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Spatio-temporal analysis of tuberculosis incidence in North Aceh District, Indonesia 2019-2021

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Abstract

Tuberculosis (TB) infection continues to present as a leading cause of morbidity and mortality in North Aceh District, Aceh Province, Indonesia. Local TB spatial risk factors have been investigated but space-time clusters of TB in the district have not yet been the subject of study. To that end, research was undertaken to detect clusters of TB incidence during 2019-2021 in this district. First, the office of each of the 27 sub-districts wasgeocoded by collecting data of their geographical coordinates. Then, a retrospective space-time scan statistics analysis based on population data and annual TB incidence was performed using SaTScan TM v9.4.4. The Poisson model was used to identify the areas at high risk of TB and the clusters found were ranked by their likelihood ratio (LLR), with the significance level set at 0.05.There were 2,266 TB cases reported in North Aceh District and the annualized average incidence was 122.91 per 100,000 population. The SaTScan analysis identified that there were three most like clusters and ten secondary clusters, while Morans'*I*showed that there was spatial autocorrelation of TB in the district. The sub-district of GeureudongPase was consistently the location of most likely clusters. The indicators showed that there were significant differences between TB data before the COVID-19 pandemic and those found during the study period. These findings may assist health authorities to improve the TB preventive strategies and develop public health interventions, with special reference to the areas where the clusters were found.

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Introduction

According to the (World Health Organization WHO) and the Ministry of Health of Republic of Indonesia (MoH), tuberculosis (TB) remains a major public health problem in the world (WHO, 2021) as well as locally (MoH, 2020). Caused by the bacillus *Mycobacterium tuberculosis,* TB results in high morbidity and mortality making this infection one of the great threats in the world. Indeed, it is still one of the top ten causes of death in the world (WHO, 2021). Indonesia reports a high number of TB cases and the country ranks ninth amongst the twenty TB countries with high burdens due to an incidence rate of 301 per 100,000 populations (The World Bank 2022a, 2022b). However, only 47% of all cases are detected and reported to the National TB Program (the national target is 70%) (MoH, 2020)

Aceh Province has one of the highest TB incidence of all provinces in Indonesia. Based on Aceh Health Profile, the case notification rate (CNR) in the province was 115 per 100,000 population (Provincial Health Office of Aceh, 2021). The report also states that the CNR in North Aceh District currently is 840 per 100.000 population making the district the highest CNR in the province while, the achievement of the treatment success rate of TB is still below 85% (the national target is 90%) (PHO, 2021). The incidence rates of TB in North Aceh District 2019-2021 were 149, 114 and 106 per 100,000 population, respectively (PHO, 2021). At first glance, these numbers seem to be decreasing. However, this could be due to the occurrence of COVID-19 in the district, which made other diseases, including TB, less noticed. As a result, treatment became neglected as almost all resources in both health sectors and others activities focused on handling COVID-19. This condition made the reported TB case discovery spuriously decrease significantly (Caren *et al*., 2022; Chan *et al*., 2021; Lestari *et al*., 2022; Utomo *et al*., 2022).

In recent years, geographic information systems (GIS) and spatial analysis have often been applied to understand the patterns of the spread and distribution of infectious diseases (Yue *et al.*, 2018; Endy *et al*., 2002; Zulfikar *et al.*, 2020). Some previous

studies reported that the spatial distribution of TB was non-random and clustered (Gwitira *et al*., 2021; Im, 2021; Wang *et al*., 2012, 2019). The spatial autocorrelation analysis also found that the TB incidence was strongly spatially clustered in the hotspot areas (Dismer *et al*., 2021; Gwitira *et al*., 2021; Im, 2021; Wang *et al*., 2012). Spatial temporal analysis is commonly used in GIS andcan be conducted by analyzing secondary data. Thus, this analysis can identify clusters of TB cases and high-risk areas that can assist health planning by sharpening the focus of attention on TB control programmes.

