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Spatio-Temporal Analysis of Tuberculosis Clusters in a Region of Topographic Diversity: A Case Study from West Sulawesi Province, Indonesia

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ABSTRACT

Introduction: Several studies on tuberculosis (TB) using spatial and time clustering analyses have been conducted in Indonesia, however none have specifically focused on regions characterized by diverse topography. This study aimed to identify geospatial clusters of TB cases in West Sulawesi Province, Indonesia, an area known for its topographic variability.
Methods: An ecological study design was employed. TB case data, including bacteriologically confirmed and clinically diagnosed cases, were obtained from the Tuberculosis Information System (Sistem Informasi Tuberkulosis, SITB) of the West Sulawesi Provincial Health Office, covering the period from January 1, 2020, to December 31, 2023. Spatial visualization was performed using QGIS version 3.40.0. Cluster detection and spatial pattern analysis were conducted using SaTScan version 10.2.5.
Results: TB cases in West Sulawesi formed clusters. A total of 17 clusters were identified—4 primary (most likely) clusters and 13 secondary clusters. In 2020, the primary cluster was located in Bambang Village, Bambang Subdistrict. In 2021, the primary cluster was in Lambanan Village, Mamasa Subdistrict. In 2022, the primary cluster was in Ulumambi Barat Village, Bambang Subdistrict, and in 2023, the primary cluster was again in Lambanan Village, Mamasa Subdistrict.
Conclusion: This study found that the most likely TB clusters from 2020 to 2023 were consistently located in the eastern part of West Sulawesi Province, specifically in Mamasa Regency, an area characterized by mountainous terrain. This suggests that various environmental, social, and economic factors unique to mountain communities may influence TB transmission dynamics. The findings highlight the need for geographically tailored intervention strategies, including mobile TB services, community-based education, enhanced surveillance systems, the establishment of local TB support networks, and improved healthcare infrastructure adapted to mountainous areas. Future research should consider integrating genotypic, molecular, and geospatial approaches to advance global TB control efforts.

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INTRODUCTION

World Health Organization (WHO) has identified Tuberculosis (TB) as a critical issue, particularly within the context of the Sustainable Development Goals (SDGs), which aim to end the TB epidemic by 2030(1). The Global TB Report 2024 stated that 8.2 million new TB cases were identified in 2023, an increase from 7.5 million cases in 2022 and 7.1 million cases in 2021. Indonesia remains the second-largest contributor to TB cases globally, following India. The WHO report also highlights that the largest contributors to the global increase in TB cases between 2020 and 2023 were Indonesia, the Philippines, and Myanmar. The global TB incidence rate is estimated to have risen by approximately 4.6 percent during this period (2).

More than 724,000 new TB cases were identified in Indonesia in 2022, with the number rising to 809,000 cases in 2023. This figure is significantly higher compared to the pre-pandemic years, when annual case detection averaged below 600,000 (3). The Ministry of Health has set a target for West Sulawesi Province to detect approximately 5,060 TB cases in 2024, with the aim of reducing the incidence rate by 80% toward TB elimination by 2030. Although the TB case detection rate has steadily increased over the past four years, from 51% in 2022 to 72% in 2023, it still falls short of the established target (4). Treatment adherence remains a significant challenge in achieving TB elimination goals (5). Therefore, strong commitment and tangible actions from all stakeholders are essential to accelerate TB control efforts, ensuring Indonesia meets its 2030 TB elimination target (6).

One approach to accelerating TB control efforts is by understanding both the spatial and temporal patterns of TB transmission (7,8). The combination of spatial analysis and time clustering provides in-depth, evidence-based data for policymakers to design more effective and targeted interventions (9). Results from these analyses can predict potential future hotspots(7), enabling earlier preventive measures to minimize disease transmission more effectively. Understanding the spatial and temporal distribution of TB is essential for planning focused control activities, particularly in resource-limited regions (10).

