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Tuberculosis in Aceh Province, Indonesia: a spatial epidemiological study covering the period 2019–2021

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Abstract

The purpose of this study was to determine whether there were any TB clusters in Aceh Province, Indonesia and their temporal distribution during the period of 2019–2021. A spatial geo-reference was conducted to 290 sub-districts coordinates by geocoding each sub-district's offices. By using SaTScan TM v9.4.4, a retrospective space-time scan statistics analysis based on population data and annual TB incidence was carried out. To determine the regions at high risk of TB, data from 1 January 2019 to 31 December 2021 were evaluated using the Poisson model. The likelihood ratio (LLR) value was utilized to locate the TB clusters based on a total of 999 permutations were performed. A Moran's *I* analysis (using GeoDa) was chosen for a study of both local and global spatial autocorrelation. The threshold for significance was fixed at 0.05. At the sub-district level, the spatial distribution of TB in Aceh Province from 2019-2021 showed 19 clusters (three most likely and 16 secondary ones), and there was a spatial autocorrelation of TB. The findings can be used to provide thorough knowledge on the spatial pattern of TB occurrence, which is important for designing effective TB interventions.

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Introduction

Tuberculosis (TB) is an airborne, chronic infectious disease caused by *Mycobacterium tuberculosis* bacteria, an intracellular pathogen primarily affecting the lungs but also other parts of the body. According to the World Health Organization (WHO), the disease continues to pose a serious threat to global public health especially in many developing countries, is the second most common cause of mortality after COVID-19 and ranks first in low-income and middle-income countries (WHO, 2023). An estimated 10.6 million new TB infections were diagnosed with globally in 2021 (WHO, 2023)

In Indonesia, TB remains an important public health problems (MoH, 2020) The country has the second highest TB burden after India. Based on the estimated TB incidence, in 2021, there were as much as 969,000 new cases per year in Indonesia. However, only 443,235 cases (53.8%) were notified, which means that the given prevalence is highly doubtful and that the real presence of TB is at least double that reported. The TB incidence in Aceh Province is one of the highest in Indonesia. Based on the Aceh health profile 2021, it is estimated that incidence of TB was 354 per 100,000 population, with a death rate of 52 per 100,000 population. The case notification rate (CNR) in 2019-2021 were 161, 115 and130 per 100,000 population, respectively (national: 163 per 100,000 population), while the success rate (SR) were 89.5%, 83.8%, and 89.4%, respectively (national: 85.9%; national target ≥ 90%) (Provincial Health Office of Aceh, 2021).

Numerous studies have been investigated to determine the risk factors of TB in Aceh Province (Sasilia *et al.*, 2017; Aditama, Sitepu & Saputra, 2019; Novita, Abdullah & Hermasnyah, 2021) However, none of them explored the spatial epidemiology of TB in the province. Geographic Information Systems (GIS) and spatial analysis can be used to comprehend the patterns of infectious diseases in including TB (Endy *et al.*, 2002; Yue *et al.*, 2018;

Zulfikar *et al.*, 2020). Globally, the use of these toolsl have been applied for public health research (Yu *et al.*, 2020; Zulfikar *et al.*, 2020; Kibuuka *et al.*, 2021; Pasaribu *et al.*, 2021; Fahdhienie & Sitepu, 2022)

According to the findings of earlier investigations, the spatial distribution of TB is non-random and clustered (Wang *et al.*, 2012, 2019; Gwitira *et al.*, 2021; Im & Kim, 2021). Spatial temporal analysis by GIS is frequently used and can be conducted on secondary data. To the best of our knowledge, this is the first spatial-temporal analysis of TB in Aceh Province. Its purpose was to ascertain whether there were any TB clusters in the Aceh Province, Indonesia as well as their temporal distribution over the three-year period (2019-2021). By concentrating attention on the TB control program, this research pinpoints high-risk locations where there are clusters of TB cases.

Materials and Methods

Study area

The study area was in Aceh Province which consists of 23 districts, 290 sub-districts, and 6,514 villages. The total population in the province was 5,274,871, with the density varying in each sub-district, from 17 to 4,122 people per km^2. Aceh is located around 01º 58' 37.2" – 06º 04' 33.6" N and 94º 57'57.6" – 98º 17' 13.2" E (Figure 1).

Data

The monthly numbers of clinically confirmed TB cases from 1 January 2019 to 31 December 2021 were obtained from the Provincial Health Office of Aceh. These data were compiled from active and passive case finding in the community and were recorded into the electronic surveillance TB information system (SITB). The data were the aggregated sub-districts' total of TB cases. Data of sub-district's population were obtained from the Aceh Province Bureau of Statistics (2020). Geo-coding of each sub-district offices by Google Maps application were obtained to represent each geographic coordinates (latitude and longitude). Spatial data visualization was done with quantum GIS (QGIS) (QGIS, 2024).

