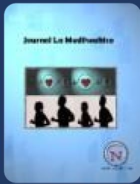

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Spatial Analysis of Childhood Tuberculosis in Boyolali Regency

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Abstract

Childhood tuberculosis (TB) in Boyolali Regency has shown a significant increase. Spatial analysis research has not previously been conducted in Boyolali, which prompted the researcher to investigate and analyze the spatial distribution patterns and clusters of childhood TB cases. This study employs a quantitative descriptive design and was conducted in the working area of the Boyolali Regency Health Office from March to June 2025. Sampling techniques involved secondary data geospatial collection, the use of geographic coordinates of primary health center administrative areas, and Google Earth. The data population included childhood TB cases in Boyolali Regency from 2021 to 2023, along with data on total population, population density, and BCG immunization coverage. The research instrument used a secondary data recording table. Data analysis was performed using QGIS and SaTScan software. The results identified significant clusters in the central and southern regions, particularly in the working areas of Boyolali 1 & 2, Mojosongo, Teras, and Banyudono health centers. Spatially, population density was found to influence the incidence of childhood TB cases, whereas BCG immunization coverage was not sufficient to suppress incidence rates.

Introduction

Tuberculosis (TB) is one of the top ten causes of death globally and is the leading cause of death from infectious diseases. This illness is caused by a complex organism known as Mycobacterium tuberculosis, which includes M. bovis and M. canetti (along with several other types that do not infect humans). TB can affect anyone, including children, adults, and the elderly. Although recovery is possible, delays in diagnosis and treatment can increase the risk of complications that may result in death (Rachmad et al., 2025). TB spreads through droplets or sputum particles from active patients when they cough, sneeze, or talk, which are then inhaled by healthy individuals (Girsang et al., 2023; Stadnytskyi et al., 2021; Swalehe & Obeagu, 2024; Randall et al., 2021; Coleman et al., 2022).

Recently, TB cases have been rising, particularly among vulnerable age groups such as children (Wulanda., 2021). Several factors that increase the risk of TB transmission in children include previous contact with adults who have TB, inadequate nutritional intake, and incomplete BCG (Bacillus Calmette-Guerin) immunization (Hasnanisa., 2023; Yang et al., 2021; Rajeshwar, 2024). Delays in diagnosis allow the infection to spread uncontrollably, thereby increasing the risk of severe complications and even death. Diagnosing TB in children is not easy, as it is often difficult to differentiate between primary infection (which typically does not cause significant lung damage) and Pulmonary Tuberculosis, which can lead to overdiagnosis and overtreatment in children (Fitriyani & Sari, 2021; Bothamley et al., 2023; Vonasek et al., 2021).

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According to the WHO Global Tuberculosis Report 2020, it is estimated that around 10.6 million people worldwide were affected by active TB in 2022. Of this number, approximately 1.3 million cases were in children under the age of 15, making TB the leading cause of death among children (Siame & Chama, 2025). The African continent recorded around 320,000 TB cases in children. This figure represents a significant proportion, accounting for one-third of all childhood TB cases globally (Dhanny & Sefriantina., 2022). It is estimated that around 67 million children have received the BCG vaccine to prevent severe TB. However, approximately 400,000 children with TB go undetected or unrecorded each year. Furthermore, 96% of children who die from TB do not receive adequate access to TB treatment (Brigden et al., 2021).

Based on the 2022 Indonesian Health Profile data released by the Center for Data and Information (Pusdatin) of the Indonesian Ministry of Health, TB cases in children accounted for 11.98%, or approximately 63,111 cases. Of that number, most cases were found in boys, with a total of 33,122 cases, while cases in girls were recorded at 29,989 (Andini & Martya., 2021). A total of 101,160 children should have been detected and treated for TB, but only about 62% were reached. This indicates that efforts to detect and treat TB in children have not yet met the expected target of 75% (Ministry of Health, Republic of Indonesia, 2022).

There should be approximately 101,160 children infected with TB who need to be detected and treated. West Java, Central Java, and East Java recorded the highest number of cases in Indonesia (Bunga, E. 2022). These three provinces accounted for about 38% of all TB cases in Indonesia (Ministry of Health, Republic of Indonesia, 2022). TB cases in Central Java Province remain high. According to the Health Office's pocketbook, during the third quarter of 2022, 42,148 TB cases were reported, equivalent to 113.8 cases per 100,000 population. Data from the Boyolali Regency Health Office also revealed a sharp increase in TB cases among children. The incidence rate of childhood TB rose from 22 cases per 100,000 population in 2021 to 50 cases per 100,000 population in 2022, then dramatically increased to 187 cases per 100,000 population in 2023. This significant rise indicates an alarming development in the spread of TB among children in the Boyolali Regency (Boyolali Regency Health Office, 2021, 2022, 2023).

The World Health Organization (WHO) has set an ambitious target to eliminate tuberculosis. It aims to reduce TB incidence by 80% and TB-related deaths by 90% by 2030 (Amalia & Setiyadi., 2021). The Indonesian Ministry of Health has also prepared a strategic plan in line with global goals to eliminate TB by 2030. The target is to reduce the incidence to 80%, or 65 cases per 100,000 population, and to reduce the mortality rate to 6 per 100,000 population. This goal will be achieved by expanding TB detection and treatment coverage to 90%, increasing TB treatment success rates to 90%, and providing TB preventive therapy (TPT) to 80% of at-risk populations (Roempoembo & Winarti., 2024). However, the TB treatment success rate in Indonesia has not yet reached the national target. In 2021, Indonesia recorded only a 73% treatment success rate, while the national target was 90% (Nayaka, 2023).

Here is how community participation can help address TB: Educating and Spreading Information raising public awareness through education and outreach is crucial (Purwoko et al., 2020). Efforts to educate the public on TB prevention and treatment have been carried out by local governments, for example in Bandung City. To ensure successful educational strategies and awareness campaigns, strong collaboration between governments, educational institutions, non-governmental organizations, and local communities is essential (Rachmawati & Cancerita., 2021; Potts-Datema et al., 2005; O'Sullivan, 2008). Additionally, the use of interactive methods, such as incorporating social games into TB education, has proven effective in increasing community engagement and learning outcomes (Sudana et al., 2020; Questa et al., 2020; Bonney et al., 2009).

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Utilizing Geographic Information Systems (GIS) to visualize health data in the form of maps is an effective strategy. This approach can help policymakers at all levels of government make better-informed decisions on key health issues. Furthermore, this visualization simplifies the selection of appropriate health programs for implementation at regional and regency health facilities (Srisantyorini et al., 2019). GIS can also be used as a teaching tool to evaluate the effectiveness of past public health programs (Rachmawati & Cancerita., 2021).

Geographic Information Systems (GIS) can be used to analyze and create maps related to health data. For instance, GIS can visualize the geographic distribution of vulnerable populations, disease outbreaks and health issues, the location of health facilities, and analyze potential factors contributing to diseases. Moreover, this technology can be used to measure the correlation between risk factors and health outcomes resulting from environmental health issues, as well as the impact of communicable and vector-borne diseases (Rachmawati & Cancerita., 2021). The analysis results can serve as a basis for decision-making in determining which population groups and geographic areas should be prioritized when implementing health programs (Rachmawati & Cancerita., 2021).