To the best of our knowledge, this is the first study of spatial-temporal analysis of TB in North Aceh District, Indonesia. We therefore aimed to investigate the presence of TB clusters in this district and investigate the temporal distribution pattern of TB clusters over the three last years (2019-2021).

Material and Methods

Study area and time

The study area was North Aceh District, which consists of 27 sub-districts and 852 villages. The total population in the district was 619,407 with the population density varying from 19 to 1,299 people per km^2 depending on sub-district. North Aceh District is located around 4.46.00º – 5.00.40ºN and 96.52.00º – 97.31.00º E (Figure 1). The study took place from 1 January 2019 to 31 December 2021.

Data

The monthly numbers of clinically confirmed TB cases from 1 January 2019 to 31 December 2021 were obtained from the District Health Office of North Aceh. The data used in this study were aggregated villages' total number of TB cases. Population data were obtained from the North Aceh Bureau of Statistics (North Aceh Bureau of Statistics 2020b). The geographical coordinates of each village office were obtained by geo-coding and application of Google Maps.

Statistics

To identify if there were differences in the data of TB before COVID-19 (data 2016-2018) and the data of TB in the study period, we employed the paired t-test.

Space-time scan statistic

To conduct the retrospective space-time analysis, we downloaded the SaTScan TM v9.4.4 software (Kulldorf, 2005).A Poisson model was used to identify sub-districts at high risk of TB

