

## The 2<sup>nd</sup> FORSTAT International Conference



# Spatial and Temporal Dynamics of Measles Cases in DKI Jakarta, Indonesia, 2016 to 2025

*Muhamad Nobel Fauzan<sup>a</sup>, Sarini Abdullah<sup>a\*</sup>*

<sup>a</sup> Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Indonesia

\*Corresponding author: sarini@sci.ui.ac.id

### ABSTRACT

Measles remains a significant public health threat in densely populated urban settings like DKI Jakarta, Indonesia, where sustaining herd immunity is challenging. To optimize public health responses, the main objective of the research is to evaluate the spatial and temporal dynamics of measles over a ten-year period from January 2016 to December 2025 using Local Indicators of Spatial Association (LISA). Epidemiological data were obtained from the Jakarta Provincial Health Office, aggregating case reports exclusively from hospitals across the province. The analysis involved calculating incidence rates and applying spatial clustering techniques to detect localized transmission hotspots. Results indicate a total of 6,951 cases, revealing a cyclical three-year outbreak pattern with significant peaks in 2017, 2023, and an unprecedented surge in 2025 totaling 4,616 cases. Spatial analysis identified persistent high-risk transmission hotspots in North Jakarta, specifically Koja and Cilincing, alongside a newly emerging hotspot in Kalideres, West Jakarta. Furthermore, children under five years old experienced the highest incidence rates, particularly within these specific hotspot districts. The conclusion emphasizes that prioritizing localized interventions and targeted vaccination strategies in these defined geographic clusters and vulnerable age demographics is essential to control transmission and mitigate future outbreaks.

**Keywords:** Measles; Spatial Analysis; Local Indicators of Spatial Association; Temporal Dynamics; DKI Jakarta

## 1. Introduction

Measles is a highly contagious vaccine-preventable disease that remains a significant public health threat, particularly in densely populated urban settings where herd immunity thresholds are difficult to sustain [1]. Despite global elimination goals, recent years have witnessed a resurgence of measles outbreaks worldwide [2]. In Indonesia, the capital province of DKI Jakarta represents a critical sentinel site for monitoring these transmission dynamics [3].

The primary objective of the Jakarta Health Office (Dinas Kesehatan DKI Jakarta) surveillance system is to detect epidemiological shifts rapidly and guide targeted public health responses. However, a critical analytical gap exists in the current utilization of surveillance records; while the official platform effectively provides raw descriptive data categorized by age groups, gender, and administrative locations, the system lacks advanced spatial and long-term temporal analysis capabilities [4]. To optimize public health responses and bridge the analytical gap, this report analyzes surveillance data stratified at the sub-district (kecamatan) level. Given the administrative complexity of Jakarta, this level



of analysis offers an effective balance between granularity and abstraction, allowing for the identification of transmission clusters without the noise often associated with hyper-local data.

This research evaluates the spatial and temporal dynamics of measles in DKI Jakarta over a ten-year period, from January 2016 to December 2025. Specifically, the study aims to characterize the cyclical nature of outbreak waves, including the unprecedented surge observed in 2025, and to identify geographic hotspots where intense transmission is concentrated across neighboring districts which are statistically validated using Local Indicators of Spatial Association (LISA) [5]. By differentiating between transient outbreaks and persistent endemic reservoirs, this analysis provides a spatial evidence base to support decision-making and prioritize public health resources for the most vulnerable areas.

## 2. Theoretical Framework

Measles is a highly contagious disease where maintaining high herd immunity is crucial, especially in densely populated urban environments [1]. Sustaining these immunity thresholds is often difficult, which can lead to the resurgence of transmission and the formation of cyclical outbreak waves [2].

To monitor these transmission dynamics, public health responses rely heavily on passive surveillance systems [4]. The surveillance process aggregates daily case reports from a network of local healthcare facilities, primarily hospitals, to provide a rapid assessment of the regional public health situation [4]. Analyzing these epidemiological data at an appropriate administrative scale, such as the sub-district level, balances spatial granularity with data stability, mitigating the noise inherent in hyper-local records [4].