According to a study by Nayaka et al. (2023), the use of GIS to analyze the spatiotemporal distribution of new smear-positive pulmonary TB cases in Batang Regency showed a decline in the number of houses meeting health standards over time and with increasing population. Meanwhile, in terms of location, altitude did not appear to significantly affect the pattern of new pulmonary TB case distribution. Additional information was obtained from research by Hartanto et al., who studied the spatial distribution of pulmonary tuberculosis in Semarang City.

Their findings showed that nearly all pulmonary TB cases were found in high-density areas (more than 400 people/km²) and areas with altitudes below 150 meters above sea level (Hartanto et al., 2023). Meanwhile, research by Tamiima (2022) in Sorolangun Regency during 2015–2021 showed a negative spatial autocorrelation, indicating that TB case distribution tended to be scattered rather than forming clusters. This suggests that other factors such as population mobility and social heterogeneity influence the distribution pattern. Therefore, it can be concluded that GIS is effective for data mapping and can serve as a valuable reference to guide policymakers in determining health priorities.

Currently, spatial analysis has not yet been utilized in Boyolali Regency, and there is no clear data distribution regarding childhood TB cases. This situation reflects a lack of information needed to understand the disease's prevalence in Boyolali Regency. Without sufficient data, efforts to prevent and treat TB in children become more difficult, as the extent of disease spread cannot be accurately determined. Based on the background explained above, the researcher is interested in conducting a spatial study on childhood TB incidence in Boyolali Regency. This study aims to understand the distribution pattern of childhood TB cases and observe the factors related to TB incidence in Boyolali from 2021 to 2023, so that it can serve as a foundation for designing more effective disease control strategies.

Methods

This study is a descriptive quantitative research using a Geographic Information System (GIS) approach aimed at analyzing the spatial distribution patterns and clusters of childhood tuberculosis (TB) cases in Boyolali Regency from 2021 to 2023. The sampling technique involved the collection of secondary geospatial data, including the use of geographic coordinates of primary healthcare administrative areas and Google Earth. Spatial data of primary healthcare boundaries were obtained from shapefiles downloaded from open-access sources, analyzed using QGIS, and validated through overlay with OpenStreetMap layers and recent satellite imagery from Google Earth to ensure conformity with actual administrative boundaries. All spatial data layers were reprojected to a unified coordinate reference system

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(EPSG:4326 – WGS 84) using QGIS to prevent spatial misalignment. The spatial unit of analysis was the health center administrative area (Puskesmas catchment area), as this aligns with the health service delivery structure and TB surveillance reporting. Clusters were identified using SaTScan's Discrete Poisson Model, with minimum cluster size set at 5 cases and maximum radius at 50% of population at risk to reduce false-positive detection. The data used in this study are secondary data, including the number of childhood TB cases from 2021 to 2023, population size, population density, and BCG immunization coverage, obtained from the Boyolali District Health Office and the Central Bureau of Statistics of Boyolali Regency. The research instrument consisted of a data recording table for secondary data. Data analysis was conducted using GIS to produce spatial maps of the study area, with spatial analysis performed on the related variables. The data were analyzed using QGIS and SaTScan software.

Results and Discussion

Research Area

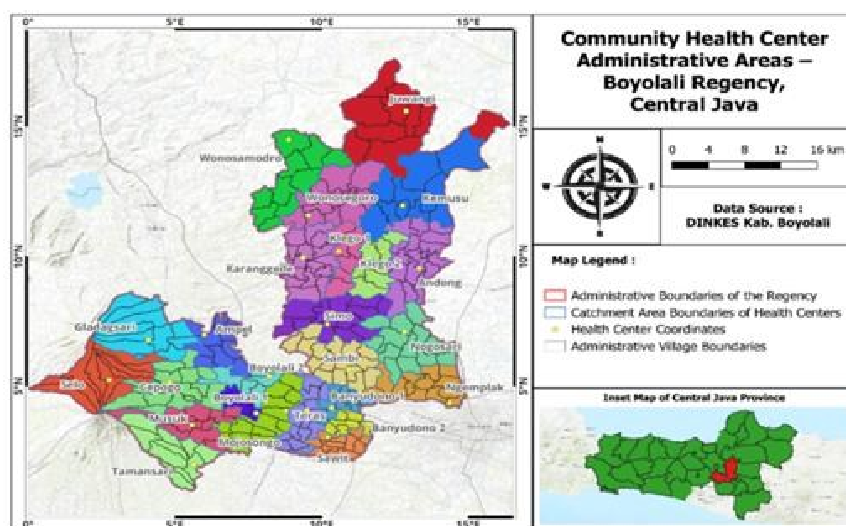

Figure 1. Community Health Center Administrative Areas Boyolali Regency Central Java

This study was conducted within the working areas of all Puskesmas (Community Health Centers) across Boyolali Regency from 2021 to 2023. Spatial analysis identified a total of 25 Puskesmas (Health Centers) located within 22 districts, with three districts Boyolali, Banyudono, and Klego each having two Puskesmas (Health Centers).

Overview of Childhood TB Cases in 2021–2023

Childhood tuberculosis (TB) cases in Boyolali Regency, recorded across 25 Community Health Centers (Puskesmas) from 2021 to 2023, showed fluctuations in the number of reported cases. The findings revealed that some areas consistently reported childhood TB cases over the past three years. The study also found several Puskesmas (Health Centers) that reported only one case or no cases at all in certain years. Meanwhile, some districts experienced significant increases and decreases in the number of cases. Table 1 presents the number of childhood TB cases from 2021 to 2023 as follows:

Table 1. Childhood TB Cases in Boyolali Regency, 2021–2023

Health Center	Child TB Cases in 2021	Child TB Cases in 2022	Child TB Cases in 2023	Child TB Cases in 2021–2023
Selo	0	0	1	1
Ampel	2	3	12	17
Gladagsari	2	3	0	5

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Cepogo	3	7	13	23
Musuk	1	4	9	14
Tamansari	0	3	5	8
Boyolali 1	1	10	24	35
Boyolali 2	7	7	38	52
Mojosongo	6	5	63	74
Teras	2	12	31	45
Sawit	1	4	7	12
Banyudono 1	3	7	16	26
Banyudono 2	0	5	8	13
Sambi	0	6	30	36
Ngemplak	0	7	34	41
Nogosari	5	4	26	35
Simo	5	2	13	20
Karanggede	1	9	6	16
Klego 1	0	1	4	5
Klego 2	1	2	4	7
Andong	1	2	7	10
Kemusu	1	1	1	3
Wonosegoro	0	1	4	5
Wonosamudro	0	3	1	4
Juwangi	0	1	2	3
Total	42	109	359	510