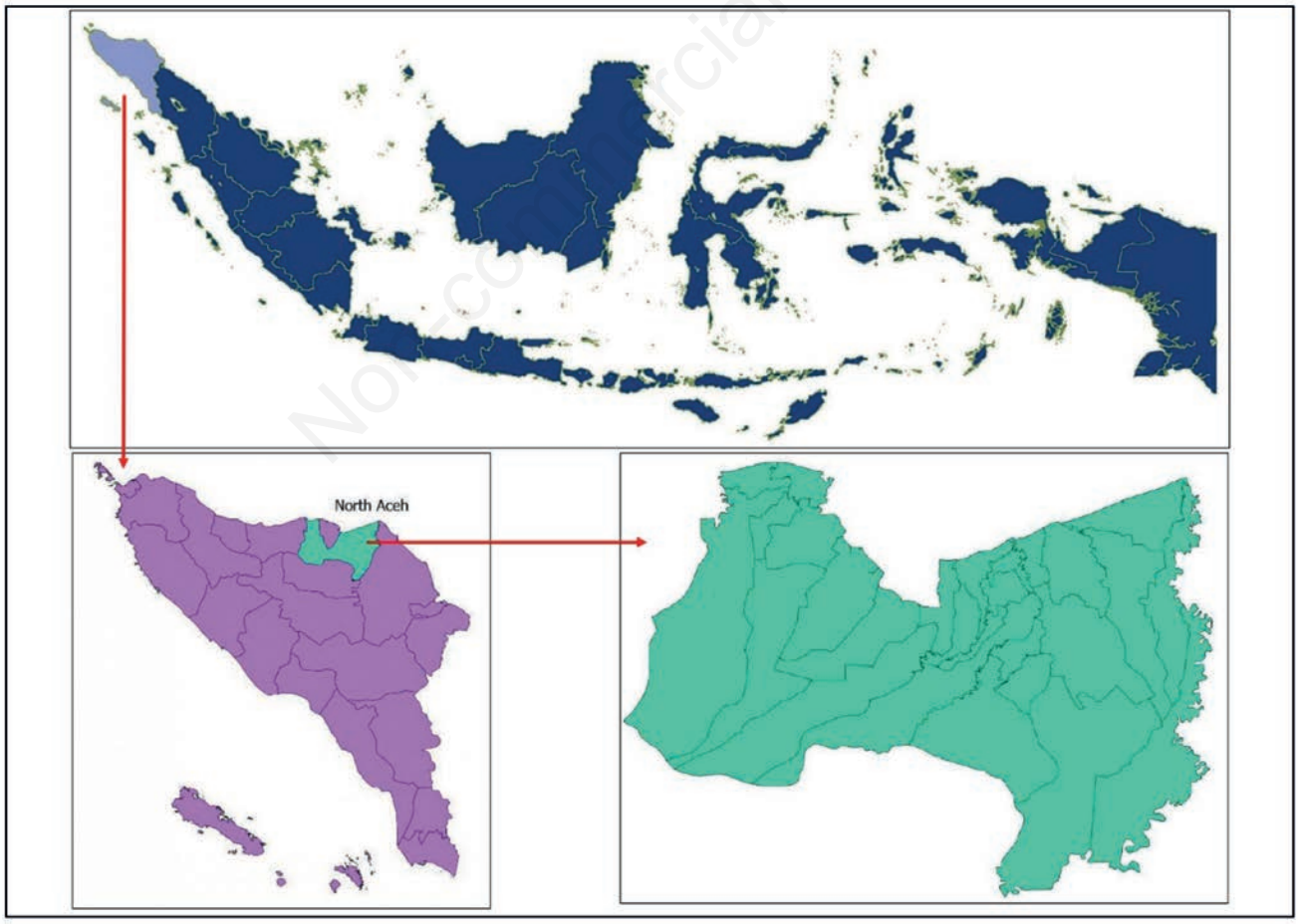

Figure 1. Location of the study area.

during the study period. The test of significance of the identified clusters of TB rested on comparing the likelihood ratio (LLR) against the null distribution, which holds that the relative risk of TB is the same within the window compared to the outside. The null hypothesis was obtained from Monte Carlo testing (Kulldorf, 2005).The number of permutation conducted was 999 and the significance level 0.05. The TB cluster with the highest LLR number was determined as the most likely cluster, while the other clusters were accepted as secondary ones (Gwitira *et al*., 2021; Kulldorf, 2005; Wang *et al*., 2012)

Spatial autocorrelation analysis

To conduct spatial autocorrelation analysis we downloaded GeoDa (GeoDa, 2022), a software that helps exploring and modelling spatial patterns. Univariate Moran's *I* (GeoDa, 2020) was employed to test global spatial autocorrelation while local indicator of spatial autocorrelation (LISA) (GeoDa, 2020) was used to test local spatial autocorrelation. Moran's *I* coefficient is used to test the spatial dependence or spatial autocorrelation between observations or locations andrangesfrom-1 to1. The zero score indicates randomness, *i.e.* absence of cluster of TB cases, while the positive score indicates that the distribution of TB cases tend to be spatially clustered. A negative score indicates complete dispersion of TB cases (ArcGIS Pro., 2022; Richie, 2022; Statistics How to, 2022).

Results

Descriptive analysis

In the three-year analysis of TB data, 2,266TB cases had been reported in North Aceh District and the annualized average incidence of TB was 122.91 per 100,000 population. During the time before the study (data from 2016-2018), there were 3,430 TB cases in the area and the annualized average incidence data was 195.99 per 100,000 population. Also other indicators of TB showed that there were significant differences between data before COVID-19 and the study period (Table 1, Figure 2).

Table 1. Results of the paired t-test.

Indicators (average)	2016-2018	2019-2021	p
Incidence rate	195.99	122.91	0.003
Case notification rate	213.33	552	0.023
Cure rate	58	29	0.02
Success rate	87.33	99	0.014