Furthermore, statistical spatial analysis is required to validate geographic areas of intense transmission [5]. Local Indicators of Spatial Association identifies where high disease rates group together geographically [5]. Within this spatial calculation, a "High-High" hotspot indicates a location with a high infection rate surrounded by neighboring areas that also experience high rates, marking a significant transmission cluster [5]. Additionally, the methodology identifies spatial outliers, including "High-Low" areas representing high rates near low rates, and "Low-High" areas representing low rates near high rates [5].

## 3. Methods

### 3.1 Data Acquisition and Preprocessing

This study utilizes a retrospective descriptive and spatial analysis design. Because the research analyzes aggregated, anonymized, and publicly accessible secondary epidemiological data, the study is exempt from institutional ethical review. The primary epidemiological data, spanning from January 2016 to December 2025, were obtained from the passive surveillance system of the Jakarta Provincial Health Office [4]. The raw dataset aggregated daily patient statuses, categorizing individuals as currently treated, recovered, or deceased. To reconstruct a continuous daily time series, missing dates within the ten-year observational period were padded and filled with zero values to prevent temporal gaps in the analysis.

Because the raw records did not explicitly state daily new infections, the incidence of new cases at a specific time was derived mathematically using a daily balancing equation. The calculation estimated new cases by subtracting the sum of daily recoveries and deaths from the difference in currently treated patients between the current day and the previous day. The equation is defined as follows:

$$NC_t = CT_t - (CT_{t-1} - R_t - D_t) \quad (1)$$

where  $NC$  represents new cases,  $CT$  represents currently treated patients,  $R$  represents recovered patients,  $D$  represents deceased patients, and  $t$  represents the specific day.

In instances where the calculation yielded a negative value, indicating a discrepancy likely caused by under-reported patient outcomes or administrative delays, the value of new cases was adjusted to zero. Furthermore, the dataset was categorized into six specific age groups to evaluate demographic vulnerabilities: under 5 years, 5 to 9 years, 10 to 14 years, 15 to 19 years, 20 to 44 years, and 45 years and older.

To support the spatial and incidence rate calculations, sub-district (kecamatan) administrative boundaries were acquired from the Geospatial Information Agency [6]. A critical harmonization process

was conducted to standardize sub-district nomenclature between the health surveillance records and the geospatial shapefiles, resolving discrepancies such as spacing and typographical variations. Additionally, annual population data at the sub-district level (2016–2025) were compiled and integrated into the dataset using official publication series from Statistics Indonesia (Badan Pusat Statistik) for DKI Jakarta [7]. Missing historical population data were imputed using adjacent yearly values, and the population for the year 2025 was projected based on the available 2024 demographic figures

### 3.2 Spatial and Statistical Analysis

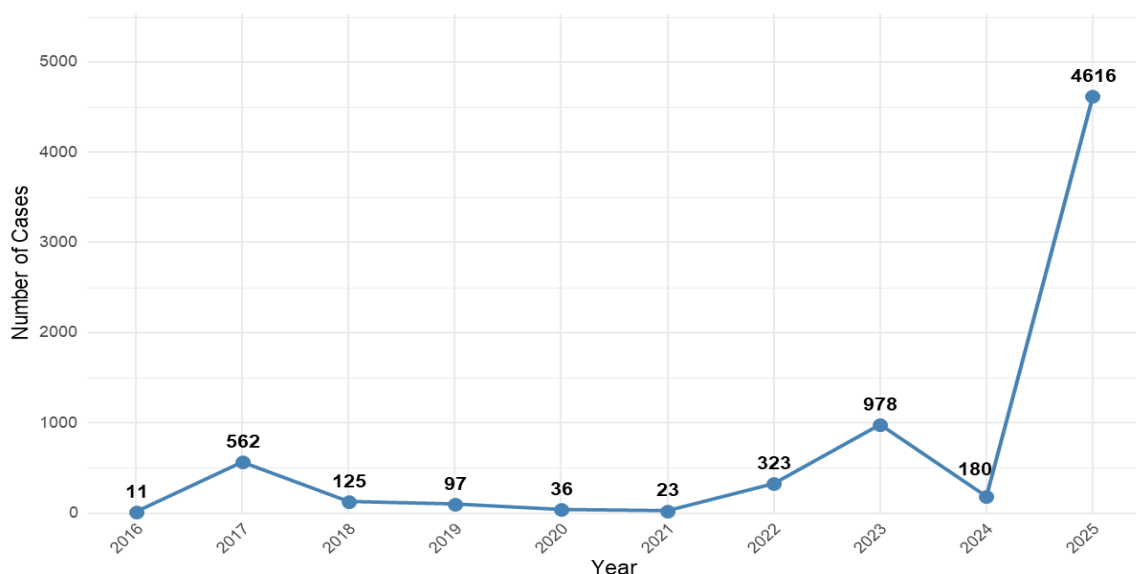
To evaluate the geographical distribution of measles, spatial autocorrelation was measured using the Global Moran's I statistic to determine if the incidence rates clustered across the province. The spatial relationships between sub-districts were defined using a Queen contiguity spatial weights matrix, meaning districts sharing any boundary or vertex were considered neighbors. Queen contiguity was selected to capture all possible directions of disease transmission across adjacent administrative borders, a crucial factor when analyzing highly contagious airborne viruses. Following the global assessment, Local Indicators of Spatial Association were applied to identify specific localized clusters and spatial outliers [5].