Descriptive Analysis of the Distribution of Childhood TB Cases in 2021–2023

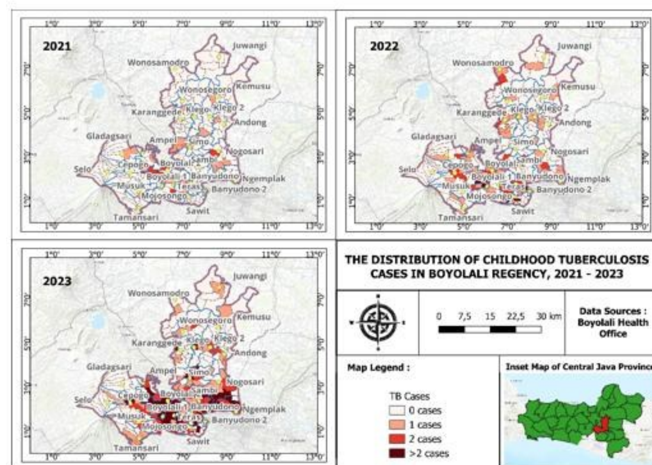

Figure 2. The Distribution Of Childhood Tuberculosis Cases In Boyolali 2021-2023

In 2021, most areas in Boyolali Regency reported no childhood TB cases (displayed in white on the map). Only a few locations reported 1 case (light red) or 2 cases (red). Areas with 2 childhood TB cases included specific villages within the working areas of Nogosari Health Center, Tamansari Health Center, Boyolali 1 Health Center, and Boyolali 2 Health Center, with the highest number of cases found in the Boyolali 2 area. These findings indicate that the distribution of childhood TB in 2021 was still limited to certain health centers.

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In 2022, there was a significant increase in both the number and distribution of childhood TB cases. More areas experienced cases compared to 2021. Dark red, indicating more than 2 cases (>2), began to appear especially in several villages within the working areas of Teras Health Center, Banyudono 2 Health Center, and Boyolali Health Center with the highest number of cases found in the Teras area. This indicates a geographic expansion of childhood TB spread in the central region of Boyolali Regency. Areas that previously reported no cases began to show 1–2 cases, highlighting the need for enhanced early detection and prevention measures.

In 2023, a major surge occurred in both the number and spread of childhood TB cases. Several areas in Boyolali Regency showed high-intensity color zones, particularly dark red (>2 cases). The southern and central regions such as Boyolali 1 & 2 Health Centers, Mojosongo Health Center, Teras Health Center, Banyudono Health Center, Ngemplak Health Center, and Nogosari Health Center recorded the highest number of cases, with Mojosongo reporting the most. Previously low-risk areas such as Selo, Kemusu, and Wonosegoro also began to report new cases. This indicates that childhood TB has become a more serious and widespread public health issue, requiring stronger interventions for control and mitigation.

Descriptive Analysis of Childhood TB Cases in Relation to Population Variables (2021–2023)

Relationship Between Childhood TB Cases and Population Size

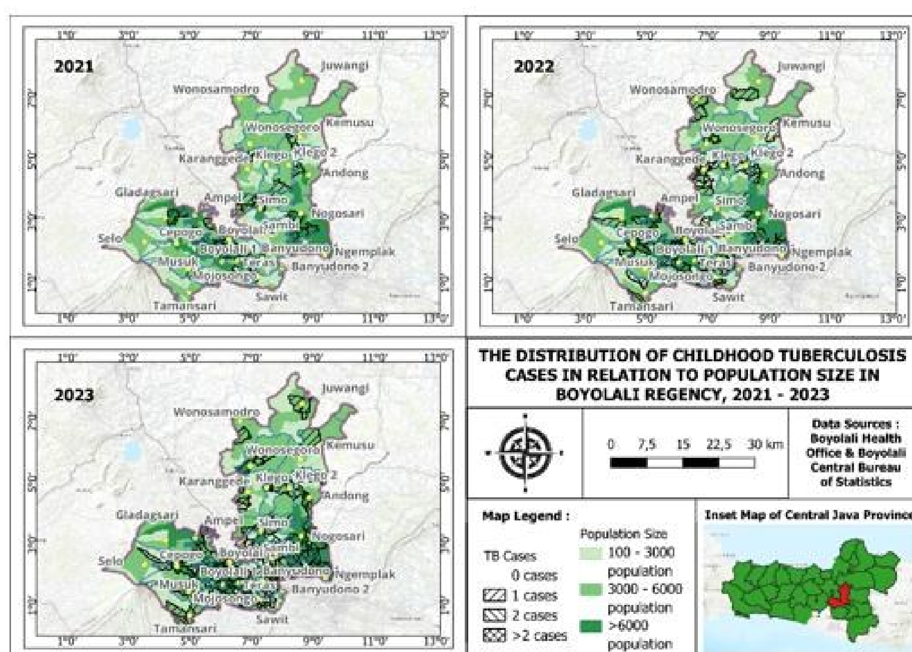

Figure 3. The Distribution Of Childhood Tuberculosis Cases In Relation To Population Size In Boyolali Regency 2021-2023

The 2021 map shows that most areas in Boyolali Regency did not report any childhood TB cases (indicated by the absence of shading). Several villages within the working areas of health centers with high population sizes (>6,000 residents) such as Ampel, Cepogo, Boyolali 1 & 2, Mojosongo, and Nogosari began to show childhood TB cases, mostly with 1 to 2 cases (indicated by diagonal right and left shading). However, no area reported more than two cases. Overall, the distribution of childhood TB cases in 2021 remained relatively low and was not evenly spread throughout the region.

In 2022, there was an increase in the spread of childhood TB cases compared to the previous year. Areas with one or two cases expanded both in number and geographic coverage. Cases exceeding two began to emerge in several villages, such as those in the working areas of Teras Health Center, Banyudono 2 Health Center, and Boyolali 1 Health Center. Regions with high

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population density tended to experience more cases, suggesting a correlation between population density and the number of childhood TB cases. However, some less populated areas still reported no cases (white areas), especially in the northern and western regions.

The 2023 map revealed a significant increase in the distribution of childhood TB cases. Most of the central, southern, and western areas already reported childhood TB cases, with many showing more than two cases (indicated by full crosshatching). Areas such as the Boyolali 1 & 2, Mojosongo, Teras, Banyudono, Ngemplak, and Nogosari Health Centers became the main clusters with the highest case distribution. Nearly all high-population areas reported childhood TB cases. Additionally, several areas with medium population sizes (3,000–6,000 residents) also began to report more than two cases. This indicates an increase in transmission and/or improved case detection and reporting.