Although several studies on TB using spatial analysis and time clustering have been conducted in Indonesia (7,8,19–25,11–18) ,there is a lack of research specifically examining TB spatial distribution in regions with diverse topographies, such as West Sulawesi Province. Topography plays a critical role in the epidemiology of infectious diseases like TB. Geographic variations, especially between mountainous areas and lowlands, significantly influence TB distribution, transmission, and control. The physical condition of houses in mountainous areas, particularly ventilation, often does not meet health standards (26), additionally, the humidity and temperature in mountainous regions create a favorable environment for TB-causing bacteria (27). This situation is further exacerbated by limited access to healthcare facilities, including long distances, poor road conditions, and transportation difficulties, which hinder timely access to treatment in these areas (28).

Geospatial analysis allows for the identification of *most likely clusters*—areas with statistically significant concentrations of TB cases. Spatial analysis aimed at identifying high TB burden areas based on influencing factors can enhance surveillance efforts (29). Clustering knowledge is particularly beneficial for TB control, as it provides information on high-risk populations and areas (30). Identifying clusters and high-risk regions supports evidence-based decision-making in TB control efforts. This study also serves as a scientific foundation for designing more effective interventions in areas with limited healthcare access. Consequently, this research represents a crucial step in strengthening TB control strategies in Indonesia. The aim of this study is to identify geospatial clusters of TB cases in West Sulawesi Province, Indonesia, which features diverse topography.

METHOD

Research Type

This study used a quantitative approach with an ecological research design.

Population and Sample/Informants

The total population of the province is 1,481,077, with a population density of 89 individuals per km². The study included all bacteriologically confirmed and clinically diagnosed tuberculosis (TB) cases that received treatment between January 1, 2020, and December 31, 2023.

Research Location

The research was conducted in West Sulawesi Province, Indonesia, a region characterized by diverse topography, including lowland, highland, and mountainous areas. This geographic variability provides a unique context for exploring the relationship between topography and the spatial clustering of TB cases. Geographically, West Sulawesi lies between 0° 12' - 3° 38' South Latitude and 118° 43' 15" – 119° 54' 3" East Longitude (31).

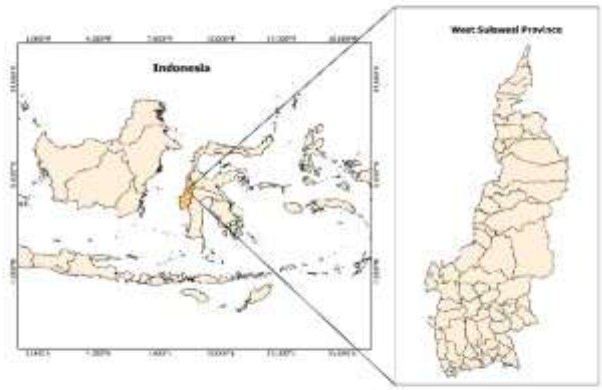

Figure 1. Location of the Study Area

Instrumentation or Tools

Sub-district population data were obtained from the Central Bureau of Statistics of each regency within West Sulawesi Province. Geographic coordinates (latitude and longitude) of village offices were collected via Google Maps.

Data Collection Procedures

TB case data were extracted from the Tuberculosis Information System (SITB), a digital surveillance platform managed by the West Sulawesi Provincial Health Office for recording and reporting TB cases (32). The dataset comprised aggregated TB case counts at the village or urban ward level.

Potential Bias

TB case data from the SITB include only diagnosed cases under treatment; latent infections and undiagnosed or unreported cases (e.g., those not accessing health services) were not captured, potentially leading to underestimation of the true disease burden.

Data Analysis

The spatial distribution of TB cases in West Sulawesi Province was analyzed using SaTScan v10.2.5 software (33). The analysis covered the period from January 1, 2020, to December 31, 2023, applied a Retrospective Purely Spatial and Space-Time Analysis using a discrete Poisson probability model. The temporal unit was defined monthly. The maximum spatial cluster size was set at 25% of the population at risk. Clusters with the highest log-likelihood ratio (LLR) were identified as primary (most likely) clusters, while others were classified as secondary clusters (34). Spatial visualization was performed using QGIS version 3.40.0 (35). Descriptive statistics were also used to summarize the trends of TB cases and the TB incidence rate in West Sulawesi Province from 2020 to 2023.