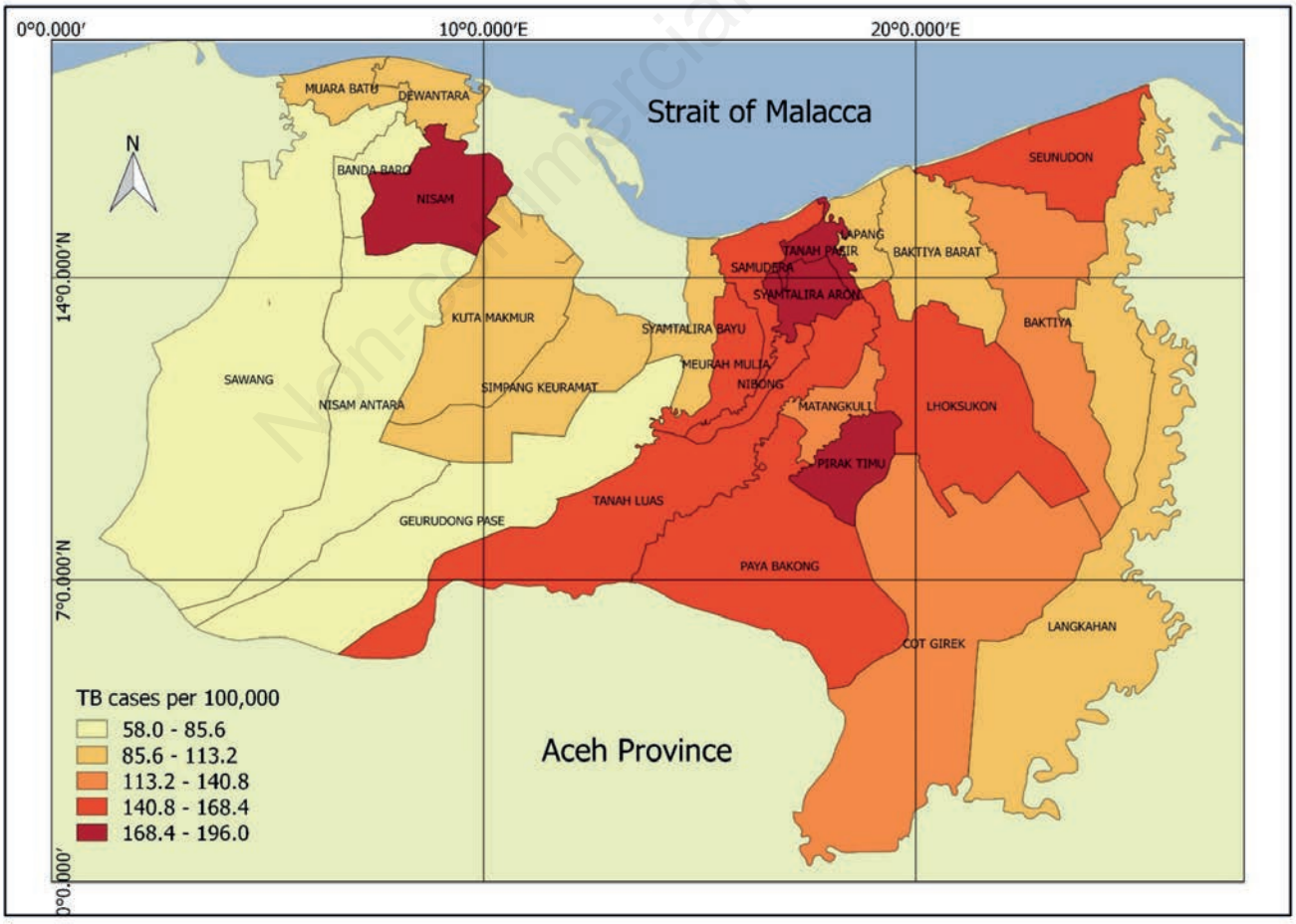

Figure 2. Annualized average incidence of TB in North Aceh District 2019–2021.

In the three-year study period, the annualized average incidence of TB ranged from 58 to 196 per 100,000 population. The sub-district of Geureudong Pasehad the lowest incidence (58 per 100,000 population), while the sub-district of Nisam had the highest (196 per 100,000 population)

Space-time analysis

The result of the space-time scan statistics analysis of TB for the study period are shown below (Table 2). The analysis detected a total of 13 clusters, one of which was a most likely cluster that appeared over the whole three-year period. There were also six, three and one secondary cluster(s) emerging in 2019, 2020 and 2021, respectively (Table 2, Figure 3).