Relationship Between Childhood TB Cases and Population Density

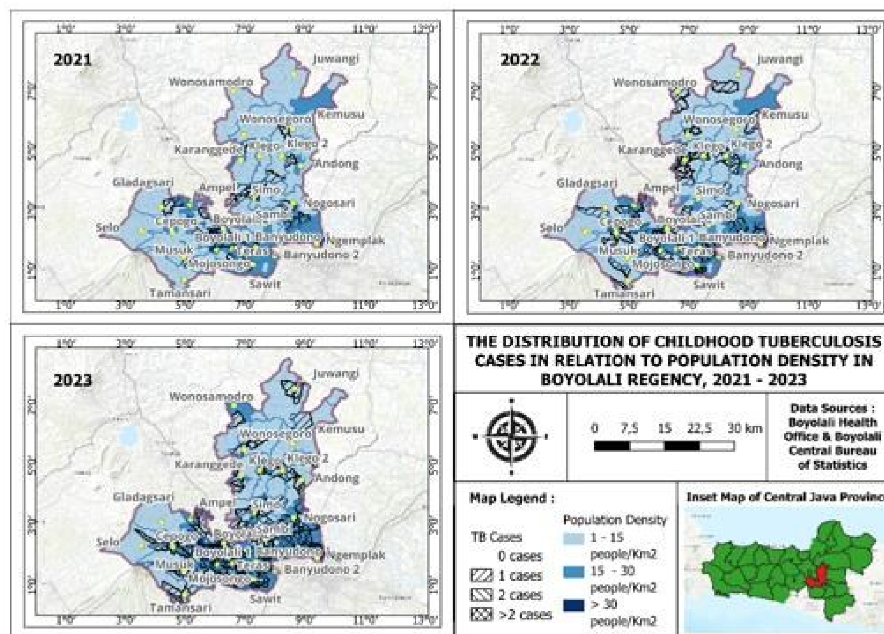

Figure 4. The Distribution Of Childhood Tuberculosis Cases In Relation To Population Density In Boyolali Regency 2021-2023

In 2021, areas with high population density (>30 people/km²) were generally located in the southern part of Boyolali Regency, such as the working areas of Boyolali 1 and 2 Health Centers, Banyudono 1, and Ngemplak. These densely populated areas recorded more childhood TB cases (indicated by diagonal shading). TB cases also appeared in areas with medium density (15–30 people/km²), such as the working areas of Nogosari, Sawit, Mojosongo, and Gladagsari Health Centers. In contrast, areas with low population density (1–15 people/km²), such as Selo, Wonosamodro, and Juwangi Health Centers, generally did not report any cases. The distribution of childhood TB cases tended to follow the pattern of population density, where the denser the area, the higher the number of reported childhood TB cases.

In 2022, the distribution of childhood TB cases increased in several areas compared to the previous year. Some villages within health center working areas with high population density (>30 people/km²), such as Ngemplak and Boyolali 1, showed a rise in the number of cases, even reaching more than two cases. Medium-density areas (15–30 people/km²), such as Mojosongo, Sawit, Banyudono 1 & 2, and Nogosari, continued to report cases. On the other hand, low-density areas such as Selo and Juwangi remained relatively unaffected or only recorded one case. The distribution pattern remained consistent, with most TB cases occurring in densely populated areas. However, there were signs that cases began to appear more evenly in medium-density areas, suggesting a wider potential spread compared to 2021.

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In 2023, the number and distribution of childhood TB cases increased significantly. The rise was especially evident in the southern areas, such as the working areas of Boyolali 1 & 2, Teras, and Ngemplak, which are classified as high-density regions. These areas dominated with more than two cases per area. In addition, moderately populated areas such as Mojosongo, Sambi, and Nogosari also recorded more cases than the previous year. Some areas that previously reported no cases, such as Kemusu and Wonosegoro, began to record one or two cases. This pattern further reinforces the positive correlation between population density and the number of childhood TB cases and indicates a possible broader transmission to areas with medium and low population densities.

Relationship Between Childhood TB Cases and BCG Immunization Coverage

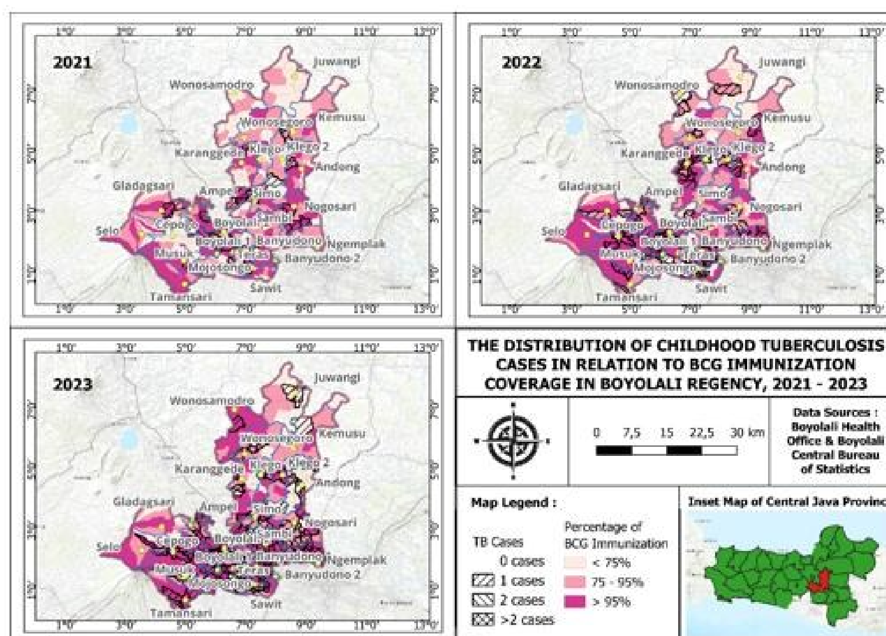

Figure 5. The Distribution Of Childhood Tuberculosis Cases In Relation To BCG Immunization Coverage In Boyolali Regency 2021-2023

In 2021, most areas in Boyolali Regency showed high BCG immunization coverage, particularly above 95%, indicated by a deep fuchsia color. Nevertheless, childhood TB cases were still reported in several areas with high immunization coverage, including the working areas of Musuk, Boyolali 1 & 2, Mojosongo, Nogosari, and Simo Health Centers, each recording one to two cases. This indicates that high immunization coverage does not fully guarantee that an area will be free of childhood TB cases. Conversely, some areas with low immunization coverage (<75%), such as those in the working areas of Cepogo and Juwangi Health Centers, reported no childhood TB cases.

In 2022, BCG immunization coverage generally remained dominated by areas with coverage above 95%. However, compared to the previous year, there was an increase in the number of areas with childhood TB cases, particularly in the central and western parts of the regency. Health centers such as Karanggede, Sambi, and Gladagsari experienced an increase in childhood TB cases, with several areas reporting one to two cases. In contrast, health center areas with low immunization coverage continued to show low or even zero cases, such as parts of Selo and Juwangi. This pattern further emphasizes that immunization coverage is not the only factor influencing the spread of childhood TB.

In 2023, a surge in the number of areas with childhood TB cases was observed. Nearly all areas in the central and southern parts of Boyolali Regency showed higher case intensity, with most health centers recording more than two childhood TB cases. Although BCG immunization coverage remained relatively high in many areas, childhood TB cases continued to be

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widespread and even expanded compared to the previous two years. Areas such as Ampel, Teras, Boyolali 1 & 2, and Cepogo, which were previously relatively stable, now showed a significant increase in the number of cases. This phenomenon indicates that although the immunization program remains well implemented, a more comprehensive and multi-faceted approach is required.