Ethical Approval

This study received ethical approval from The Research Bioethics Committee of Medicine/Health, Faculty of Medicine, Sultan Agung Islamic University, Semarang (Approval Number: 100/III/2024/Komisi Bioetik). The confidentiality of all data was strictly maintained throughout the research process.

RESULTS

Based on Figure 2, the trend of TB cases in West Sulawesi Province from 2020 to 2023 shows a steady increase. The highest number of cases was recorded in 2023, with 3,110 cases, while the lowest was in 2020, with 1,895 cases. The total number of TB cases over the four-year period amounted to 9,536 cases.

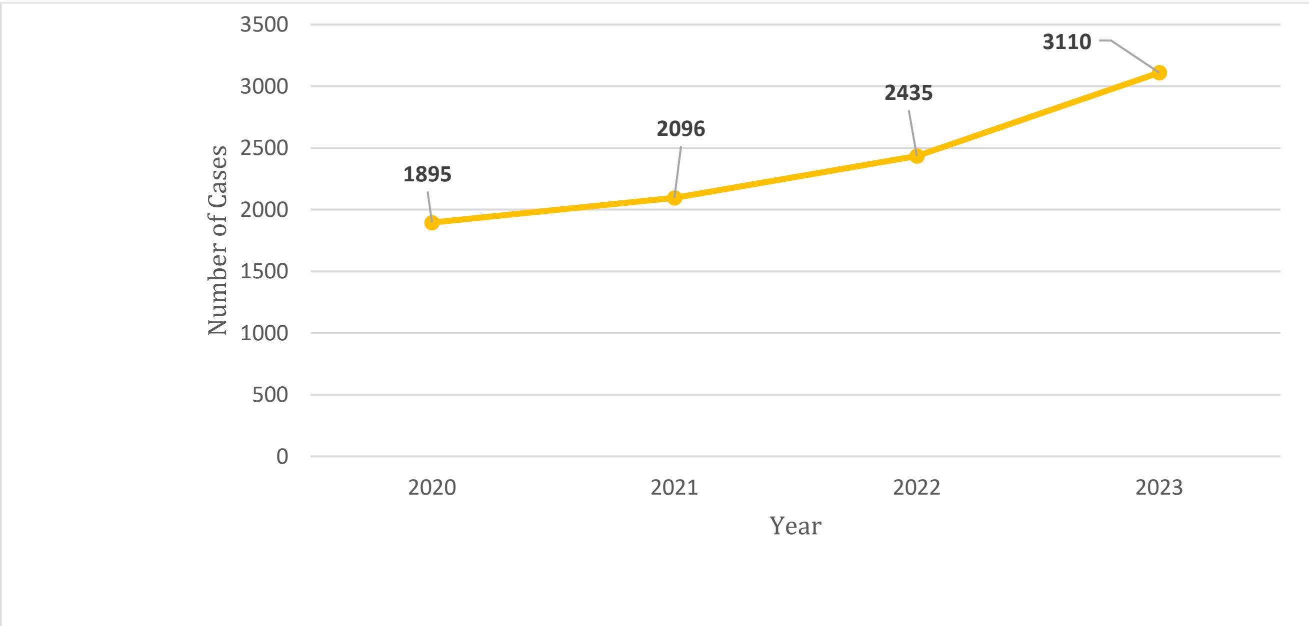

Figure 2. Trend of TB Cases in West Sulawesi Province (2020-2023)