Spatial autocorrelation

Spatial autocorrelation analysis was performed in GeoDa. Based on the results of the spatial autocorrelation analysis with Moran's *I* (Table 3, Figure 4) with the significance level set as

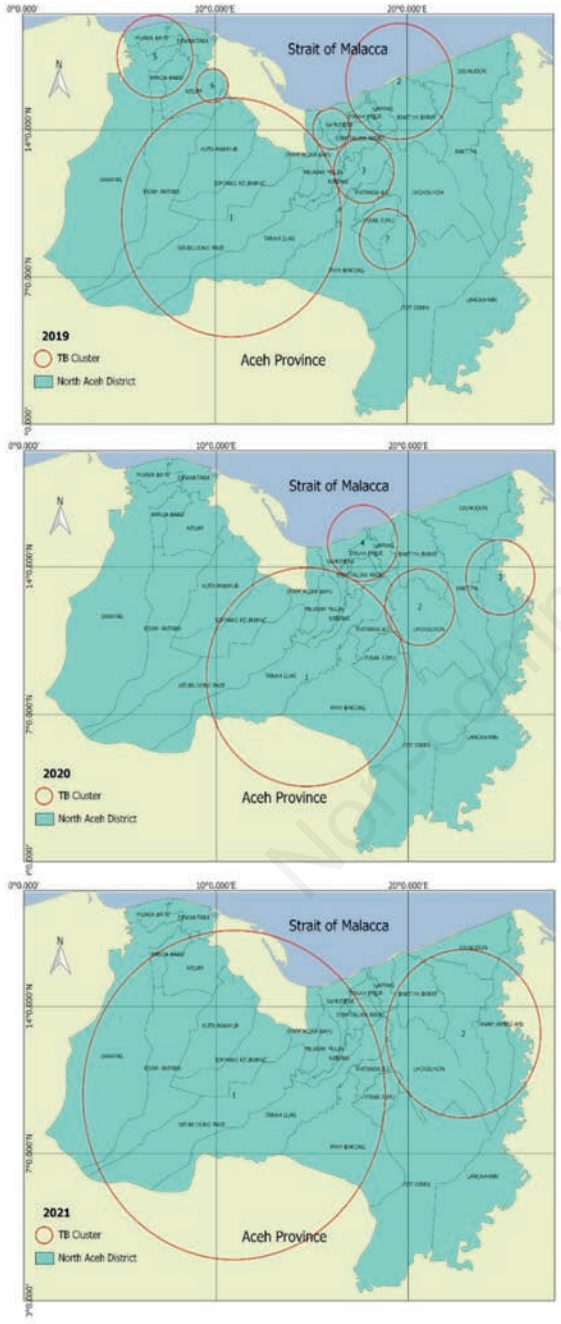

Figure 3. Spatial distribution of the statistically significant most likely and secondary clusters of TB in North Aceh District 2019-2021.

