Geospatial Health 2025; volume 20:1372

Typhoid fever in Jakarta, Indonesia 2017-2023: spatial clustering and seasonality of hospitalization data to inform better intervention

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Key words: typhoid fever, clustering, surveillance, rainfall, seasonality, Indonesia.

Ethical considerations: this study analyzed publicly available, aggregated notification data managed by the Government of Jakarta, therefore, ethical approval is not required. The use of anonymized hospital data was permitted by the Provincial Health Office of Jakarta.

Contributions: MM, PWD, study conceptualization; MM, PWD, statistical methodology; MM, PWD, EPA, formal analysis; MM, BR, AY, EPA, project administration; MM, MAN, WR, DL, Data curation and validation; PWD, funding; MM, writing (original draft); all authors, writing (review and editing).

Conflict of interest: the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding: this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability: all general data generated or analysed during the study are available publicly at https://surveilans-dinkes.jakarta.go.id/

Acknowledgments: the authors thanked to the Jakarta Provincial Government for providing the data.

Received: 5 January 2025.
Accepted: 4 April 2025.

Geospatial Health 2025; 20:1372
doi:10.4081/gh.2025.1372

Abstract

Typhoid fever is one of the common enteric fevers in developing countries, especially in emerging metropolitan areas in Indonesia. Yet, studies on spatial and temporal distribution of tyhoid fever are lacking. This study was conducted to analyze retrospective hospital-based data at the village level over the period 2017-2023 to understand the spatial and temporal variation of typhoid fever in Jakarta. Spatial analyses were performed by Moran's *I* and Local Indicators of Spatial Association (LISA) to examine spatial clustering of typhoid incidence and to identify high-risk villages for typhoid fever, respectively. Seasonal decomposition analysis was performed to investigate the seasonality of this infection. A total of 57,468 typhoid cases, resulting in a cumulative incidence of 533.99 per 100,000 people, were reported during the study period. The incidence was significantly clustered (I=0.548; p=0.001) at the village level across Jakarta. Statistically significant high-risk clusters were detected in the South and East of Jakarta that were heterogeneous over time. We identified seven persistent high-risk clusters in the eastern part of the city and two in the southern part. Moreover, the typhoid incidence showed a strong seasonality trend, significantly associated with monthly total rainfall (p=0.018). The study revealed a significant spatial variation with strong seasonality in typhoid incidence across the city suggesting a variation in transmission intensity and needs for effective public health interventions, especially in the high-risk areas. Improvement in water and sanitation facilities, hygiene awareness and surveillance are essential to help reduce typhoid transmission in Jakarta.

Introduction

Typhoid fever is a serious and life-threatening enteric infection caused by *Salmonella typhi*, a Gram-negative bacterium of serotype *typhi*. Globally, it is estimated that only in 2017, typhoid fever caused 10.9 million (95% confidence interval (CI) 9.3–12.6 million) cases and 116,800 (95% CI 65,400–187,700) fatalities, with the highest burden mostly in developing countries (GBD 2017 Typhoid and Paratyphoid Collaborators, 2019; WHO, 2024). Typhoid fever is more prevalent among children and young people (Ochiai *et al.*, 2008; Akullian *et al.*, 2015; GBD 2017 Typhoid and Paratyphoid Collaborators, 2019). The infection is transmitted from person to person through unsafe food and water and poor personal hygiene habits due to lack of clean water and sanitation facilities (Alba *et al.*, 2016; Brockett *et al.*, 2020). Antimicrobial resistance (AMR) is a growing concern, with over 60% of strains currently resistant to the four most used antibiotics (Chiou *et al.*, 2014; Carey *et al.*, 2023; Chandrasekaran & Balakrishnan, 2011).

Since 2008, WHO recommends the use of the Typhoid Conjugate Vaccine (TCV). A reiterated position paper emphasizing the use of TCV for high-risk population in countries with high prevalence of typhoid disease or antimicrobial-resistant *S. typhi* was issued in 2018. This paper also recommends other public health interventions, such as awareness campaigns, improvement in sanitation infrastructures, strengthening case ascertainment and treatment (WHO, 2019). However, so far TCV has only been introduced nationally into the routine immunisation schedule in 5 countries (Hancuh *et al*., 2023).