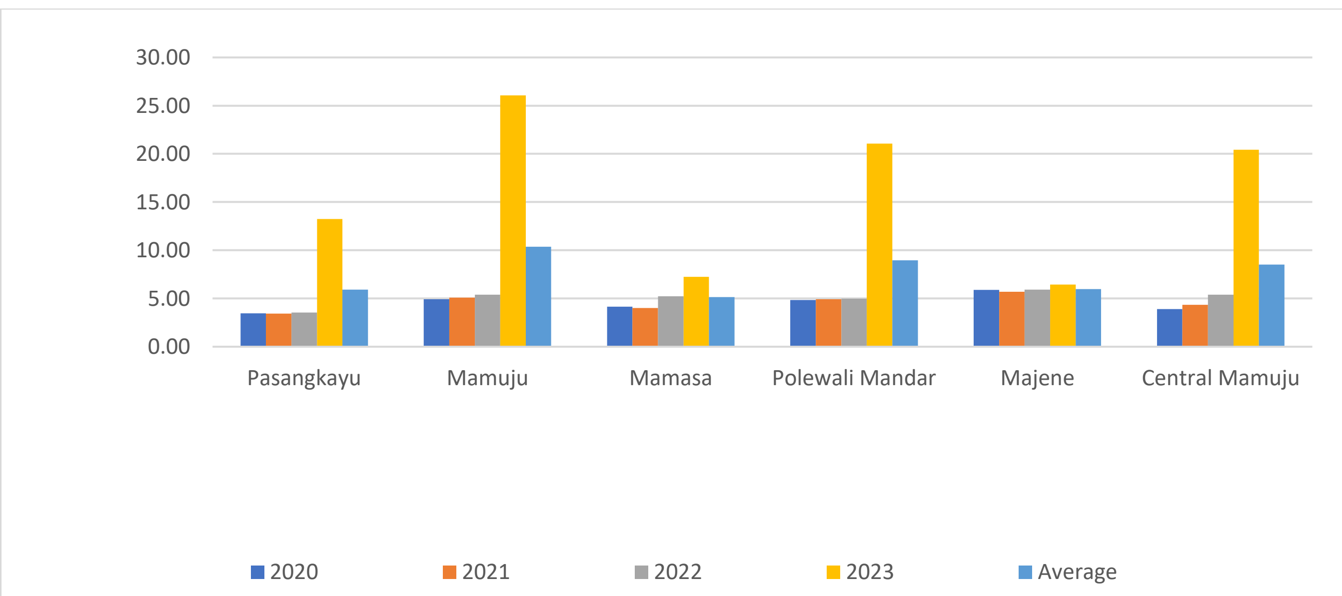

Figure 3. TB Incidence Rate in West Sulawesi Province (2020-2023)

According to Figure 3, the annual TB incidence rate during the four-year study period ranged from 3.43 to 26.08 per 10,000 population, with an average annual incidence rate of 7.34 per 10,000 population. The lowest incidence rate was recorded in Pasangkayu Regency in 2021, while the highest was observed in Mamuju Regency in 2023.

Table 1. Results of the TB Case Clustering Analysis for 2020-2023 with 25% Population (Purely Spatial Analysis)

Year	Cluster type	Geographical coordinates	Radius (km)	Cases (no.)	Expected cases (n0.)	People at risk (n0.)	RR	LLR	P*
2020	Most Likely cluster	-2.953518 S 119.198474 E	42.25	289	123.31	29123	2.59	88.45	<0.001
	1st secondary cluster	-3.382708 S 118.881657 E	19.56	204	113.49	26804	1.89	31.45	<0.001
	2nd secondary cluster	-2.395703 S 119.676162 E	45	43	18.77	4434	2.32	11.57	0.002
2021	Most Likely cluster	-2.911781 S, 119.421645 E	54.90	306	157.01	35882	2.11	61.07	<0.001
	1st secondary cluster	-3.327612 S, 118.843327 E	26.18	273	161.66	36944	1.79	34.97	<0.001
	2nd secondary cluster	-0.953045 S, 119.509177 E	6.48	39	14.41	3293	2.74	14.38	<0.001
	3rd secondary cluster	-3.491559 S, 119.083763 E	0	7	0.46	106	15.21	12.5	<0.001
	4th secondary cluster	-2.853993 S, 118.798627 E	20.36	123	83.01	18970	1.51	8.78	0.02
	5th secondary cluster	-2.234691 S, 119.386031 E	13.18	48	25.28	5776	1.92	8.19	0.039
2022	Most Likely cluster	-2.916930 S 119.261876 E	42.50	242	111.52	24844	2.30	60.74	<0.001
	1st secondary cluster	-3.382708 S 118.881657 E	18.48	206	119.10	26532	1.80	27.62	<0.001
	2nd secondary cluster	-3.085548 S, 118.836603 E	13.53	66	35.76	7967	1.87	10.39	0.011
	3rd secondary cluster	-2.264229 S 119.296965 E	18.41	141	98.68	21982	1.46	8.39	0.044
2023	Most Likely cluster	-2.911781 S 119.421645 E	49.26	321	145.85	30532	2.34	83.35	<0.001
	1st secondary cluster	-3.315823 S 118.849339 E	27.18	333	216.15	45247	1.61	29.45	<0.001
	2nd secondary cluster	-2.288651 S 119.301396 E	17.64	159	109.27	22875	1.48	10.32	0.017
	3rd secondary cluster	-2.853993 S 118.798627 E	20.36	199	143.34	30005	1.41	10.16	0.021