Within the spatial computation, the incidence rates were standardized. A High-High hotspot is defined as a district with an above-average incidence rate surrounded by neighbors also exhibiting above-average incidence rates, indicating a statistically significant transmission center [5]. Spatial outliers include High-Low and Low-High areas, while areas lacking statistical clustering are categorized as not significant. The statistical significance of the identified spatial clusters was evaluated and categorized at multiple alpha levels, specifically  $p < 0.05$ ,  $p < 0.01$ , and  $p < 0.001$ .

Furthermore, to differentiate between transient outbreaks and persistent endemic zones, a temporal hotspot frequency analysis was conducted. The procedure involved calculating the annual incidence rate for each individual year from 2016 to 2025, utilizing the specific population data corresponding to each respective year to ensure accuracy. The spatial clustering method was then applied iteratively to each annual dataset. The iterative process allowed for the tracking and counting of High-High cluster recurrence in the exact same geographic areas over the ten-year observational period.

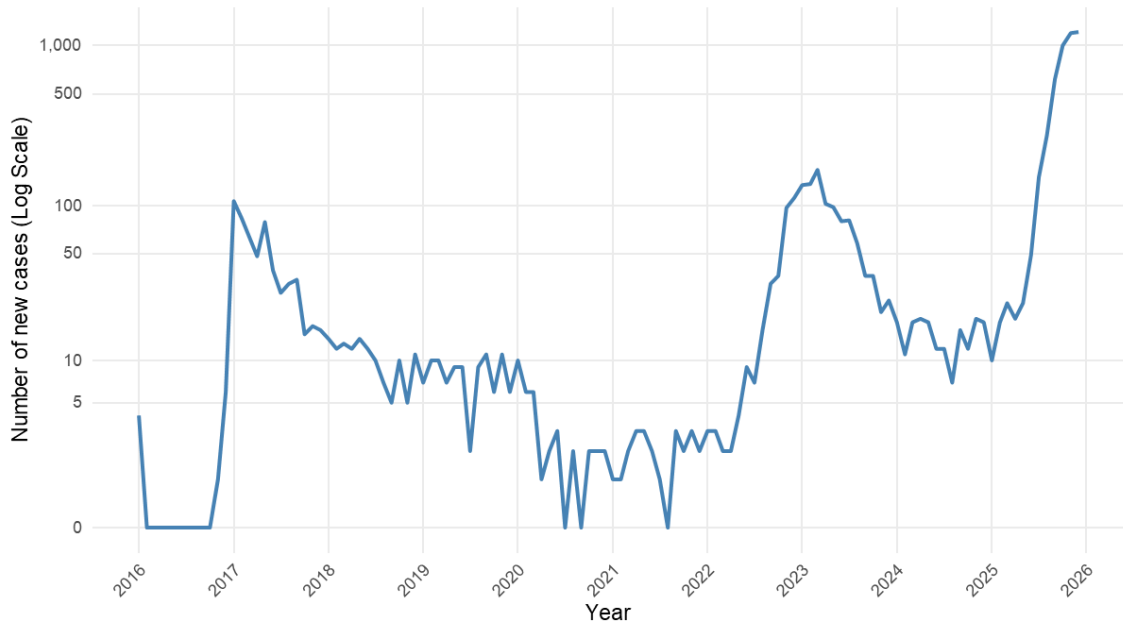