Typhoid fever remains a common, endemic disease in Indonesia that has shown a significant increase in incidence each year, with currently 500 cases per 100,000 population and a mortality rate ranging from 0.6 to 5% (Nelwan *et al.*, 2023). In Indonesia, GBD 2017 Typhoid and Paratyphoid Collaborators (2019) estimated that approximately 489,762 (95% CI: 277,552-794,178) Disability-Adjusted Life Years (DALYs) were lost due to typhoid and paratyphoid in 2017. Several local population-based studies have been conducted in Indonesia, aiming at understanding transmission and risk factors of typhoid fever (Velema *et al.*, 1997; Gasem et al., 2001; Vollaard et al., 2004; Alba et al., 2016). Better access to water and sanitation leading to improved hygiene behaviour are known to reduce the risk of typhoid infection (Gasem *et al.*, 2001; Alba *et al.*, 2016). The true prevalence of typhoid fever in Indonesian communities remains unclear but estimate are likely to be lower than the actual burden due to underreporting and diagnostic challenges. Clinical misdiagnosis of typhoid fever is often experienced in areas where dengue and malaria are particularly endemic, as it closely mimics other febrile illnesses (Crump, 2010).

Globally, the use of geospatial techniques infectious diseases, and for public health in general, has been growing rapidly in the past decades (Fletcher-Lartey & Caprarelli, 2016; Widawati *et al.*, 2023). Understanding distribution of the disease, both spatially and temporally, could help policymakers to identify and prioritize areas and populations that are most at risk, in which prevention and control efforts including vaccination should be put in place. The use of Geographic Information Systems (GIS) and spatial statistics for understanding typhoid epidemiology have also been reported in many locations (Dewan *et al.*, 2013; Mohan *et al.*, 2021; Ren *et al.*, 2023; Ahmmed *et al.*, 2024). Yet, there is so far any study on investigating the spatial and temporal patterns of typhoid at a finer scale in Indonesia. The aim of the current study was to explore the geographical and temporal variation of typhoid fever and to identify areas at higher risk in Jakarta.

Materials and Methods

Study area and population

A descriptive ecological observational study was performed in Jakarta, Indonesia (6.208°S, 106.846°E). It has an area of 623.33 km^2 and had a population of about 10 million people in 2020. Administratively, Jakarta has six districts, 44 sub-districts and 267 villages. One district (Kepulauan Seribu), comprising 105 small islands off the coast in the Java Sea and includes 6 villages with a total population of 21,000 people, was not part of the study. The population density ranges from 2,423 to 18,761 people per km^2 (Jakarta Provincial Bureau of Statistics, 2023).

Data collection

The study was restricted to all confirmed hospitalized typhoid cases that were notified during the period 1 January 2017, to 31 December 2023. We retrieved these typhoid data in May 2024 from the routine public surveillance database managed by the Provincial Health Office of Jakarta (2024). Apart from the diagnosis, the hospital admission data contained information includes age, gender, date of admission and residential address. The database consisted of up to 36 diseases reported by 200 hospitals and 333 primary health care across Jakarta, including respiratory infections, vaccine-preventable diseases, diarrhoeal diseases, mosquito-borne and zoonotic diseases. This information was anonymized and aggregated at the population level. A typhoid case was defined as any individual who presented with typhoid fever clinical signs such as fever (≥38°C) lasting for at least three days, abdominal pain, nausea, diarrhoea, constipation, intestinal or abdominal discomfort including extended abdomen, and diagnosed with a blood-culture confirming *S. typhi* infection or positive by the Widal test or Tubex (WHO, 2003). As denominator for incidence rate calculation, an annual village-level population data for the same period was obtained from a report issued by the Jakarta Provincial Bureau of Statistics (2024). Daily rainfall data from January 2017 to December 2023 in Jakarta were obtained from the Meteorological, Climatological and Geophysical Agency, Indonesia (https://dataonline.bmkg. go.id/home). Total monthly rainfall data were calculated by merging daily values.

Mapping incidence and potential clustering

To perform spatial analysis of typhoid incidence across Jakarta, we georeferenced the patient data by residential address and used the village (*kelurahan*) as the spatial unit of the analysis. Only villages in mainland Jakarta (n=261 out of 267) were included in the study. All typhoid cases in each village were linked to village-level shapefiles or polygons. A village-level administrative shapefile map for Jakarta was obtained from the Statistics Service Information System, Central Bureau of Statistics of Indonesia (2024). This shapefile encompassed polygons outlining the village boundaries of the province, from which we derived the centroids of each village. The incidence per 10,000 population was calculated. To map the cumulative incidence, natural breaks method was applied to improve class differentiation by minimizing the variance within classes and maximizing it between them. A classification of 5 classes: <10, 10-20, 20-30, 30-40, and >40 per 10,000 population was applied for annual crude incidence of tyhoid to easily observe changes of incidence at the village level over the study period. Pearson's correlation test was for examination of the association between population density and typhoid cases.