Figure 1. Location of the study area.

Table 1. TB clusters based on space-time analysis in Aceh Province, 2019-2021.

Year	Cluster type	Geographical coordinates	Radius (km)	Cases (no.)	Expected cases (no.)	People at risk (no.)	RR	LLR	p
2019	Most likely	4.46807 N / 97.576433 E	29.9	58	18	1389	3.3	28.3	< 0.001
	1st secondary	4.237551 N / 96.360973 E	24.9	228	137	10612	1.7	26.1	< 0.001
	2nd secondary	4.973523 N / 97.621506 E	13.4	152	88	6848	1.7	19.3	< 0.001
	3rd secondary	4.749581 N / 96.935585 E	47.6	585	454	35252	1.3	18.6	< 0.001
	4th secondary	5.413185 N / 95.443607 E	13.5	149	88	6874	1.7	17.4	< 0.001
	5th secondary	5.251847 N / 96.250656 E	8.6	123	72	5554	1.7	15.5	< 0.001
	6th secondary	5.161943 N / 97.298827 E	6.7	35	12	922	2.9	14.8	< 0.001
2020	Most likely	4.710152 N / 95.521079 E	4.7	458	223	16275	2.1	99.6	< 0.001
	1st secondary	4.459729 N / 96.530204 E	4.5	181	95	6944	1.9	31.4	< 0.001
	2nd secondary	4.992387 N / 97.230117 E	4.9	96	47	3436	2.1	19.8	< 0.001
	3rd secondary	5.463987 N / 95.383637 E	5.5	94	50	3617	1.9	16.1	< 0.001
	4th secondary	5.161943 N / 97.298827 E	5.2	43	17	1208	2.6	14.8	< 0.001
	5th secondary	4.914255 N / 97.751251 E	4.9	36	14	965	2.7	13.4	< 0.001
2021	Most likely	4.81045 N / 95.489852 E	78.4	841	557	43952	1.6	69.1	< 0.001
	1st secondary	4.918687 N / 97.591865 E	15.6	177	92	7252	1.9	31.5	< 0.001
	2nd secondary	4.258084 N / 96.416471 E	29.3	125	69	5422	1.8	18.8	< 0.001
	3rd secondary	4.992387 N / 97.230117 E	8.6	86	44	3400	2.1	16.7	< 0.001
	4th secondary	4.625164 N / 96.722992 E	10.1	44	20	1527	2.3	11.6	0.002
	5th secondary	5.135966 N / 96.771077 E	5.6	50	26	2046	1.9	8.8	0.022

RR, relative risk; LLR, likelihood ratio.

Space-time scan statistic

We downloaded the SaTScan TM v9.4.4 program (SaTScan, 2021a) to carry out the retrospective space-time analysis. During the period of 1 January 2019 to 31 December 2021, sub-districts with a high TB risk were identified using a Poisson model (SaTScan, 2021b). The likelihood ratio (LLR) against the null distribution derived from the Monte Carlo hypothesis testing (SaTScan, 2021b) served as the basis for the test of significance for the discovered clusters of TB. The significance level was set at 0.05, and 999 permutations. The null hypothesis of this study assumed that the relative risk of TB was the same within the window as as the outside. The cluster with the highest LLR number determined as most likely TB cluster, and others as secondary clusters. (Kulldorf, 2005; Wang *et al.*, 2012; Gwitira *et al.*, 2021)

Spatial autocorrelation analysis

We downloaded GeoDa (GeoDa, 2021b) to perform a spatial autocorrelation analysis. The local indicator of spatial autocorrelation (LISA) (GeoDa, 2021a) was used to evaluate local spatial autocorrelation while the univariate Moran's *I* test (GeoDa, 2021a) was used to test global spatial autocorrelation. Moran's *I* coefficient represents a numerical representation of the spatial autocorrelation value. By examining the breadth of space and distribution of spatial data, it provides an overview of global spatial patterns. The outcome displays an overview of global spatial patterns that either are random, clustered or scattered based on this statistical analysis, with the coefficient ranging from -1 to 1. The zero score indicates absence of clusters, a positive score indicates spatial clustering, while a negative score indicates dispersion (ArcGIS Pro, 2022; Richie, 2022).

Results

Descriptive analysis

In Aceh Province, 21,907 TB cases were reported in the three-year examination of TB data, with an annualized average incidence of 415.31 per 100,000 population. The annualized average incidence of TB throughout the three-year study period varied from 138.35 to 783.21 per 100,000 population. The incidence was lowest in Sabang District and highest in Lhokseumawe (Figure 2).