*Statistically significant at p=0.05

As shown in Table 1, the analysis detected a total of 17 clusters that statistically showed significance, with each having one main cluster (most likely cluster) during the four-year period. Additionally, there were 13 potential clusters (secondary clusters) detailed as follows: two in 2020, five in 2021, three in 2022, and three in 2023.

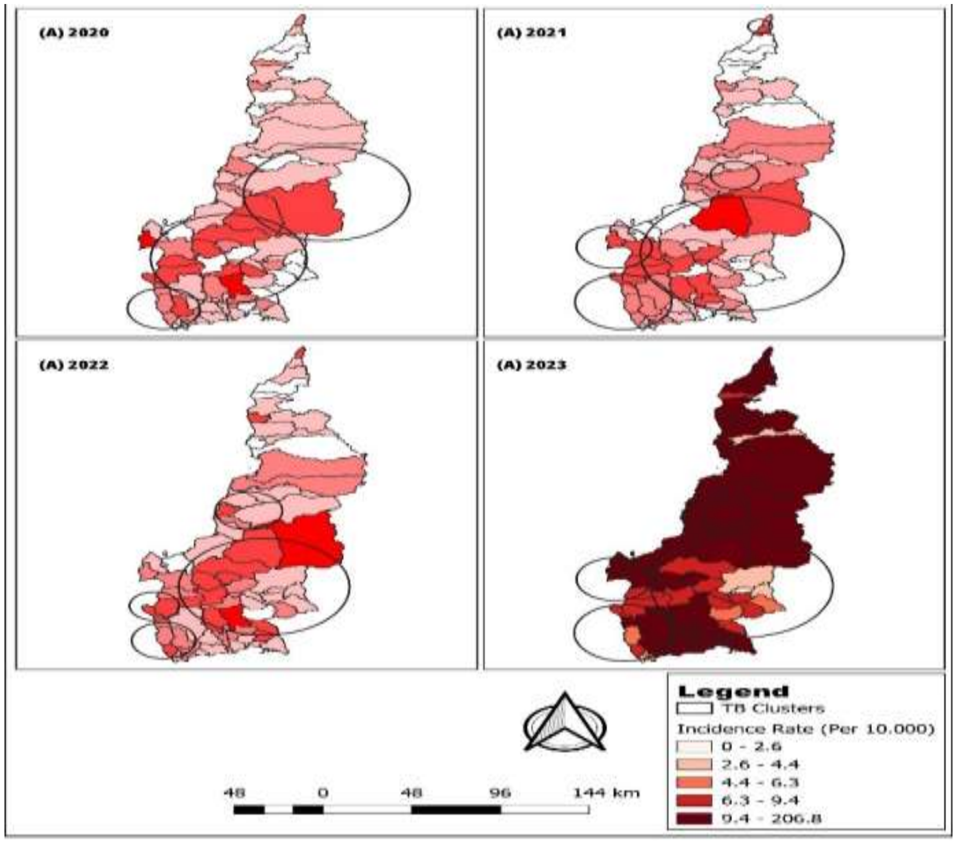

Figure 4. TB Clusters Map in West Sulawesi Province for 2020-2023

Based on Figure 4, it can be seen that the most likely TB clusters in West Sulawesi Province from 2020 to 2023 consistently remained in the same area, specifically in the eastern part of the province, which has a mountainous topography. In 2020, the main cluster was located in Bambang Village, Bambang Subdistrict, Mamasa Regency. In 2021, the main cluster was in Lambanan Village, Mamasa Subdistrict, Mamasa Regency. In 2022, the main cluster was in Ulumambi Barat Village, Bambang Subdistrict, Mamasa Regency. In 2023, the main cluster was in Lambanan Village, Mamasa Subdistrict, Mamasa Regency.

DISCUSSION

The number of tuberculosis (TB) cases in West Sulawesi Province from 2020 to 2023 has shown an increasing trend each year. This increase not only reflects the recovery of the healthcare system post-COVID-19 pandemic but also improvements in the detection and reporting systems, including the provision of laboratories and more adequate healthcare facilities. Indonesia's commitment to addressing TB is evident with the highest case notifications in history in 2022 and 2023. This is the result of strengthening the national program, focusing on case tracing and more intensive case management.

Geospatial analysis shows that the most likely TB clusters in West Sulawesi Province from 2020 to 2023 were consistently located in the eastern part of the province, namely Mamasa Regency, which has a mountainous topography. Previous research has shown that TB incidence tends to be higher in mountainous areas compared to non-mountainous areas (36). This study aligns with the research conducted by Chen, Jinou, et al. (2019), which stated that TB clusters were concentrated in the northeastern part of Yunnan, a mountainous region (37). Other studies have also reported the occurrence of TB clusters in mountainous areas (38). This may be linked to various environmental, social, and economic factors influencing TB transmission dynamics.