An annual Moran's *I* statistics was performed to assess the general spatial clustering of the incidence of typhoid fever (*i.e.*, observed cases per 10,000 population) at the village-level across Jakarta for the period of 2017–2023. A spatial weight matrix was constructed based on Queen spatial contiguity. The Moran's *I* coefficient ranges from − 1 to 1, where positive value indicates positive spatial autocorrelation, negative value the opposite, while values near zero mean that the data are randomly distributed (Moran, 1950). We performed a pseudo-significance test with 999 permutations (p<0.05) that allowed us to reject the null hypothesis of spatial randomness in the data. The Moran *I* is calculated using the following equation (Anselin, 2020):

$$I = \left(\frac{n}{S_0}\right)\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\, z_i z_j}{\sum_{i=1}^{n} z_i^2} \qquad \text{Eq. 1}$$

where z_i is the deviation of an attribute for area *i* from its mean (x_i – X); $W_{i,j}$ the spatial weight between areas *i* and *j*; *n* the total number of villages; and *So* the aggregate of all spatial weights.

We then conducted Local Indicator of Spatial Association (LISA), to identify local, specific, significant clusters. The spatial patterns in the LISA cluster map were divided into five categories: High–High (HH), Low–Low (LL), Low–High (LH), High–Low (HL), and Not Significant (NS) where HH indicates positive clusters or hotspots and LL negative or coldspots, with LH and LH showing outliers indicating a spatial association of dissimilar values, with the former defined as areas with low values surrounded by areas with high areas and the latter high values surrounded by lower ones implying a spatial heterogeneity (Anselin, 1995). Using estimates of observed vs. expected incidence from the LISA analysis, each village could be defined as a hotspot, coldspot or outlier. A Z-score is generated by the LISA analysis to determine the level of clusters significance. Surroundings with spatial clusters are indicated by high positive Z-scores, while the presence of spatial outliers by low Z-scores. A pseudo *p*-value was calculated using 999 permutations, a value corresponding to the summary of the results from the null reference distribution that the assumed notifications were randomly distributed across the study area (Anselin, 2020). All spatial analyses were performed by using GeoDA v.1.22.0.49 software (Anselin *et al.*, 2006), whereas the maps were produced by QGIS version 3.2.0.

Temporal distribution, seasonality and its correlation with rainfall

The monthly incidence of cases of typhoid fever was summarized. The distribution of typhoid incidence was plotted by month. Seasonal decomposition analysis was conducted to explore the presence of seasonality of typhoid fever during the period 2017-2023. Seasonal trend decomposition was used to extract smooth estimates.

$$Y_t = T_t + S_t + R_t \qquad \text{Eq. 2}$$

where *T* indicates the trend: *S* the seasonality; and *R* the residuals the model errors from the observed time series line *Y* over time *t* (Cleveland *et al.*, 1990). The association between monthly rainfall and monthly typhoid incidence was tested by Pearson's correlation test. All statistical analyses were performed by using SPSS 21.0 (IBM Corp., New York, NY, USA).

Results

A total of 57,468 cases of typhoid fever were reported during the study period (Table 1). The cumulative incidence of typhoid fever was estimated to be 533.99 per 100,000 population. The number of hospitalized typhoid cases was dominated by patients 20–44 year-olds (n=22,632; 39.4%), followed by children <5 years (n=8764; 15.3%). The large proportion of cases was contracted by females (n=34,172; 57.7%). The cumulative incidence of hospitalized typhoid fever was geographically varied at the village level across Jakarta (Figure 1), with the high-incidence villages spread in south Jakarta ranging from 110-286.3 per 10,000 population.

Figure 2 shows the trend of typhoid incidence (per 100,000 population) in Jakarta during 2017-2023. The incidence was relatively fluctuated during the study period, with the highest monthly incidence observed in March 2019 (18.67/100,000 population). The incidence was significantly decreased during 2020-2021, followed by a resurgence in the incidence in the mid of 2021 to 2023.

Spatial and temporal of typhoid incidence

Our results indicate a dynamic change in pattern of incidence of hospitalized typhoid fever at the village level during the period of 2017-2013 (Figure 3). High-incidence villages were clearly observed in East and South Jakarta from 2017-2019, but there was a significant change in pattern in 2020-2021, in which the rates of typhoid declined substantially in 92-99% of the villages across Jakarta. In 2022-2023, the incidence increased slightly in some villages in the South.