Space-time analysis

As seen in Table 1, the analysis detected a total of 19 clusters, one of which was a most likely cluster and it appeared over the whole three-year period (Figure 3). There were also 16 secondary clusters (six in 2019 and five in each of 2020 and 2021).

Spatial autocorrelation

It was determined that there existed spatial autocorrelation of TB in Aceh Province over the three-year study period based on the findings of the spatial autocorrelation analysis with Moran's *I* at the significance level of 0.05 (Table 2).

Discussion

In this study, sub-district level spatial cluster analysis of TB and exploratory spatial data analysis were carried out in Aceh Province, Indonesia. The results of the study showed that TB displays spatial variability, as shown by the presence of spatial clusters in particular areas. To locate the TB spatial clusters in the study area, we employed SaTScan and LISA. The fact that the two methods find TB clusters in similar places suggests that they are workable and effective solutions for locating and identifying areas with a high prevalence of TB. However, the identification of clusters by spatial scan statistics by using SaTScan was more localized (Laohasiriwonget al, 2017).

The study found that Pidie, North Aceh and Bireun were the districts with the consistently most likely TB cluster in the three-year study period. This may occur as a result of a number of socioeconomic issues in the region, e.g., population density and a high rate of poverty (Aceh Province Bureau of Statistics, 2021). The presence of TB in areas with high population density would prove the number of infections due to increasing prevalence of coughing, sneezing or spitting, while a significant proportion of the poor may be linked to overcrowding, which will boost disease transmission for the same reasons. The association between high density and poverty with TB is well established and widespread (Srivastava & Mishra, 2019; Maina *et al.*, 2021; Lee *et al.*, 2022).

The BCG vaccine is still the gold standard for TB prevention due to its effectiveness in avoiding TB that can be fatal. It is the only vaccine against the disease that is currently approved. Many studies have shown that low coverage of TB immunization is associated with the incidence of TB (Michelsen *et al.*, 2014; Sweeney *et al.*, 2019; Trollfors, Sigurdsson & Dahlgren-Aronsson, 2021).

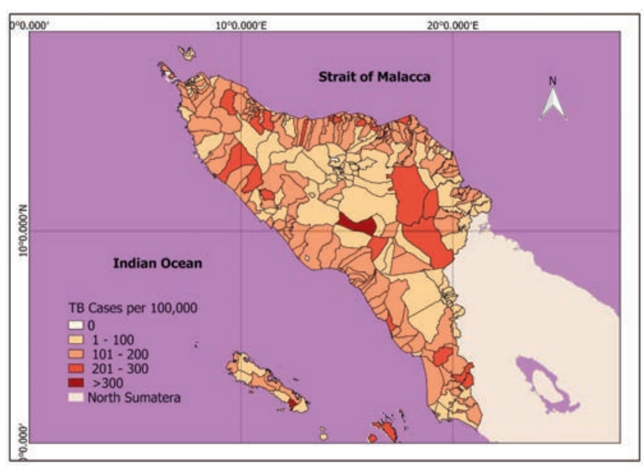

Figure 2. Annualized average incidence of TB in Aceh Province, 2019–2021.

Table 2. Results of spatial autocorrelation

Year	p	Moran's *I*	*Z*
2019	0.001	0.298	7.628
2020	0.002	0.142	3.837
2021	0.001	0.207	5.316

Importantly, Pidie, North Aceh and Bireun are districts with low coverage of BCG immunization in Aceh Province, which could explain the levels of infection there.

The finding that TB cases frequently cluster in specific locations suggests that this area is of interest for public health responses and interventions, including targeted active case finding, early treatment, DOTS testing, and improving environmental quality (McAllister *et al.*, 2017; Wang *et al.*, 2019; Fahdhienie & Sitepu, 2022). It is strongly advised to conduct more research on the potential socioeconomic and environmental factors influencing the spatial distribution of TB in Aceh Province. A recent, previous study in Aceh suggests that the main causes of TB are low levels of humidity in dwellings, low levels of light exposure, low levels of education, inadequate knowledge of the disease, presence of co-