Based on population density analysis, the most likely TB cluster areas in Mamasa Regency had a low population density, which was 86 people/km² in 2020 and increased to 108 people/km² in 2023. Despite the low population density, TB clusters can still emerge in small communities with close contact, such as in Mamasa Regency. The settlement pattern in highland areas is highly influenced by topography and soil fertility. The settlement pattern in highland areas typically spreads along slopes and clusters in areas with fertile and relatively flat land (39). A lifestyle with intensive interaction within small communities can increase the risk of TB transmission, even though the overall population is not dense.

The physical condition of homes in mountainous areas, which are mostly traditional houses with poor ventilation, contributes to the increased risk of TB transmission through the air (26). Poor ventilation has been proven to significantly contribute to TB transmission (40–42). Research has mentioned that humidity impacts TB incidence (40,43). The high humidity and low temperatures at night in mountainous areas create an environment that supports the survival of *Mycobacterium tuberculosis*. Humidity affects the human circulatory system, increasing the human body's susceptibility to infectious diseases (27). Humid air supports the survival and reproduction of *Mycobacterium tuberculosis*, increasing the risk of TB (44,45).

Mountainous areas tend to be inhabited by communities with low economic status, inadequate sanitation, and overcrowded housing in small communities, which increases vulnerability to TB. There is a high risk for TB in areas associated with low socioeconomic conditions (41,46–49), with increased TB incidence in low-income populations (50). Overcrowded environments with poor housing conditions significantly contribute to TB transmission (29,40). Housing density also contributes to the occurrence and transmission of tuberculosis (41,42,51)

Socio-cultural factors have a significant influence on community perceptions of TB, contributing to its rapid and easy transmission to others (52). The low level of education in mountainous areas affects treatment-seeking behavior. Individuals with higher knowledge tend to have a broader perspective on healthcare services(53). Additionally, well-educated individuals are more likely to adhere to prescribed TB treatment and complete the full course of medication, reducing the risk of transmission and the development of drug resistance (54).