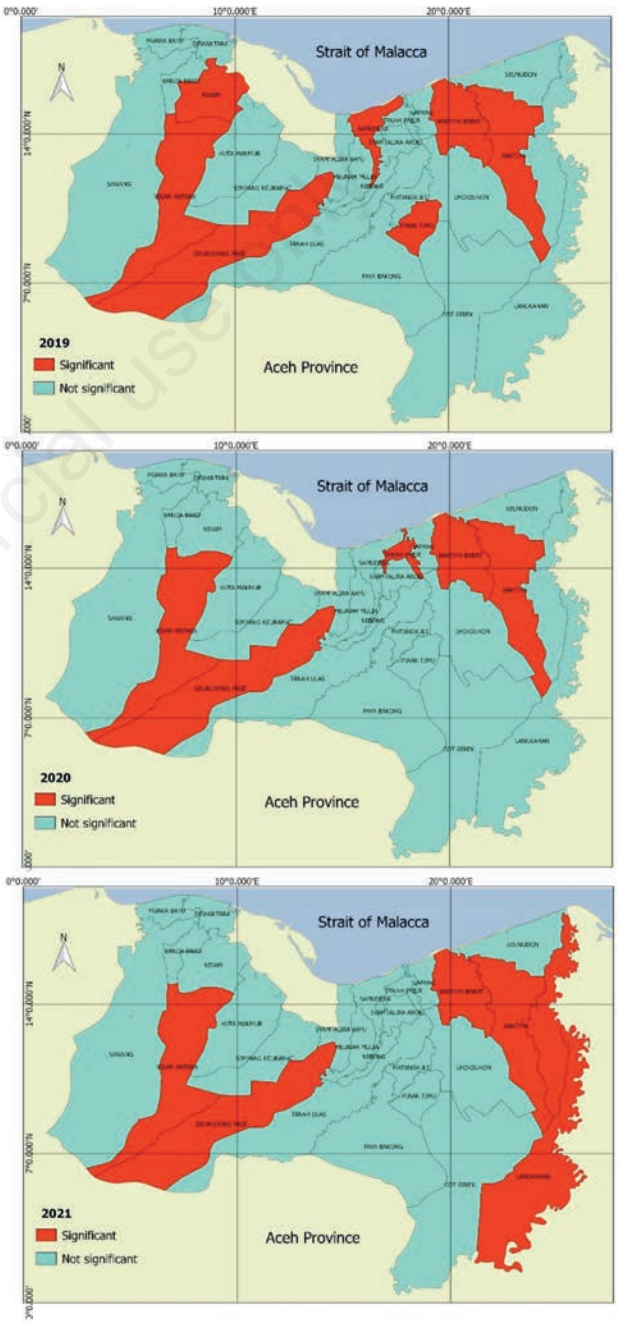

Figure 4. Spatial distribution of TB at the sub-district level in North Aceh District 2019-2021.

Table 2. TB clusters based on spatial temporal analysis in North Aceh District 2019-2021.

Year	Cluster type	Geographical coordinates	Radius (km)	Cases (no.)	Expected cases (no.)	People at risk (no.)	RR	LLR	p
2019	Most likely	4.995814 N/ 97.065978 E	18.14	129	47	2392	3.02	51.9	<0.001
	1st secondary	5.181754 N/ 97.316555 E	8.79	71	24	1232	3.08	30.6	<0.001
	2nd secondary	5.059917 N/ 97.263891 E	4.95	97	43	2186	2.39	26.5	<0.001
	3rd secondary	5.116918 N/ 97.215403 E	3.1	49	20	997	2.58	15.9	<0.001
	4th secondary	5.215667 N/ 96.951781 E	6.26	86	50	2530	1.79	11.5	0.004
	5th secondary	5.175847 N/ 97.037746 E	2.58	20	6	289	3.56	10.9	0.006
	6th secondary	4.966179 N/97.299011 E	4.58	17	5	232	3.76	9.9	0.014
2020	Most likely	4.965042 N/ 97.176486 E	16.6	166	102	12812	1.81	20.1	<0.001
	1st secondary	5.0604414 N/ 97.345764 E	5.75	61	104	13056	1.54	12.1	0.004
	2nd secondary	5.100763 N/ 97.465887 E	5.69	62	103	12861	1.56	10.8	0.013
	3rd secondary	5.147564 N/ 97.26036 E	5.79	55	29	3659	1.96	9.6	0.04
2021	Most likely	4.994334 N/ 97.068123	24.99	280	198	23299	1.76	23.5	<0.001
	1st secondary	5.078126 N/ 97.410674 E	12.78	163	235	27646	1.58	19.1	<0.001

RR=relative risk; LLR= likelihood ratio.

0.05, it was decided that there was spatial autocorrelation of TB in North Aceh District in the three-year study period.

Table 3. Results of spatial autocorrelation.

