysis (Sugiyono, 2022; Sudaryono, 2021). No individual-level sampling was performed, as the unit of analysis remained the district or city. The inclusion criterion was all districts and cities within East Java Province with available diphtheria case data and environmental indicator data for the 2022–2024 period as published in the official East Java Provincial Health Profile. Districts or cities with incomplete data for any of the three study years were retained in the analysis but documented appropriately to maintain geographic completeness (Putri & Mahmudah, 2025).

Instruments and Data Sources

This study relied exclusively on secondary data obtained from the East Java Provincial Health Profile for the years 2022, 2023, and 2024, published by the East Java Provincial Health Office (East Java Provincial Health Office). Secondary data constitutes a valid instrument for ecological and spatial analyzes in public health research, particularly when primary data collection across 38 administrative

units over multiple years is infeasible due to logistical and resource constraints (Emzir, 2022). The data extracted included: (1) the annual number of confirmed diphtheria cases per district/city; (2) population density (persons per km²) per district/city; and (3) the percentage of households with access to healthy homes (percentage of healthy home coverage) per district/city. The healthy home indicator in Indonesia is assessed based on the implementation of Community-Based Total Sanitation (STBM) across its five pillars, together with Household Indoor Air Quality Management (PKURT), as outlined in the Indonesian Ministry of Health guidelines (Subuatwati et al., 2024; Kamilla et al., 2024). The administrative boundary shapefile for East Java Province used in cartographic analysis was obtained from the Geospatial Information Agency of Indonesia (Geospatial Information Agency/BIG), ensuring geometric accuracy of spatial visualization at the district and city level.

The research procedure was conducted in three sequential phases: data preparation, spatial data integration, and map production. In the preparation phase, secondary data on diphtheria case counts, population density, and healthy home coverage were compiled and organized by district/city and year (2022, 2023, 2024) into a structured tabular format. Each variable was then categorized into tiered classifications to facilitate graduated color mapping: diphtheria case counts were classified into five interval categories; population density was classified into three categories (low, medium, high); and healthy home coverage was classified into three categories (low, medium, high) based on the distribution range of values observed across all 38 districts and cities (Salsabila et al., 2024; Anggraini & Hendrati, 2023). In the second phase, the tabular data were joined to the East Java administrative boundary shapefile using the district/city identifier as the common key field within QGIS version 3.34.3. Overlay mapping was subsequently performed to visually integrate population density and healthy home coverage data with diphtheria case distribution, producing separate overlay maps for each of the three study years. In the final phase, all maps were exported and reviewed for cartographic accuracy, including legend clarity, color graduation consistency, and spatial correctness of administrative boundaries (Kamilla et al., 2024).

Data analysis was conducted using Quantum GIS (QGIS) version 3.34.3, an open-source geographic information system application widely used in spatial epidemiology for map production, attribute data management, and spatial overlay analysis (Kamilla et al., 2024; Suciptawati et al., 2024). The primary analytical technique applied was descriptive spatial analysis through choropleth mapping, in which color gradients were assigned to each administrative unit based on the magnitude of the variable being visualized. Choropleth mapping is a standard spatial epidemiological method that enables the identification of geographic clustering, hot spots, and distributional inequalities in health outcomes across administrative boundaries (Putri & Mahmudah, 2025; Anggraini & Hendrati, 2023). Additionally, overlay analysis was employed to superimpose population density and healthy home coverage layers onto the diphtheria case distribution layer, enabling visual co-examination of spatial co-occurrence patterns between the dependent and independent variables. The resulting maps were analyzed descriptively to identify whether districts and cities with high population density or low healthy home coverage exhibited higher diphtheria case counts compared to areas with contrasting characteristics. This approach aligns with the ecological study design, in which associations are described at the aggregate level rather than tested through inferential statistical methods (Sudaryono, 2021; Emzir, 2022).

Given that this study utilized exclusively secondary data derived from publicly available government health profiles, no direct involvement of human subjects was required, thereby precluding the need for individual informed consent. Nevertheless, the research adhered to the principles of research ethics applicable to secondary data utilization, including accuracy in data reporting, transparency in source attribution, and avoidance of data manipulation that could misrepresent the epidemiological situation in any district or city (Sugiyono, 2022). All data were used solely for scientific and academic purposes in accordance with applicable regulations governing the secondary use of government health data in Indonesia. The study did not require formal ethical clearance from an institutional review board; however, all data collection and analysis procedures were conducted in

compliance with the data use policies of the East Java Provincial Health Office and the Indonesian Ministry of Health (Fitriani et al., 2024; Karyanti, 2022).