## 4. Results and Discussion

### 4.1 Temporal Trends of Measles Cases



**Figure 1.** Total Measles Cases per Year in Jakarta from 2016 to 2025

Moving to the annual timeline, the chart presents yearly measles cases in Jakarta from 2016 to 2025. The data shows extreme volatility over the decade. An initial surge occurred in 2017 with 562 cases. Following the 2017 peak, case numbers dropped steadily, reaching a low of only 23 cases in 2021, followed by a significant increase to 978 cases in 2023 and a temporary decrease in 2024. In the year 2025, an unprecedented explosion happened, logging 4,616 confirmed cases.

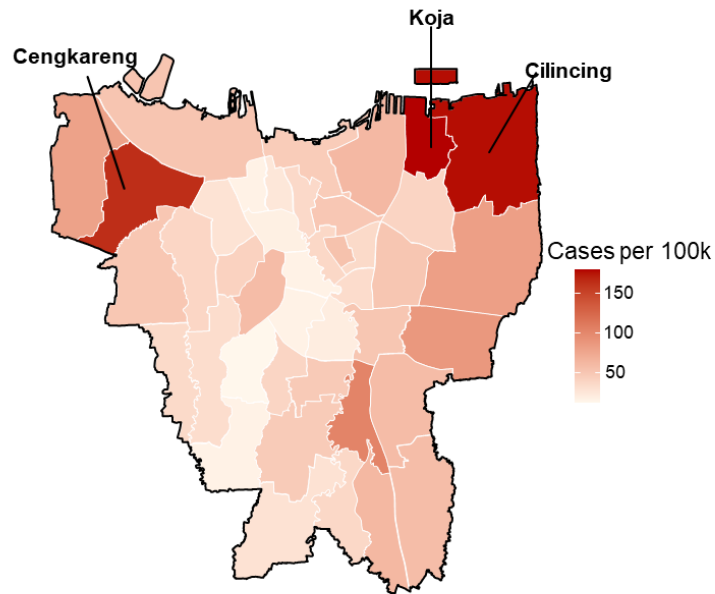


**Figure 2.** Total Measles Cases per Month in Jakarta from 2016 to 2025

Shifting focus to the monthly timeline, the chart now displays how many cases were registered each month across the ten-year period. The rate continued increasing towards the end of 2025, possibly continuing at least until the beginning of 2026. Observing this acceleration along with the peaks in 2017 and 2023 reveals the possibility of a cycle occurring around every three years for measles outbreaks, denoted by the lines on the chart. However, a noticeable gap exists in 2020, where a peak is missing. One possible reason for the absence of a 2020 surge is strict COVID-19 pandemic protocols, such as social distancing and school closures, which temporarily suppressed normal transmission patterns.