Cluster Analysis of Childhood TB Cases

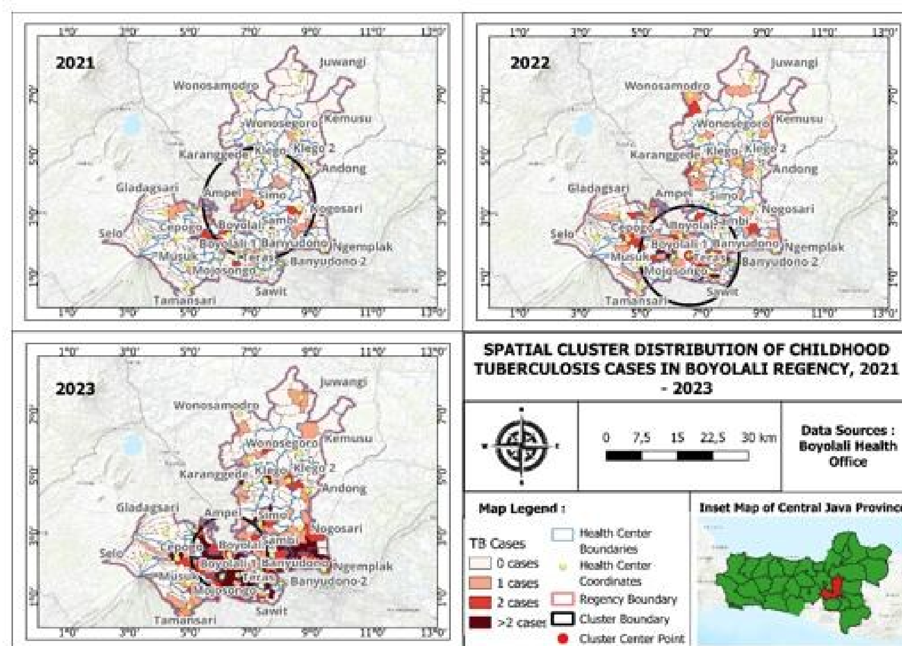

Figure 6. Spatial Cluster Distribution Of Childhood Tuberculosis Cases In Boyolali Regency 2021-2023

In 2021, the spatial distribution of childhood tuberculosis (TB) cases in Boyolali Regency showed an uneven pattern, with higher concentrations of cases in specific areas. Based on SaTScan analysis using the Discrete Poisson model, one statistically significant cluster was identified, encompassing nine health center areas: Simo, Nogosari, Karanggede, Boyolali 2, Klego 1, Klego 2, Banyudono 1, Teras, and Mojosongo. This cluster was centered at coordinates 7.439441° S and 110.676026° E, with a radius of 11.78 km and a population of 391,426. Of the 42 total childhood TB cases recorded in the regency, 30 occurred within this cluster, whereas the expected number was around 15.21. The observed-to-expected ratio (O/E) was 1.97, with a relative risk (RR) of 4.40 and a p-value of 0.00026, indicating strong statistical significance. This means that in 2021, if there was a childhood TB case within the cluster, individuals residing within a 11.78 km radius of the case's location had a 4.40 times higher likelihood of contracting tuberculosis. This suggests a non-random concentration of childhood TB cases, particularly in the central part of the regency.

In 2022, the distribution of childhood TB cases in Boyolali Regency showed a significant increase compared to the previous year. Based on spatial analysis using the SaTScan method, one statistically significant primary cluster was identified, covering eight health center areas: Mojosongo, Teras, Boyolali 1, Boyolali 2, Banyudono 1, Banyudono 2, Sawit, and Musuk. The cluster was centered at coordinates 7.537455° S and 110.635289° E with a radius of 10.49 km, encompassing a population of 307,903. Within this cluster, 54 childhood TB cases were recorded, compared to the expected number of 30.64 cases, yielding an observed-to-expected ratio of 1.76 and a relative risk (RR) of 2.51, with a p-value of 0.00026, indicating high statistical significance. This means that in 2022, residents within a 10.49 km radius of a childhood TB case had a 2.51 times greater risk of infection. In general, TB cases were more

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widely distributed across various areas, with the highest concentration in the southern and southwestern parts of the regency.

In 2023, there was a significant surge in childhood TB cases in Boyolali Regency, with a total of 359 cases and an annual incidence of 32.5 per 100,000 population, a sharp increase from previous years. Based on spatial analysis using the Purely Spatial method and Discrete Poisson model, one statistically significant primary cluster was identified, covering the health center areas of Boyolali 1, Boyolali 2, Mojosongo, Teras, and Banyudono 1. This cluster was centered at coordinates 7.496620° S and 110.618103° E, with a radius of 8.05 km and a population of 222,896. A total of 172 childhood TB cases occurred within this cluster, compared to the expected number of 72.49 cases. The observed-to-expected ratio was 2.37, and the relative risk (RR) was 3.64, with a p-value of 0.0001, indicating strong statistical significance. This means that in 2023, if a childhood TB case occurred within the cluster, individuals living within an 8.05 km radius of that case had a 3.64 times higher likelihood of contracting tuberculosis. The spatial pattern shows that the southern, southwestern, and southeastern regions of Boyolali have become the epicenters of case accumulation.

Table 2. Cluster Analysis of Childhood TB Cases

Year	**Cluster type**	**Coordinates (Latitude, Longitude)**	**Period**	**Radius (km)**	**Case s (n)**	**Expected Case (n)**	**People at risk**	**RR**
2021	Most Likely Cluster	7.439441 S, 110.676026 E	1/1/2021 – 31/12/2021	11.78	30	15.21	391.426	4.4
2022	Most Likely Cluster	7.537455 S, 110.635289 E	1/1/2022 – 31/12/2022	10.49	54	30.64	307.903	2.51
2023	Most Likely Cluster	7.496620 S, 110.618103 E	1/1/2023 – 31/12/2023	8.05	172	72.49	222.896	3.64

Discussion

Incidence of Childhood TB Cases in Boyolali Regency (2021–2023)

The data on childhood tuberculosis (TB) cases in this study were obtained from officially reported records by the Boyolali Regency Health Office during the period of 2021 to 2023. Childhood TB cases in Boyolali showed a significant increase over the years: 42 cases in 2021, rising to 109 in 2022, and then surging to 359 cases in 2023. In 2021, childhood TB cases were relatively low and concentrated in only a few Puskesmas (Health Center) service areas. Most villages under the 25 Puskesmas (Health Centers) did not report any cases at all (indicated in white on the map). The majority of reported villages had only one or two cases, mostly located in the working areas of Nogosari, Mojosongo, Simo, Boyolali 1, and Boyolali 2.