RESULTS AND DISCUSSION

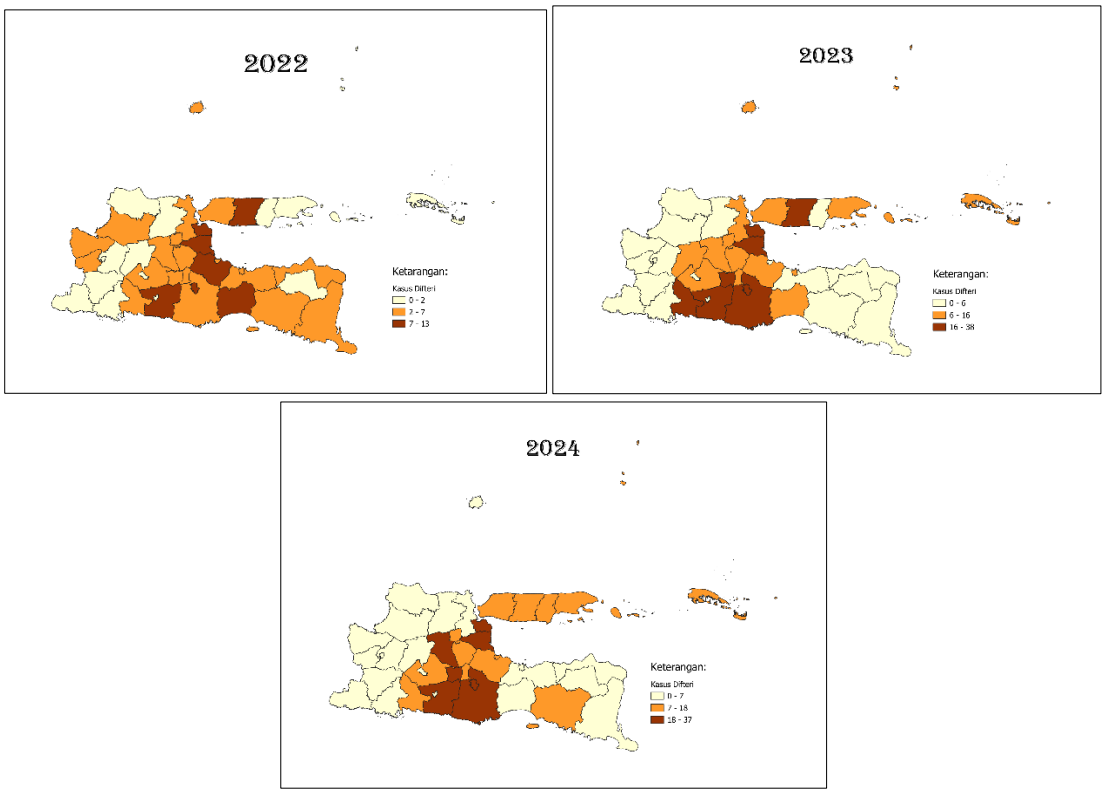


Figure 1. Map of the Distribution of Diphtheria Cases in East Java Province in 2022-2024

Based on case reports for the 2022-2024 period, Sidoarjo Regency was recorded as the region with the highest number of cases, with 74 cases, followed by Surabaya City with 68 cases, and Blitar Regency with 66 cases. East Java Province recorded 909 diphtheria cases during the 2022-2024 period. The number of cases increased annually, with the highest number of cases recorded in 2024, with 397 cases.

PatternThe distribution of diphtheria cases in East Java Province from 2022 to 2024 is shown in Figure 1. The map shows a color gradient indicating an increase in diphtheria cases over a three-year period. In 2022, 13 districts/cities recorded 0-2 diphtheria cases. In that year, the highest number of cases was found in Surabaya City, with 13 cases. An increase in cases was seen in 2023, with 9 districts/cities reporting between 16-38 cases. Furthermore, in 2024, 7 districts/cities recorded 18-37 diphtheria cases.