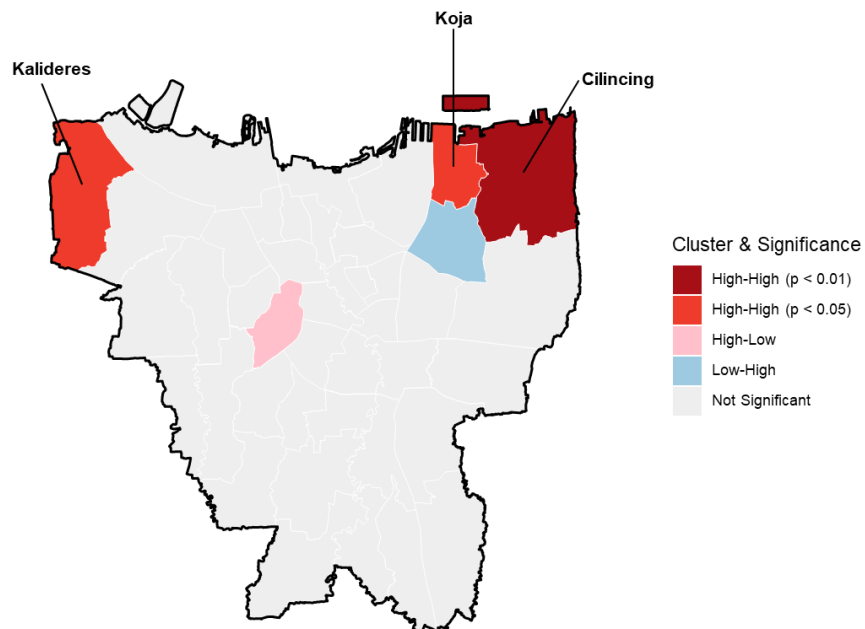
The unprecedented surge observed in Jakarta during 2025 aligns with broader epidemiological warnings. The World Health Organization documented a worldwide resurgence of measles fueled by declining immunization coverage, a trend clearly reflected in the severe local outbreak [2]. Furthermore, the localized peak recorded in 2023 mirrors the national upward trajectory documented in the 2023 Indonesian Health Profile, confirming that transmission dynamics in the capital city serve as a highly sensitive indicator for wider national public health shifts [3].

#### 4.2 Spatial Distribution and Hotspot Analysis



**Figure 3.** Cumulative Incidence Rate of Measles in DKI Jakarta (2016 - 2025) Normalized by Average Population.

The cumulative incidence rate across the ten-year period highlights the districts with the highest long-term disease burden. Koja and Cilincing in North Jakarta, along with Cengkareng in West Jakarta, recorded the highest cumulative rates.

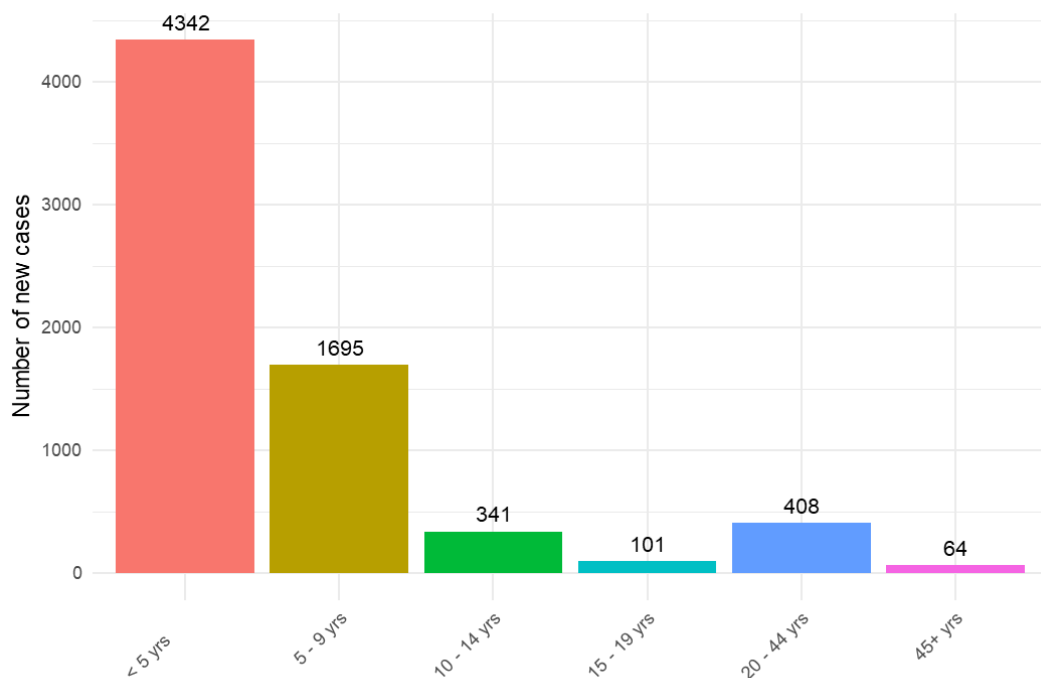


**Figure 4.** LISA Cluster Map of Measles Incidence Rate in DKI Jakarta (2016 - 2025). Based on Incidence Rate per 100,000 Population. High-High (Red) Indicates District with High Risk Surrounded by High-Risk Areas.