The low number of reported TB cases in 2021 may be attributed to the COVID-19 pandemic, which caused several health facilities to limit sputum examination for suspected TB due to operational restrictions. This aligns with findings from Amalia & Setiyadi (2021), who stated that the COVID-19 pandemic had a negative impact on TB case detection, particularly for children, due to reduced health services and shifting healthcare priorities. The low case numbers may also reflect suboptimal case reporting and limited case finding. Moreover, the coverage of TB screening and diagnostic services in 2021 across Boyolali Puskesmas (Health Centers) may not have been evenly distributed, possibly leading to undetected mild cases (Ratnasari et al., 2021). This explains why only a few areas reported cases, while the majority appeared as "zero case" zones.

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In 2022, there was a notable increase in both the number (109 cases) and geographical spread of childhood TB. Areas previously "clean" from cases began to report one or two cases. High-intensity clusters (marked in dark red) started to appear in villages under the Puskesmas (Health Centers) of Teras, Banyudono 2, and Boyolali 1, indicating a wider transmission of childhood TB compared to the previous year. According to the Ministry of Health of Indonesia (Kemenkes RI), increased detection of childhood TB in certain regions is often linked to active case finding and improved reporting mechanisms. A study in Pakistan (Malik, Hussain, Creswell, et al., 2021) showed that implementing active case finding and contact tracing programs could triple the number of detected cases compared to non-intervention periods. In Boyolali, the local government and health authorities in 2022 began strengthening case detection efforts by enhancing reporting systems and providing incentives for field workers to conduct home visits. While this may have contributed to the increase in reported cases, it may also reflect a real increase in community transmission, particularly in medium to high-density areas.

The year 2023 marked the peak of childhood TB incidence in Boyolali, with 359 reported cases. Almost all Puskesmas (Health Centers) reported at least one case, with high-intensity areas (>2 cases) concentrated in the Puskesmas (Health Centers) working areas of Boyolali 1 & 2, Mojosongo, Teras, Banyudono, Ngemplak, and Nogosari. This widespread increase suggests that childhood TB was no longer a localized issue but had become a regency-wide public health concern. This finding is consistent with national and provincial trends that showed increased childhood TB cases post-COVID-19, where TB screening services had been disrupted during 2020–2021 (Ministry of Health RI, 2022). According to WHO, post-pandemic years saw a rise in TB cases in densely populated areas. A similar trend occurred in Boyolali, where high-density regions such as Boyolali 1 & 2, Mojosongo, Teras, and Ngemplak became epicenters in 2023. Overall, these distribution patterns confirm that both demographic factors (population density) and service factors (improved detection) played a significant role in the spatial expansion of childhood TB in Boyolali Regency.

Environmental Factors: Population Size and Density

Population size refers to the number of individuals residing in a specific administrative region. Descriptive analysis from 2021–2023 shows that the majority of childhood TB cases occurred in villages with high populations (>6,000 people). In 2021, areas such as Ampel, Cepogo, Boyolali 1 & 2, Mojosongo, and Nogosari—with relatively large populations—already recorded 1–2 childhood TB cases. This trend intensified in 2022 and 2023, with densely populated villages not only reporting cases but shifting into high-category zones (>2 cases), particularly in Boyolali 1 & 2, Teras, and Mojosongo.

The positive correlation between population size and TB incidence has been established in previous studies. Areas with larger populations tend to have more cases (Surjati Endang, 2020). Additionally, some moderately populated villages (3,000–6,000 people), such as those in the Sambi, Ngemplak, and Nogosari areas, also experienced case spikes, suggesting that TB transmission is not limited to highly populated zones. Hartanto et al. (2023) observed that high inter-village mobility can increase the risk of respiratory disease transmission, such as TB, due to a higher likelihood of contact with infected individuals. In Boyolali, inter-regional mobility (e.g., for economic or educational activities) increased following the relaxation of COVID-19 restrictions, creating new risks of transmission in previously unaffected villages.

Population density (people/km²) also showed a strong positive correlation with the number of TB cases. In 2021, several high-density areas (>30 people/km²), such as Boyolali 1, Boyolali 2, Banyudono 1, and Ngemplak, reported childhood TB cases (1–2 cases), while low-density areas (<15 people/km²), such as Selo, Wonosamudro, and Juwangi, typically did not report any cases. This pattern became more pronounced in 2022 and 2023, as high-density regions

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(Boyolali 1 & 2, Teras, Mojosongo, Ngemplak) emerged as the epicenters of the outbreak. High-density areas increase the risk of exposure to TB, and children are especially vulnerable when exposed in such environments (Deva, 2018). This supports the findings of Hajarsjah et al. (2018), who stated that population density influences the risk of childhood TB, as denser populations lead to more intense interpersonal interactions, facilitating the spread of Mycobacterium tuberculosis.

The number and distribution of people in an area determine its population density, which in turn affects the speed of disease transmission, the number of potential patients during outbreaks, and the adequacy of available health services (Hastuti et al., 2016). High population density is one of the main contributors to TB incidence. This research aligns with findings by Saputra & Wahjuni (2020), which confirmed a significant influence of population density on TB incidence. Thus, the results of this study reaffirm that population density is a key demographic factor affecting the distribution of childhood TB.

BCG Immunization Coverage

BCG immunization is a major protective intervention against severe TB in children. However, research has shown varying levels of BCG effectiveness in reducing TB incidence (Wulanda., 2021). The findings of this study indicate that, from 2021 to 2023, most areas in Boyolali had BCG coverage rates above 95%, yet childhood TB cases continued to emerge and even increased over time. In 2021, nearly all villages reported BCG coverage of ≥95%, yet some Puskesmas (Health Centers) areas—including Musuk, Boyolali 1 & 2, Mojosongo, Nogosari, and Simo—still recorded 1–2 TB cases. In 2022, even as BCG coverage remained high, areas such as Karanggede, Sambi, and Gladagsari also saw increased childhood TB cases. This suggests that high vaccination coverage alone does not completely prevent TB incidence in children.

Studies such as Ozdemir et al. (2020) confirm that BCG vaccination does not fully protect children from TB infection. According to Wijaya et al. (2021), BCG immunization does not prevent primary TB infection but reduces the risk of severe complications, such as TB meningitis and pleural effusion. Children who have received BCG but still develop TB may be influenced by other risk factors, including close contact with adult TB patients, poor nutritional status, overcrowded living conditions, high humidity, and poor environmental hygiene (Kuswantoro, 2002). Wulanda & Delilah (2021) also emphasized that BCG mainly protects against severe TB forms, not infection itself. Thus, in populations with high BCG coverage, childhood TB cases may still occur if other risk factors like malnutrition and contact with undiagnosed adult TB cases are present.

In 2023, despite BCG coverage remaining above 95% in most areas, TB cases were increasingly reported even in high-coverage zones. This shows that BCG vaccination alone is not sufficient to fully prevent TB transmission in children. Hasnanisa et al. (2023) also found that high BCG coverage did not necessarily reduce childhood TB incidence, particularly when contact screening and case detection programs were suboptimal. This study did not directly assess the quality of immunization services; however, the presence of cases in high-coverage areas calls for a deeper evaluation of immunization implementation, effectiveness, and timeliness (Arimaswati et al., 2022). Overall, the finding that high BCG coverage does not correspond with lower TB incidence highlights the need for a multisectoral approach to childhood TB prevention. In addition to maintaining immunization levels, efforts should focus on strengthening contact screening, improving diagnostic services, and addressing child nutrition.