Table 1. Characteristics of hospitalized typhoid cases in Jakarta, Indonesia 2017-2023

	Frequency	%
Age group (years)		
<5	8,764	15.3
5-9	7,685	13.4
10-14	4,710	8.2
15-19	4,798	8.3
20-44	22,632	39.4
45-54	4,618	8.0
55-64	2,841	4.9
>65	1,420	2.5
Sex		
Male	25,012	42.3
Female	34,172	57.7
Total	57,468	100

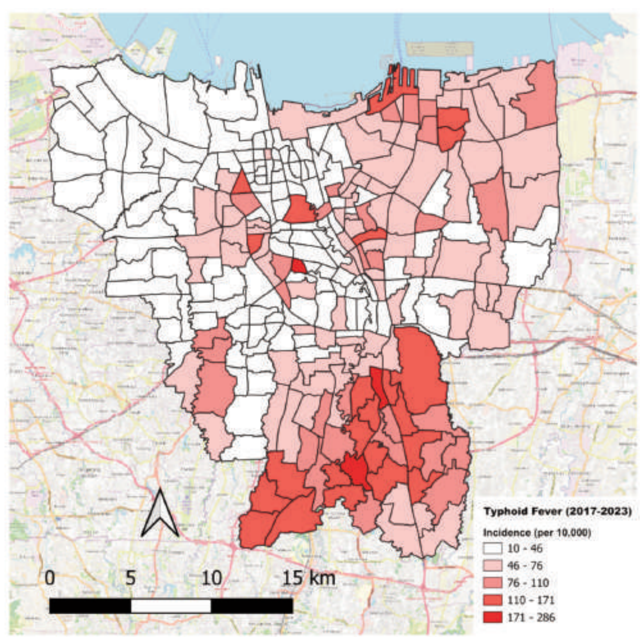

Figure 1. Cumulative incidence per 10,000 people of typhoid at the village level in Jakarta, Indonesia 2017-2023.

Spatial clustering and hotspots of typhoid fever

As indicated by Moran's *I* statistic, the cumulative incidence of typhoid fever was significantly spatially clustered (I=0.548; p =0.001). Annual Moran's *I* coefficients significantly fluctuated over time, ranging from 0.299 (p<0.001) in 2021 to 0.582 (p<0.001) in 2017. Pearson correlation test showed a moderate positive correlation between variation in population and typoid cases at village level (r= 0.566, p = 0.001).

The HH clusters shifted dynamically over time across Jakarta but were mostly seen in South and East Jakarta (Figure 4). A high number of HH clusters were observed in 2018 (n=40) and 2019 (n=38) with 17,171 and 17,084 people at risk, respectively. The number of HH villages declined in 2021 (n=20) but rebounded in 2023 (n=31). In contrast, the number of LL clusters dropped over time (Table 2). Further, our analysis revealed a total of 37 statistically significant HH clusters in 10 sub-districts (*kecamatan*) in three regions in Jakarta during the study period, with the estimated a total of 1,492,957 people at risk (Table 3). Additionally, we identified seven persistent HH clusters in eastern Jakarta (Ciracas, Susukan, Baru, Cijantung, Gedong, Kalisari) and two in the southern part of the city (Tanjung Barat) during 2017-2023 (Table 3).

Temporal pattern of typhoid fever and its correlation with rainfall

The plot graph shows the monthly variability in the number of typhoid cases (Figure 5); the highest number of cases was observed in the first quarter of the year (January-March). Figure 6 further illustrates the results of seasonal decomposition analysis that indicated a strong seasonality pattern. The typhoid incidence peaked every March and dropped in July. The monthly typhoid incidence was significantly positively correlated with the monthly total rainfall (r = 0.258, p-value = 0.018) (Figure 7).

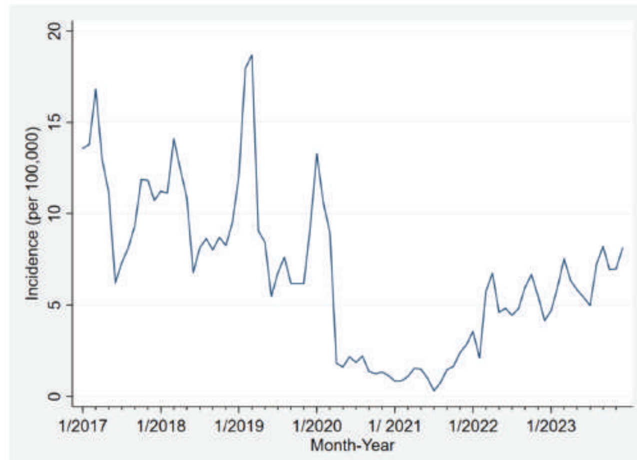

Figure 2. Annual incidence of typhoid per 100,000 population in Jakarta, Indonesia 2017-2023.

Table 2. Summary statistics of typhoid clusters in Jakarta, Indonesia 2017-2023.