MapThis distribution also indicates a clustering of high cases in central East Java. Regencies/cities with a trend toward high cases from 2022 to 2024 include Blitar Regency, Malang City, Surabaya City, Malang Regency, Sampang Regency, Sidoarjo Regency, and Tulungagung Regency. Meanwhile, regencies/cities with low cases during the 2022-2024 period include Bondowoso Regency, Blitar City, Ponorogo Regency, and Trenggalek Regency.

Distribution of Diphtheria Incidents Based on Population Density

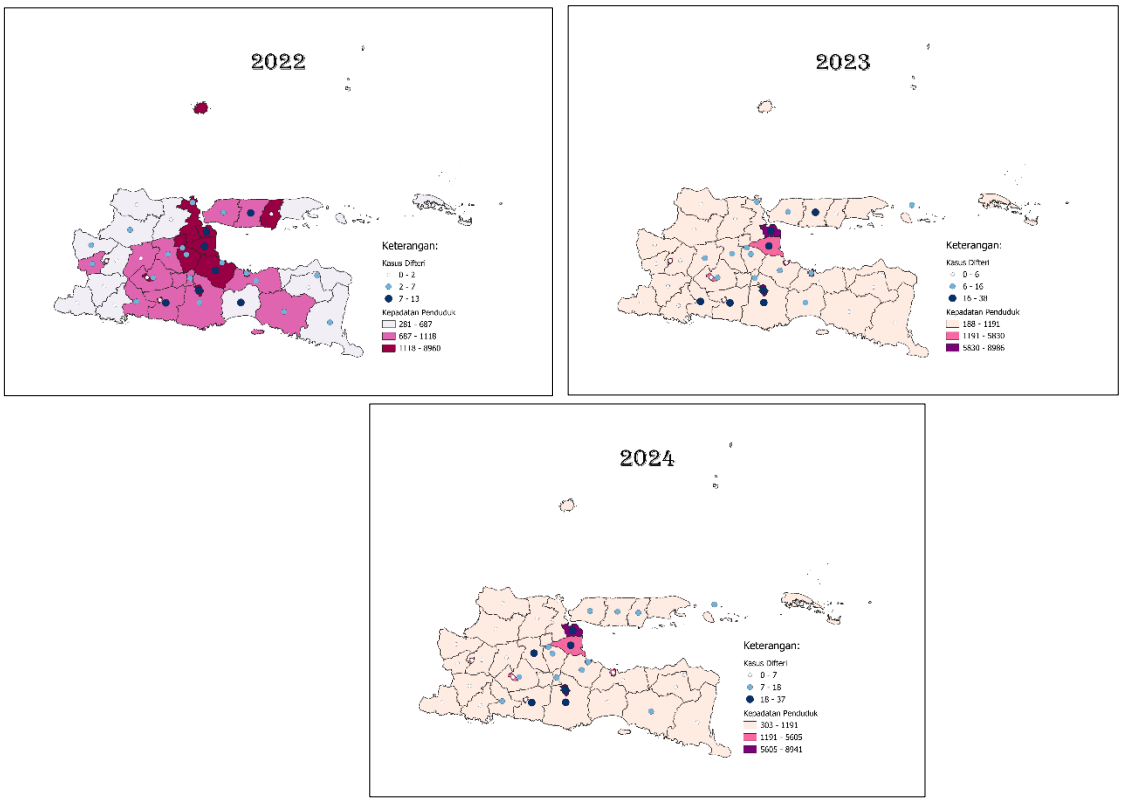
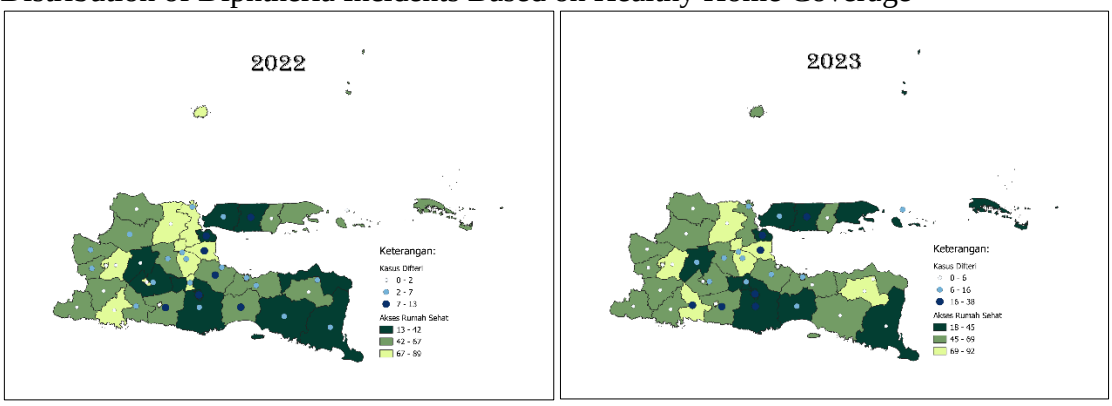