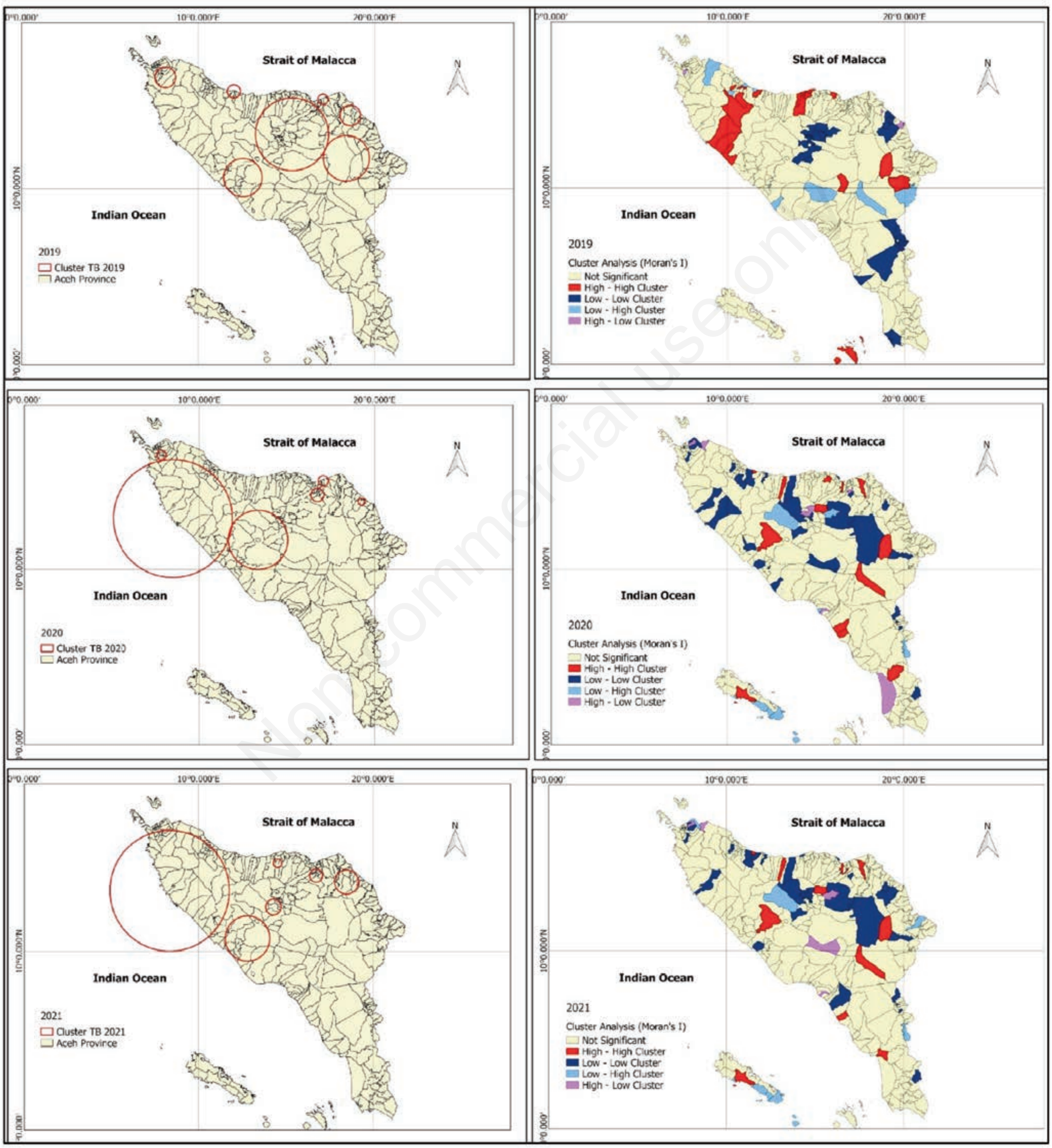

Figure 3. Spatial distribution of statistically significant clusters of TB in Aceh Province, 2019-2021.

morbidities, close contact with TB patients, low food consumption and lack of preventative actions (Fahdhienie *et al.*, 2024). This may well be true, and it would be of interest to find whether the clusters found in this study coincide with such areas. Even, if this cannot be shown, our identification of TB clusters provides a better understanding of the geography of TB in Aceh Province. When planning activities for surveillance, prevention, and control, public health officials in the district can use these results as guidance.

Our study had, however, certain drawbacks. First, only the sub-districts' offices were geo-referenced; it would be preferable to gather and coordinate all TB cases in order to include both individual and environmental risk variables. Second, because patients with TB do not seek care at the health service institutions, there is a strong level of underreporting of TB resulting in many cases being missed. Strong, regular diagnostic surveys by the routine notification system would strengthen our approach and results

Conclusions

Nineteen statistically significant TB clusters were identified in the 2019-2021 period. Most likely clusters were detected in Pidie, North Aceh and Bireun District in the three-year period of study. We also found that spatial clusters analyzed by SaTScan and LISA were located in similar locations. The findings presented provide better knowledge on the spatial pattern of TB occurrence, which is important for designing effective TB interventions.

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