Year	Cluster (type)	Population at risk	Rate*	Village (no.)	Case (no.)
2017	HH	1,037,312	1186.82	28	12,311
	LL	2,252,252	275.99	65	6,216
	LH	112,255	618.24	2	694
	HL	30,513	763.61	3	233
2018	HH	1,588,634	1.080.87	40	17,171
	LL	2,187,938	275.51	60	6,028
	LH	104,316	485.06	3	506
	HL	6,094	984.57	2	60
2019	HH	1,633,303	1.045.98	38	17,084
	LL	1,932,331	274.54	48	5,305
	LH	21,854	215.06	2	47
	HL	28,005	449.92	2	126
2020	HH	1,068,762	1.208.50	28	12,916
	LL	1,769,214	281.09	51	4,973
	LH	127,111	525.52	3	668
	HL	45,769	491.60	2	225
2021	HH	967,842	1.061.33	20	10,272
	LL	1,200,160	292.96	31	3,516
	LH	176,844	846.51	4	1,497
	HL	48,220	414.77	4	200
2022	HH	1,217,604	1.108.90	27	13,502
	LL	1,874,072	346.89	49	6,501
	LH	79,719	521.83	3	416
	HL	84,239	537.76	4	453
2023	HH	1,337,738	1.077.27	31	14,411
	LL	1,507,726	364.59	42	5,497
	LH	168,302	683.30	3	1,150
	HL	4,742	358.50	1	17

*per 100,000 population.

Discussion

Jakarta. one of the big cities in Indonesia, is facing several endemic public health problems including typhoid fever. Previous epidemiological study in Jakarta has reported that typhoid and paratyphoid fever are associated with distinct routes of transmission; the transmission occurred mainly within the household (typhoid) and outside the household (paratyphoid) related to flooding and unhygienic consumption of street foods (Vollaard *et al.*, 2004). Our study extends previous research in that we were able to investigate spatial and temporal variability in the incidence of typhoid fever at the village level in Jakarta, Indonesia. In the present study, we revealed a spatially heterogeneous distribution of typhoid incidence and persistent high-risk villages across Jakarta during the seven years of the study (2017-2023). Variation in the population positively correlated with the spatial distribution of typhoid cases. Our study also demonstrated strong seasonal spikes over the study period, which can be explained by the role of climate, such as rainfall, on the occurrence of typhoid outbreak in the city. In this study, we observed that the case distribution was relatively higher among group aged 20-44 years-old, under-5 year children, and among the females. This finding is consistent with studies elsewhere (Masinaei, Eshrati, and Yaseri, 2020). A high number of typhoid cases among these young adults might be caused by *S. paratyphi*, as reported elsewhere (Karkey *et al.*, 2010). The second largest proportion of typhoid cases observed among children under five years-old and school-aged children. Most studies have shown age as one of the important factors associated with the risk of typhoid fever (Crump & Mintz, 2010). Our findings complement previous findings that typhoid fever is commonly found in children, suggesting the importance of vaccination program towards these vulnerable populations.

In the present study, we observed a heterogeneous pattern in incidence of typhoid fever across the city during the study period. The variation in typhoid incidence over space across the city might have been driven by several factors. First, overcrowding can facilitate the spread of typhoid fever, and, as evidenced in this study, typhoid case was positively correlated with variation in the popu-

Table 3. High-risk clusters identified by LISA in Jakarta, Indonesia 2017-2023.

Region (n=3)	Sub-district (n=10)	Village (n=37)	Population at risk (no.)
South Jakarta	Jagakarsa	Ciganjur	34,943
		Cipedak	33,075
		Jagakarsa	60,612
		Lenteng Agung	55,912
		Srengseng sawah	57,308
		Tanjung Barat*	40,737
	Pasar Minggu	Kebagusan	44,795
		Ragunan	44,218
East Jakarta	Cipayung	Bambu Apus	25,433
		Ceger	12,643
		Cipayung	23,996
		Lubang Buaya	59,638
		Setu	16,587
	Ciracas	Ciracas*	67,312
		Kelapa Dua Wetan	43,867
		Rambutan	37,550
		Susukan*	36,362
	Kramat Jati	Bale Kambang	26,220
		Batu Ampar	36,164
		Cililitan	46,425
		Dukuh	24,100
		Kampung Tengah	37,652
		Kramat Jati	38,280
	Makasar	Halim Perdana Kusumah	41,846
		Kebon Pala	52,348
		Makasar	40,351
		Pinang Ranti	22,734
	Matraman	Utan Kayu Utara	31,867
	Pasar Rebo	Baru*	29,186
		Cijantung*	41,283
		Gedong*	37,495
		Kalisari*	38,380
		Pekayon	45,603
North Jakarta	Koja	Koja	41,386
		Rawa Badak Selatan	48,028
		Tugu Utara	78,585
	Tanjung Priok	Sungai Bambu	40,036

Total number of clusters identified=37; Total number of population at risk =1,492,957 people; * Seven persistent high-risk villages for typhoid during 2017-2023.