Figure 2. Overlay Map of Population Density and Diphtheria Cases in East Java Province 2022-2024

In 2022-2024, the population density in East Java Province was dominated by areas with moderate population density. The color gradation pattern of the map produced in each district/city shows a similar trend each year. During 2022-2024, 11 districts/cities exhibited high population density: Blitar City, Kediri City, Madiun City, Malang City, Mojokerto City, Pasuruan City, Probolinggo City, Surabaya City, Madiun Regency, Mojokerto Regency, and Sidoarjo Regency. The area with the highest population density was Surabaya City, with 8,986 people per square kilometer in 2023. Conversely, the area with the lowest population density was Banyuwangi Regency, with 281 people per square kilometer in 2022.

High population density has the potential to increase the risk of infectious diseases, such as diphtheria. Regencies/cities with high population densities have also been shown to have a high number of diphtheria cases, for example, Sidoarjo Regency (74 cases), Surabaya City (68 cases), and Malang City (57 cases).

Distribution of Diphtheria Incidents Based on Healthy Home Coverage



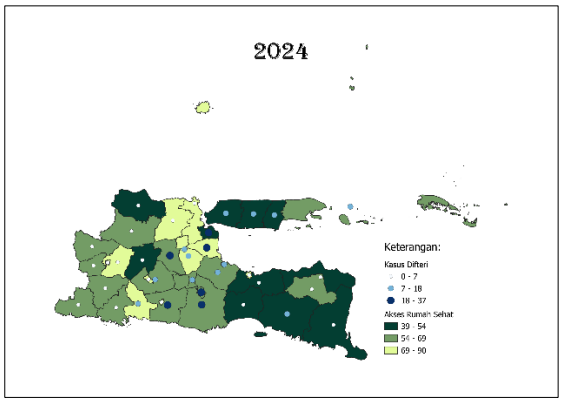


Figure 3. Overlay Map of the Distribution of Access to Healthy Homes and Diphtheria Cases in East Java Province in 2022-2024

ProgramSanitation in Indonesia is being strengthened through Community-Based Total Sanitation (STBM), which encompasses the implementation of five main pillars. These five pillars, along with the Household Air Quality Management (PKURT) indicator, are elements in the assessment criteria for access to healthy homes. Based on Figure 3, the coverage of households with access to healthy homes in East Java showed a fluctuating pattern from 2022 to 2024. In 2022, most areas of East Java Province were included in the moderate category.

Bangkalan Regency had the lowest access to healthy housing from 2022 to 2024, with 21 cases over the three years. Meanwhile, Madiun City had the highest access to healthy housing, with seven cases recorded over the three-year period.

Discussion

Diphtheria is an infectious disease caused by the bacterium Corynebacterium diphtheriae and can be spread through droplets and direct contact. Therefore, the disease is strongly influenced by environmental conditions and frequency of interaction with others. The mapping results in this study indicate that the distribution of diphtheria cases in East Java Province from 2022 to 2024 is uneven across various regions. Some districts/cities show higher case numbers than others, indicating a spatial clustering pattern. This clustering pattern is often seen in infectious diseases spread through droplets, where the spread is more intensive in areas with high levels of social interaction.

Differences in the number of diphtheria cases between regions can occur due to various factors, such as population density, residential conditions, immunization coverage, and access to health services. Research conducted in Sampang Regency showed that regional factors such as population density had a significant relationship with the number of diphtheria cases.(Putri and Mahmudah, 2025)These findings underscore the importance of a region-based approach to controlling diphtheria. The changing pattern of cases between 2022 and 2024 reflects changes in surveillance systems and community behavior following the COVID-19 pandemic. Decreased health services during the pandemic can lead to underreporting of cases, followed by a surge in cases when systems return to normal.