Meanwhile, the LISA map includes the data of neighboring districts in the calculation, allowing for the identification of spatial hotspots . A "High-High" hotspot indicates a district with a very high incidence rate surrounded by neighbors also experiencing high incidence rates . Significant High-High hotspots are located in Cilincing, Koja, and Kalideres. Although Cengkareng recorded the highest number of cases in 2025, the district is not a significant hotspot . This occurs because the areas next to Cengkareng do not have rates high enough to form a significant group . In contrast, Kalideres is a hotspot because both Kalideres and its neighboring districts show high transmission levels at the same time.

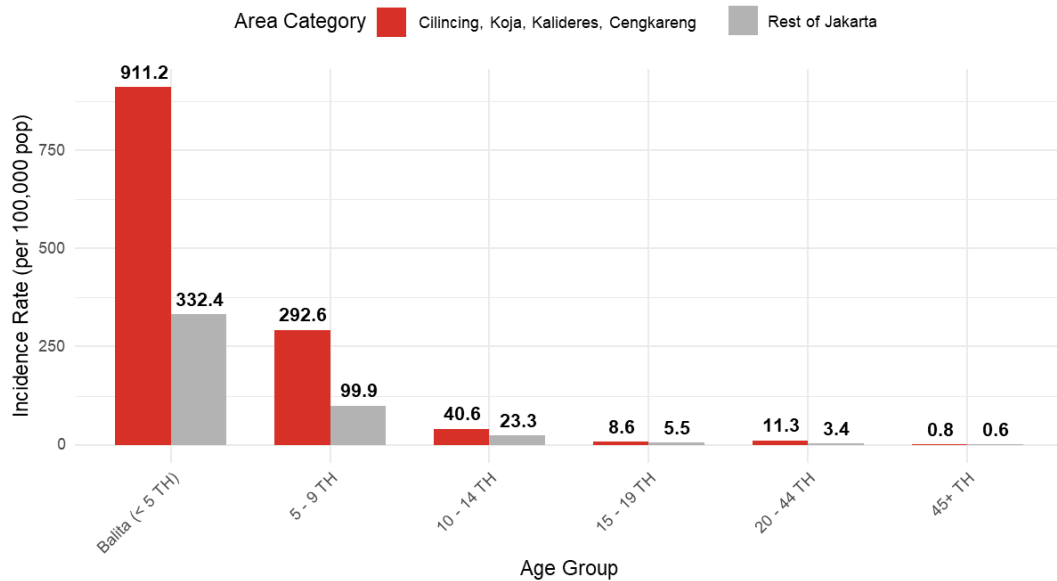
The identification of persistent localized hotspots in densely populated districts such as Cilincing, Koja, and Kalideres is consistent with previous spatial studies conducted in comparable developing environments. For example, spatial analysis utilizing Moran's I and LISA in the neighboring Serang Regency, Indonesia, demonstrated significant spatial autocorrelation, revealing clustered districts with dangerous gaps in complete immunization coverage [8]. The findings in Jakarta validate the theory that targeting specific geographic clusters is essential, as province-wide coverage averages often mask highly localized pockets of susceptibility. This dynamic is corroborated by spatial studies in other densely populated countries, such as India, where LISA mapping revealed extreme spatial heterogeneity and clustering in child vaccination dropouts across district borders [9]. Similarly, recent hotspot analysis in Ethiopia highlighted that the geographic clustering of measles risk is a recurrent feature in areas facing intense urban and socio-economic disparities [10]. Therefore, prioritizing intensive immunization campaigns in the specific High-High clusters identified in Jakarta is scientifically justified and aligns with established global spatial epidemiological evidence.

### 4.3 Age Distribution and Risk Comparison



**Figure 5.** Number of Measles Cases by Age Group in DKI Jakarta (2016 - 2025).

Children under five years dominate the total measles burden. Children under five years recorded 4,342 cases, representing the largest portion of the total count. Children aged 5 to 9 years follow with 1,695 cases. Transmission levels are significantly lower in older age groups.