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Cluster Analysis of Childhood TB Cases (2021–2023)

Spatial cluster analysis of childhood TB cases using SaTScan v10.0.1 with a Discrete Poisson model revealed a shift in cluster centers and changes in relative risk (RR) over the years. In 2021, the cluster was centered in the central part of the regency (with a radius of 11.78 km), covering areas such as Simo and Mojosongo. In 2022, the cluster shifted southwest, covering Mojosongo, Teras, and Boyolali 1 & 2, with a decreased RR of 1.76. However, in 2023, the cluster became more focused in the same Puskesmas (Health Centers) regions—Boyolali 1 & 2, Mojosongo, Teras, and Banyudono 1—while the radius shrank to 8.05 km and the RR rose significantly to 3.64.

These clusters occurred in areas with relatively high population densities, and regions that consistently appeared as clusters over the three-year period were all densely populated. The pattern of shifting and narrowing cluster radii reflects the dynamics of TB transmission following population concentration. The denser the area, the higher the likelihood of forming clusters, as evidenced by the RR increase in 2023. This supports the hypothesis that population density contributes significantly to the formation of childhood TB clusters.

These findings are consistent with research by Lestari, Makful, and Okfriani (2023), which identified a clustering pattern between TB cases and population density in West Java Province. Similarly, Wu et al. (2020) emphasized the importance of controlling population density in TB prevention strategies. Overall, identifying spatial clusters allows policymakers to better prioritize TB interventions. The persistent clusters in the southern and central parts of Boyolali (Boyolali 1 & 2, Mojosongo, Teras, and Banyudono) require special attention, including enhanced contact tracing, strengthened early detection at Puskesmas (Health Centers), and targeted community education campaigns (Yogyakarta City Health Office, 2024).

Further Considerations

Although high population density was associated with increased TB incidence, this may be compounded by socio-economic disparities. In Boyolali's urbanizing subdistricts (e.g., Mojosongo, Teras), the rise in TB cases may also reflect poor housing ventilation, overcrowding, and limited access to early screening — especially in informal settlements or peri-urban villages. Another possible driver of TB transmission is internal mobility. Central areas like Boyolali 1 & 2 and Mojosongo function as economic hubs where daily commuting and school congregation are common. These movements may facilitate cross-district transmission. Incorporating mobility patterns, e.g., through local transport data or school census points, would improve future risk mapping. Furthermore, Although this study is quantitative in nature, insights from local health workers during informal discussions revealed persistent challenges such as community stigma, delayed care-seeking behavior, and poor household compliance with follow-up visits. These findings support the need for community-based educational interventions tailored to local behavioral and cultural contexts.Thus, spatial clusters of childhood TB in Boyolali are not solely determined by population density, but also reflect deeper structural and behavioral vulnerabilities. Future TB control programs should integrate spatial analysis with socio-economic profiling and community-based insights to ensure precision in targeting interventions.

Conclusion

This study found a significant increase in childhood tuberculosis (TB) cases in Boyolali Regency from 2021 to 2023, with a notable shift in case concentration from the central region to the southern and southwestern areas. The data revealed that regions with high total population (>6,000 people/km²) and high population density (>30 people/km²) consistently showed a higher number of TB cases, indicating these demographic factors strongly influence the risk of transmission. Although BCG immunization coverage in Boyolali was relatively high

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(averaging over 95%), TB cases still emerged in areas with high immunization rates, suggesting that BCG alone may not fully prevent childhood TB. Spatial analysis using QGIS and SaTScan successfully identified significant clusters of TB cases, reinforcing the role of social interaction and population distribution in disease spread.

Suggestion

Therefore, it is suggested that the Boyolali Regency Health Office prioritize TB control efforts in densely populated areas by enhancing early detection, public education, and contact screening. Local health centers are encouraged to integrate spatial data into routine monitoring to enable more targeted and efficient interventions. Future researchers are advised to include additional variables such as air quality, nutritional status, and household TB contact, and to consider primary data collection to improve the accuracy and depth of spatial epidemiological research.

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References

Amalia, A. I., & Setiyadi, N. A. (2021). Analisis spasial tuberkulosis 2018–2020: Kabupaten Magelang, Indonesia. *Jurnal Manajemen Informasi dan Administrasi Kesehatan (JMIAK), 4*(November), 1–9.

Arimaswati, S. H., Sudiro, T. Y., Ode, K. L., & Indrayani, N. N. (2022). Analisis faktor kejadian TB paru di Kabupaten Buton Tengah. *Jurnal Ners dan Kebidanan (J Nurs Updat), 13*(1).

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C. C. (2009). Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. A CAISE Inquiry Group Report. *Online submission*.

Bothamley, G. H., Adeoye, G., Heyckendorf, J., Rowan, J., & Singla, A. (2023). The differential diagnosis of Thoracic tuberculosis: a guide to Under-and over-diagnosis. *In: The challenge of tuberculosis in the*, *101*, 90-103.

Brigden, G., Furin, J., Van Gulik, C., & Marais, B. (2015). Getting it right for children: improving tuberculosis treatment access and new treatment options. *Expert review of anti-infective therapy*, *13*(4), 451-461. https://doi.org/10.1586/14787210.2015.1015991

Bunga, E., & Basuki. (2022). Pengaruh lingkungan fisik rumah, riwayat kontak dan status gizi terhadap kejadian tuberkulosis anak di Kota Kupang. *Jurnal Pangan Gizi dan Kesehatan, 11*(2), 81–96. https://doi.org/10.51556/ejpazih.v11i2.215

Coleman, M., Martinez, L., Theron, G., Wood, R., & Marais, B. (2022). Mycobacterium tuberculosis transmission in high-incidence settings—new paradigms and insights. *Pathogens*, *11*(11), 1228. https://doi.org/10.3390/pathogens11111228

Deva, M. S. (2018). Analisis pengelompokan dan pemetaan kecamatan berdasarkan faktor penyebab penyakit TB paru di Kabupaten Padang Pariaman tahun 2016. *Kesehatan Masyarakat,* 1–101.

Dhanny, D. R., & Sefriantina, S. (2022). Hubungan asupan energi, asupan protein dan status gizi terhadap kejadian tuberkulosis pada anak. *Muhammadiyah Journal of Nutrition and Food Science, 2*(2), 58–68. https://doi.org/10.24853/mjnf.2.2.58-68

Copyright © 2025, Journal La Medihealtico, Under the license CC BY-SA 4.0

Dinas Kesehatan Kabupaten Boyolali. (2022). *Profil kesehatan Kabupaten Boyolali tahun 2021.* Dinas Kesehatan Kabupaten Boyolali.