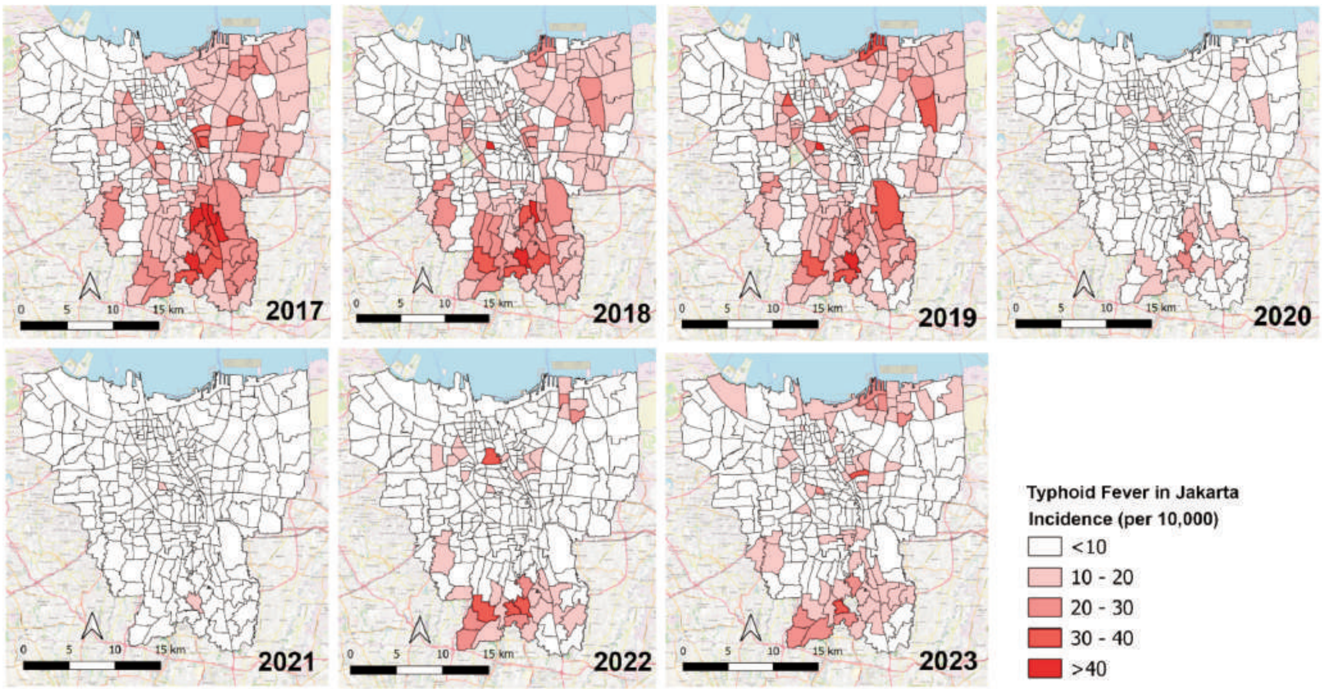

Figure 3. Spatial-temporal pattern of typhoid incidence per 100,000 population at the village level in Jakarta, Indonesia 2017-2023.