Population density is a crucial factor in the epidemiology of infectious diseases because it is related to the frequency of interactions between individuals. As the population in an area increases, the likelihood of infectious disease spread also increases. Spatial mapping results indicate that densely populated districts/cities tend to experience higher numbers of diphtheria cases. This finding aligns with research suggesting that population density is a factor in the rapid transmission of diphtheria bacteria.(Anggraini and Hendrati, 2023).

A dense population increases the likelihood of interaction between individuals, accelerating the spread of infectious bacteria through droplets. Furthermore, areas with high population density often have cramped living conditions, poor ventilation, lighting, and air quality. These conditions can prolong the presence of infectious agents in the environment and increase the risk to vulnerable individuals. However, population density is not the only factor influencing diphtheria incidence. Other

factors such as immunization coverage, socioeconomic conditions, and access to healthcare can also contribute to determining the level of risk in a region.

BesidesPopulation density and the physical condition of the home environment are important factors in the spread of infectious diseases. Homes that do not meet health standards, such as lack of ventilation, inadequate lighting, and high occupancy rates, can increase the spread of harmful microorganisms. Based on the findings of this study, districts/cities with low access to healthy homes tend to contribute to a higher number of diphtheria cases. Meanwhile, areas with high access to healthy homes show fewer diphtheria cases. This pattern indicates a relationship between the extent of access to healthy homes and the number of diphtheria cases.

This finding is in line with studies showing that diphtheria cases tend to occur in areas with low coverage of healthy homes.(Kamilla, Utama and Noviani, 2024)Homes that do not meet health standards can increase the risk of transmission by increasing exposure to infectious agents. Other studies have also shown that unhealthy home environments, poor ventilation, low lighting, and high density are major concerns in efforts to manage infectious diseases.(Kamilla, Utama and Noviani, 2024).

HouseA healthy home acts as a barrier to the spread of disease. Good ventilation can reduce the number of airborne droplets, adequate lighting can lower humidity, and low-density housing can reduce the likelihood of contact between individuals. Meanwhile, poor housing conditions increase the risk of disease spread, especially droplet-transmitted diseases like diphtheria.

CONCLUSIONS

This study demonstrates that the distribution of diphtheria cases across 38 districts and cities of East Java Province from 2022 to 2024 was spatially uneven, with a total of 909 reported cases exhibiting a consistent clustering pattern concentrated in the central and northern parts of the province, where Sidoarjo Regency (74 cases), Surabaya City (68 cases), and Blitar Regency (66 cases) emerged as the highest-burden areas over the three-year period. The spatial overlay analysis confirmed that districts and cities classified with high population density particularly the 11 urban areas including Kota Surabaya, Sidoarjo Regency, and Kota Malang recorded disproportionately higher diphtheria case counts compared to their less densely populated counterparts, suggesting that elevated interpersonal contact frequency in dense settlements amplifies droplet-mediated transmission of Corynebacterium diphtheriae. Correspondingly, areas with low healthy home (healthy home) coverage, most notably Bangkalan Regency with 21 cumulative cases and the lowest healthy home access rate in the province, showed higher case burdens relative to areas with high healthy home coverage such as Madiun City, which recorded only 7 cases over the same period, indicating that inadequate ventilation, poor indoor air quality, and substandard sanitation conditions constitute meaningful structural contributors to diphtheria risk at the ecological level.

These findings collectively affirm that environmental factors specifically population density and healthy home access play a discernible role in shaping the geographic pattern of diphtheria incidence in East Java, reinforcing the value of spatially targeted, territory-based disease prevention strategies. For public health practitioners and local health authorities, these results underscore the urgency of prioritizing community-based sanitation improvement programs (STBM) and densification management in high-risk districts, alongside sustained immunization campaigns, as part of a comprehensive diphtheria control framework. For future research, subsequent studies are encouraged to incorporate inferential spatial statistical methods such as spatial autocorrelation (Moran's I), geographically weighted regression, or spatial lag modeling — to move beyond descriptive mapping toward quantifying the magnitude and directionality of associations between these environmental determinants and diphtheria incidence. A key limitation of this study lies in its exclusive reliance on secondary aggregate-level data from official provincial health profiles, which precludes individual-

level causal inference and may be subject to surveillance and reporting inconsistencies across districts; future research should therefore seek to triangulate secondary ecological data with primary field surveys to enhance analytical validity and epidemiological precision.

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