Furthermore, people in mountainous areas often seek treatment from traditional healers before visiting healthcare facilities (55). In some local cultures, TB may be perceived as a highly feared disease or associated with negative stigma, which can impact how individuals seek medical care, their participation in prevention programs, and their willingness to share information about TB (56). These factors contribute to undetected TB cases, delayed diagnosis, and incomplete treatment, allowing TB transmission to persist (57).

The difficult terrain of mountainous regions also limits access to healthcare facilities, leading to delays in diagnosis, treatment, and contact tracing. There are many barriers to accessing TB care, one of which is the difficulty in reaching healthcare facilities, especially in mountainous areas (58,59). Barriers to access healthcare centers include long distances to the nearest facility, poor road networks, lack of transportation access, and travel costs (28). The accumulation of undetected latent cases often develops into active TB, which then becomes a source of new clusters.

The limited availability of TB testing facilities in this area exacerbates delays in handling, which can increase the risk of local transmission. TB service facilities are unevenly distributed, which can heighten the risk of TB transmission and treatment costs for patients in rural areas (60). There are no sputum smear microscopy services available. The lack of adequate laboratory personnel has been identified as a barrier to the readiness of healthcare facilities to offer quality TB services (61). Improving access to TB diagnostic services is crucial to closing the global TB detection gap, and the deployment of effective mobile screening units can help achieve this goal (62).

Public health interventions, particularly for TB, are a complex series of processes, making a combined intervention approach essential (63). Integrated prevention interventions for public health workers and professional TB centers can reduce delays in TB treatment and expand access to TB treatment facilities (42). A combination of genotypic, molecular, and geospatial approaches to examine epidemiologically related cases can enhance TB control and significantly contribute to current knowledge (47). Future research should adopt a mixed-methods approach by integrating molecular epidemiology to track TB strain variations and gain a deeper understanding of transmission dynamics.

The national TB control program may not yet fully target the needs of mountainous areas such as Mamasa Regency, both in terms of the distribution of healthcare workers and the adjustment of intervention methods based on geographic conditions. TB control strategies that could be implemented in mountainous areas such as Mamasa Regency require a local-based approach, including: Mobile TB services to expand access to diagnosis and treatment, community education on TB prevention and management, enhancing surveillance systems to detect clusters earlier, and establishing TB communities as cadres or facilitators to raise awareness and strengthen community commitment to TB control. and providing better healthcare infrastructure considering the mountainous terrain.

CONCLUSION

A total of 17 statistically significant TB clusters were identified during the 2020-2023 period. All of the most likely clusters consistently appeared in Mamasa Regency, a region characterized by mountainous topography. The spatial patterns identified through SaTScan analysis also showed geographic consistency over time. These findings provide critical insights to inform targeted TB control policies, particularly in regions with diverse and challenging terrains. The study highlights the importance of strengthening surveillance systems, enhancing diagnostic capacity, and improving access to healthcare services in high-risk, mountainous areas. Furthermore, the results underscore the urgency of developing adaptive and context-specific intervention strategies to reduce TB incidence in geographically vulnerable regions. This study contributes a strong scientific foundation to support and accelerate global TB elimination efforts.

AUTHOR’S CONTRIBUTION STATEMENT

Research proposal design by: FI, AK, and IS; FA and HA drafted the proposal and collected data; MS and KR analyzed the data; FI wrote the manuscript. All authors read and approved the final manuscript. FI = Fahrul Islam; AK = Ain Khaer; IS = Iwan Suryadi; FA = Fajar Akbar; HA = Haeranah Ahmad; MS = Muhammad Syukri; KR = Kadar Ramadhan.

CONFLICTS OF INTEREST

All The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors acknowledge the use of generative AI-assisted technology, specifically ChatGPT by OpenAI, during the preparation of this manuscript. The tool was used strictly for language refinement and summarizing scientific references that had been previously reviewed by the authors. All use was conducted under the full supervision and intellectual direction of the authors. All scientific content including research design, data interpretation, and scholarly argumentation, remains the sole responsibility of the authors. The authors have reviewed and verified the accuracy and appropriateness of all AI-assisted outputs included in this manuscript.

SOURCE OF FUNDING STATEMENTS

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