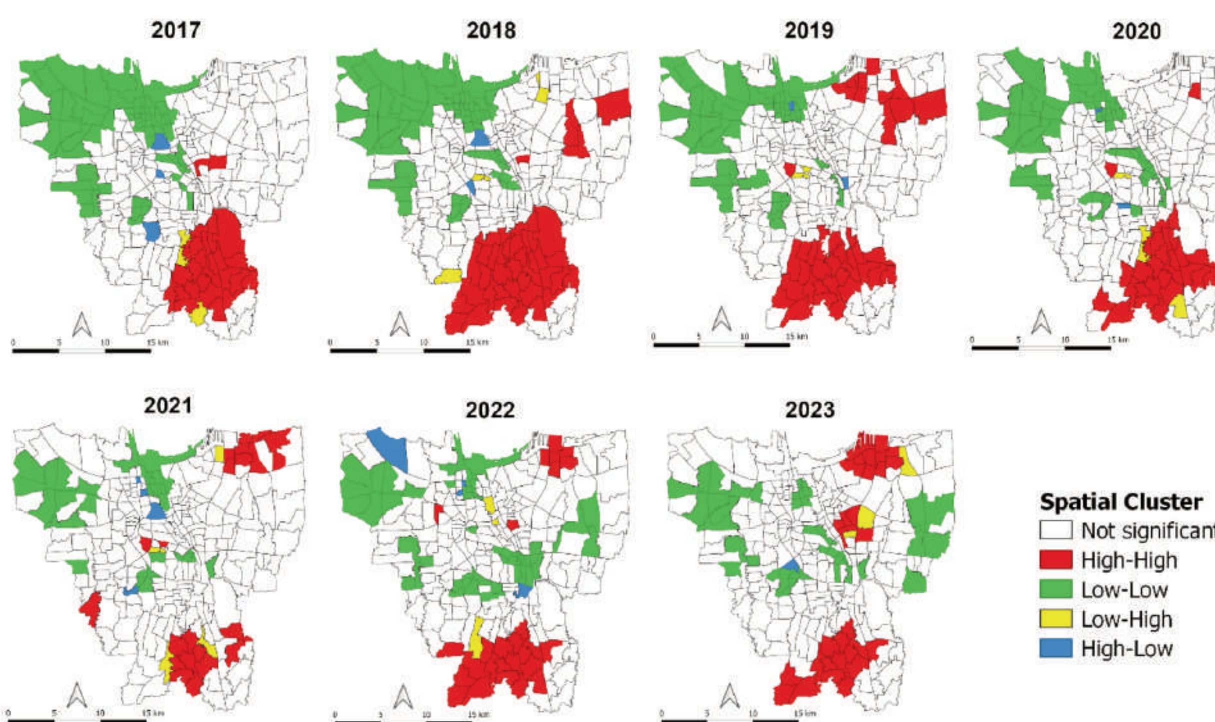

Figure 4. Annual spatial clusters distribution of typhoid at the village level in Jakarta, Indonesia 2017-2023 as determined by LISA analysis.

lation. Typhoid transmission is more common in heavily populated metropolitan environments, particularly those with insufficient sanitation (Crump & Mintz, 2010; Karkey *et al.*, 2010). Second, socioeconomic conditions may also influence the spatial variation in typhoid transmission. Inadequate access to safe drinking water, improper disposal of waste, ineffective sewage systems, and poor hygiene practices could increase the risk of typhoid transmission (Muleta & Meseret, 2025; Brockett *et al.*, 2020; Baker *et al.*, 2011). Yet, in this study, we could not draw the relationships between these factors with typhoid cases due to the paucity of area-level data on access to water, sanitation and hygiene behaviour among Jakartan population.

There has been a noticeable change in trends and distribution of incidence of typhoid fever across Jakarta during the study period, especially during 2020-2021, which coincided with the emergence COVID-19 pandemic. Notably, the typhoid incidence in Jakarta experienced a significant reduction during the pandemic. The extensive public health and social measures, such as mobility restrictions, physical distancing, and hygiene campaigns (e.g., hand washing) to control COVID-19 transmission might have caused reduction in typhoid transmission. This significant change may also reflect the impact of COVID-19 on health seeking behaviour and care availability. Some reports have shown that pandemic resulted in treatment delays, declined capacity and reduced treatment-seeking among people leading to under-reporting of diseases such as dengue (Oliveira Roster *et al.*, 2024). A similar declining trend of typhoid cases during pandemic has also been reported elsewhere (Ching *et al.*, 2024).

We detected a set of high-risk typhoid villages over the course of study. There are some areas in the East and South Jakarta where persistent high-risk clusters remained during this period. This suggests the existence of persistent exposure and transmission in these identified areas, which highlights the need for better disease control and preventive measures, such as vaccination and health promotion. Typhoid case clustering has been reported in various metropolitan environments, with connections found with population density, overcrowding, and hygiene measures (Baker *et al.*, 2011; Ali *et al.*, 2017; Mohan *et al.*, 2021).

The incidence of typhoid fever in Jakarta showed strong seasonal patterns during the period of study. The incidence was relatively higher in the first trimester of the year, peaking in March which coincides with the rainy season. Our evidence highlights the role of rainfall on the occurrence of typhoid cases. High precipitation during rainy season could lead to flooding and thus increase the exposure to contaminated environment, leading the risk of waterborne diseases such as typhoid, especially in that area where drainage system and access to safe water are lacking. Our finding is consistent with studies that showed that typhoid outbreaks mostly occurred in months with higher precipitation (Dewan *et al.*, 2013; Akullian *et al.*, 2015). The presence of strong seasonality of typhoid fever incidence in Jakarta – as evidenced in this study, can be further utilized for improving outbreak preparedness.