**Figure 6.** Incidence Rate of Measles by Age Group in DKI Jakarta (2025). Number of Cases per 100,000 Population.

Looking at the chart comparing the specific incidence rates, the risk difference is massive. In normal areas, the incidence rate is 332.4 cases per 100,000 children under five years old. However, inside the four priority districts (Cilincing, Koja, Kalideres, and Cengkareng), the rate jumps to 911.2 cases per 100,000 children in that same age group, a rate around 3 times higher than for children living in normal areas. A similar pattern of elevated risk repeats across the older age groups. For children aged 5 to 9 years, the priority districts recorded 292.6 cases per 100,000 children, compared to 99.9 cases in other areas.

## 5. Conclusion

This study evaluated the spatial and temporal dynamics of measles cases in DKI Jakarta from 2016 to 2025. The findings reveal a highly volatile transmission landscape characterized by a recurring cyclical outbreak pattern, which culminated in an unprecedented surge in 2025. Spatial analysis successfully identified distinct and persistent transmission hotspots, specifically concentrated in the northern and western districts such as Cilincing, Koja, and Kalideres. Furthermore, demographic vulnerability is acutely concentrated among children under five years of age residing within these high-risk geographic clusters. To effectively mitigate future outbreaks and sustain herd immunity, public health interventions must transition from generalized province-wide strategies to highly targeted, localized approaches. Prioritizing intensive immunization campaigns and proactive surveillance specifically within these identified endemic reservoirs and focusing on early childhood demographics will be essential for controlling measles transmission in densely populated urban environments.

## Acknowledgements

The authors deeply appreciate the frontline healthcare workers and the surveillance staff at the Jakarta Provincial Health Office for their unwavering dedication to patient care, data collection, and epidemiological reporting. The ongoing support from the Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, is also gratefully acknowledged.

**REFERENCE**

- [1] World Health Organization, "Measles and rubella strategic framework: 2021 to 2030," World Health Organization, Geneva, 2020.
- [2] World Health Organization, "Provisional monthly measles and rubella data," 2025. [Online]. Available: <https://www.who.int/teams/immunization-vaccines-and-biologicals/immunization-analysis-and-insights/surveillance/monitoring/provisional-monthly-measles-and-rubella-data>. [Accessed 15 December 2025].
- [3] Kementerian Kesehatan Republik Indonesia, "Profil Kesehatan Indonesia 2023," Kementerian Kesehatan RI, Jakarta, 2024.
- [4] Dinas Kesehatan Provinsi DKI Jakarta, "Surveilans Kesehatan DKI Jakarta," 2023. [Online]. Available: <https://surveilans-dinkes.jakarta.go.id/>. [Accessed 5 January 2026].
- [5] L. Anselin, "Local Indicators of Spatial Association LISA," *Geographical Analysis*, vol. 27, no. 2, p. 93 to 115, 1995.
- [6] Badan Informasi Geospasial, "Ina-Geoportal," 2026. [Online]. Available: <https://tanahair.indonesia.go.id>. [Accessed 12 January 2026].
- [7] Badan Pusat Statistik Provinsi DKI Jakarta, "Badan Pusat Statistik Provinsi DKI Jakarta," 2023. [Online]. Available: <https://jakarta.bps.go.id/>. [Accessed 20 December 2025].
- [8] L. Fitri and M. R. Makful, "Spatial Analysis of Immunization Coverage in Serang Regency, Indonesia in 2021," *Faletehan Health Journal*, vol. 11, no. 3, pp. 302-309, 2024.
- [9] J. Khan, A. Shil and R. Prakash, "Exploring the spatial heterogeneity in different doses of vaccination coverage in India," *PLOS ONE*, vol. 13, no. 11, p. e0207209, 2018.
- [10] A. F. Zegeye, E. G. Mekonen, B. Tekeba, T. G. Alemu, M. S. Ali, A. T. Gonete, A. T. Kassie, B. S. Workneh, T. T. Tamir and M. Wassie, "Spatial distribution and determinants of measles vaccination dropout among under-five children in Ethiopia: A spatial and multilevel analysis of 2019 Ethiopian demographic and health survey," *PLOS ONE*, vol. 19, no. 7, p. e0305393, 2024.