Year	p	Moran's *I*	Z
2019	0.034	0.582	1,142
2020	0.035	0.458	1,133
2021	0.011	0.612	1,228

Discussion

Exploratory data analysis and space time scan statistics of TB were conducted at sub-districts level of North Aceh. We mapped TB in terms of incidence data from 1 January 2019 to 31 December 2021. The identification of clusters and hotspots with spatiotemporal variation patterns that we conducted by using two spatial analyses approaches (SaTScan and GeoDa) in similar locations showed that the analyses were viable options for our research approach.

Our study revealed that there were spatial clusters and significant hotspots of TB in North Aceh District. To our knowledge, this is the first study to investigate the space-time scan statistic of TB in the district. In Indonesia, especially in Aceh Province, the use of spatial analysis of the distribution of infectious diseases with special reference to TB is still limited, even though it would contribute to a better understanding of the spatial risk factors of TB based on environmental risk factors. Our study showed that statistically significant hotspots and spatial clusters were common in the sub-districts with high populations. This finding is in line with previous studies carried by Gwitira *et al.* (2021) in Zimbabwe as well as Im in South Korea (2021). It occurred because of high population resulting in over-crowding that supported transmission of TB in the area (Aditama *et al*., 2019, 2020; Noykhovich *et al*., 2019; Ross *et al*., 2021).

The Geureudong Pase sub-district was consistently the location of a most likely cluster of TB in the three-year study period. This sub-district is divided into two parts, one mountainous and the other consisting of valley plains. Residential settlements in the sub-district are concentrated in certain areas affected by population density in certain areas, a condition facilitating transmission of TB. Besides that, Geureudong Pase is adjacent to Lhokseumawe City, which is situated in the middle of the eastern route of Sumatera, a vital distribution and trade route in Sumatera Island. The high level of community mobility to the capital city of Aceh Province (Banda Aceh), or to the city of Medan (North Sumatra Province), which is the 3rd largest city in Indonesia (North Aceh Bureau of Statistics 2020a, 2020b), also increases the risk of TB infection in Geureudong Pase.

In North Aceh District, there is obviously a tendency of TB cases to cluster in specific sub-districts, as shown by the present research. These clusters and surrounding areas should be targeted for TB prevention and control interventions and public health responses. Significant interventions such as targeted active case finding, early treatment and DOTS diagnostics (Aditama *et al*., 2019; Laghari *et al*., 2019; McAllister *et al*., 2017; Wang *et al*., 2012) could focus on these hotspots.

We also found that there were significant differences between the TB data before the COVID-19 pandemic and the three-year study period. During the pandemic, hardly any of the health programmes could run optimally, including that focused on TB. The pandemic impacted the delivery of TB services, while TB patients avoided to go to the health care providers to limit their exposure to COVID-19. This weakening of the performance of the TB programme due to the damaging presence of COVID-19 has not only been reported in the current study area but also in Indonesia in general (Caren *et al*., 2022; Lestari *et al*., 2022; Utomo *et al*., 2022).

Our findings contribute to a better comprehension of the spatial analysis of TB in North Aceh District by assessing the presence of clusters and hotspots. These results can inform public health authorities in the district when designing actions aimed at surveillance, prevention and control.

However, our study had limitations. Firstly, we only geo-referenced the village offices, it would be better to collect and coordinate all the TB cases and thus be able to also include individual and environmental risk factors (Aditama *et al*., 2020). Second, TB cases might be missed by the routine notification system because people with TB do not seek care at the health service facilities which may result in under-reporting.

Conclusions

This study showed the presence of TB spatial clusters in the North Aceh District, Indonesia. Thirteen statistically significant TB clusters were identified in the 2019-2021 period. Most likely clusters were detected in Geureudong Pase sub-district in the three-year period of study. We also found that spatial clusters and significant hotspots of TB were located in similar locations. This finding may assist health authorities to improve the TB preventive strategies and develop public health interventions especially in the areas with clusters and hotspots.

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