This study has several limitations. Firstly, we used secondary data obtained from hospital-based surveillance that prone to under-report/underestimate typhoid actual cases in the population. The report might not capture all typhoid cases in the community; for

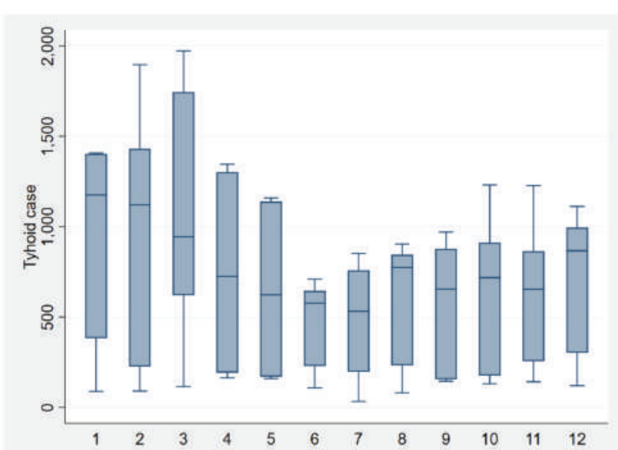

Figure 5. Monthly distribution of typhoid cases in Jakarta, Indonesia 2017-2023.

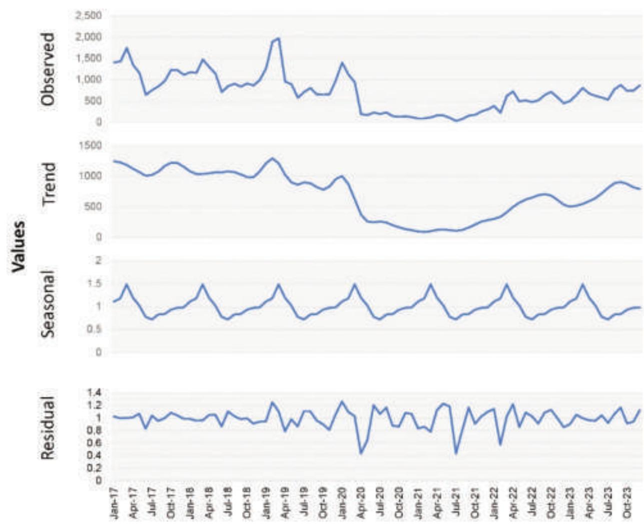

Figure 6. Seasonal decomposition plot of typhoid case in Jakarta, Indonesia 2017-2023.

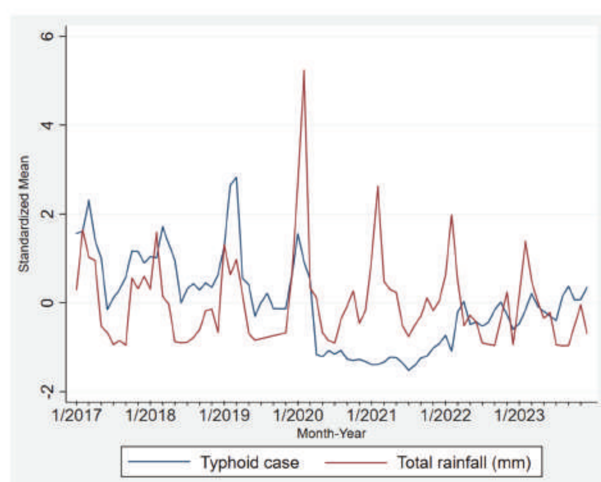

Figure 7. Association of rainfall with the typhoid case count in Jakarta, Indonesia January 2017 – December 2023. Red line: rainfall; blue line: typhoid cases; values of case counts and total rainfall is adjusted as centred (standardized) mean to allow comparison between variables.

example, people who are asymptomatic or have mild symptoms are likely not to seek treatment. In the present study, our aims were to explore the geographical and temporal patterns of typhoid incidence. Further study is required to examine social and environmental factors driving the spread of typhoid infection in the population and to characterize the circulating *S. typhi* and its resistance to available antibiotics in the community as this should improve treatment and control. Despite these limitations, this study extends the knowledge on the use of spatial-temporal analytical approaches to locate high-risk areas and role of climate on typhoid transmission in Jakarta.

Conclusions

This study demonstrates useful baseline evidence on the village-level spatial pattern of typhoid fever and its seasonality in the city of Jakarta. Evidence of high-risk clusters in certain villages in East and South Jakarta was provided. In addition, this study confirms the strong seasonality of the typhoid incidence as driven by climate variability. Future research should aimed to investigate the drivers of these geographical patterns at community level and to develop early warning systems to help guide typhoid surveillance and control strategies. The results of the study could help local health authority in defining necessary public health interventions to control typhoid transmission in Jakarta.

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