Dinas Kesehatan Kabupaten Boyolali. (2023). *Profil kesehatan Kabupaten Boyolali tahun 2022.* Dinas Kesehatan Kabupaten Boyolali.

Dinas Kesehatan Kabupaten Boyolali. (2024). *Profil kesehatan Kabupaten Boyolali tahun 2023.* Dinas Kesehatan Kabupaten Boyolali.

Dinas Kesehatan Kota Yogyakarta. (2024). *Arahan Sekda Kota Yogyakarta pada koordinasi TPCB Dinas Kesehatan.* Dinas Kesehatan Kota Yogyakarta.

Fitriyani, S., & Sari, M. (2021). Analisis spasial temporal sosiodemografi dan variabilitas iklim terhadap kejadian tuberkulosis paru BTA positif di Provinsi Jawa Barat tahun 2013–2017. *Jurnal Untuk Masyarakat Sehat (JUKMAS), 5*(2), 140–150. https://doi.org/10.52643/jukmas.v5i2.1514

Girsang, V. I., Halawa, T. B. I., Saragih, F. L., & Purba, I. E. (2023). Analisis spasial sebaran kasus tuberkulosis (TB) paru BTA+ di Kota Medan. *Jurnal Teknologi Kesehatan dan Ilmu Sosial (TEKESNOS), 5*(1), 168–179.

Hajarsjah, N., Daulay, R. M., Ramayani, O. R., Dalimunthe, W., Daulay, R. S., & Meirina, F. (2018). Tuberculosis risk factors in children with smear-positive tuberculosis adult as household contact. *Paediatrica Indonesiana, 58*(2), 66–70. https://doi.org/10.14238/pi58.2.2018.66-70

Hartanto, D., Santoso, T., & Wulandari, R. D. (2023). Distribusi spasial kasus tuberkulosis paru di Kota Semarang. *Jurnal Epidemiologi Kesehatan Masyarakat, 7*(2), 100–110.

Hasnanisa, N., Prasetyo, S., & Handayani, Y. (2023). Faktor-faktor tuberkulosis paru: Analisis spasial. *Jurnal Ilmiah Kesehatan Masyarakat, 15*(September), 107–118. https://doi.org/10.52022/jikm.v15i3.466

Hussain, H., Malik, A., Ahmed, J. F., Siddiqui, S., Amanullah, F., Creswell, J., ... & Robberstad, B. (2021). Cost-effectiveness of household contact investigation for detection of tuberculosis in Pakistan. *BMJ Open, 11*(10), e049658. https://doi.org/10.1136/bmjopen-2021-049658

Kementerian Kesehatan Republik Indonesia. (2022). *Profil kesehatan Indonesia tahun 2021.* Kementerian Kesehatan Republik Indonesia.

Kuswantoro. (2002). Faktor-faktor yang berhubungan dengan kejadian TB paru primer pada anak balita. [Skripsi, Fakultas Kedokteran Universitas Diponegoro]. Universitas Diponegoro, Semarang.

Lestari, A. A., Makful, M. R., & C. O. (2021). Analisis spasial kepadatan penduduk terhadap kasus tuberkulosis di Provinsi Jawa Barat 2019–2021. *Jurnal Cahaya Mandalika,* 577–585. https://doi.org/10.36312/jcm.v3i2.1663

Lestari, A. A., Makful, M. R., & Okfriani, C. (2023). Analisis spasial kepadatan penduduk terhadap kasus tuberkulosis di Provinsi Jawa Barat 2019–2021. *Jurnal Cahaya Mandalika,* 577–585. https://doi.org/10.36312/jcm.v3i2.1663

O'Sullivan, M. (2008). Effective International Non-Governmental Organisation (INGO) and Local Non-Governmental Organisation (LNGO) partnerships in education programmes: a case study of an Irish INGO and its partner LNGOs in Ethiopia. *Irish Educational Studies*, *27*(2), 159-176. http://dx.doi.org/10.1080/03323310802021920

Ozdemir, C., Kucuksezer, U. C., & Tamay, Z. U. (2020). Is BCG vaccination affecting the spread and severity of COVID-19? *Allergy, 75*(7). https://doi.org/10.1111/all.14344

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Potts-Datema, W., Smith, B. J., Taras, H., Lewallen, T. C., Bogden, J. F., & Murray, S. (2005). Successful strategies and lessons learned from development of large-scale partnerships of national non-gowernmental organisations. *Promotion & education*, *12*(3-4), 131-137. http://dx.doi.org/10.1080/03323310802021920

Purwoko, S., Cahyati, W. H., & Farida, E. (2020). Pemanfaatan sistem informasi geografis (SIG) dalam analisis sebaran penyakit menular TB BTA positif di Jawa Tengah. *Jurnal Ilmu Kesehatan Masyarakat.*

Questa, K., Das, M., King, R., Everitt, M., Rassi, C., Cartwright, C., ... & Elsey, H. (2020). Community engagement interventions for communicable disease control in low-and lower-middle-income countries: evidence from a review of systematic reviews. *International journal for equity in health*, *19*(1), 51. https://doi.org/10.1186/s12939-020-01169-5

Rachmad, F., Miarsa, D., Nabila, I. N., Kusumawati, E., & Alief, M. (2025). Peningkatan kesadaran hukum pada masyarakat terhadap hak dan kewajiban dalam penanganan penyakit tuberculosis. *Community Development Journal, 6*(1), 693–699. http://dx.doi.org/10.31004/cdj.v6i1.41908

Rachmawati, A., Latief, M. A., Debyanti, M., & Cancerita, S. (2021). Korelasi manifestasi klinis respiratorik dengan gambaran luas lesi tuberkulosis paru pada foto polos thoraks di RSUD Gunung Jati tahun 2021. *Tunas Medika Jurnal Kedokteran & Kesehatan, 10*(3).

Rajeshwar, X. (2024). *Prevalence of undernutrition among children (6 months to 5 years) with tuberculosis and impact of nutritional counselling and tuberculosis treatment on the nutritional status: a cohort study from Pakistan* (Master's thesis, The University of Bergen).

Randall, K., Ewing, E. T., Marr, L. C., Jimenez, J. L., & Bourouiba, L. (2021). How did we get here: what are droplets and aerosols and how far do they go? A historical perspective on the transmission of respiratory infectious diseases. *Interface Focus*, *11*(6), 20210049. https://doi.org/10.1098/rsfs.2021.0049

Ratnasari, Y., Sjaaf, A. C., & Djunawan, A. (2021). Evaluasi sistem pencatatan dan pelaporan kasus tuberculosis di Rumah Sakit Syarif Hidayatullah. *Jurnal Manajemen Kesehatan Yayasan RS. Dr. Soetomo, 7*(1), 115–124. http://dx.doi.org/10.29241/jmk.v7i1.608

Roempoembo, F. Y. Y., & Winarti, E. (2024). Pengaruh metode penyuluhan audiovisual terhadap tingkat pengetahuan dan perilaku keluarga dalam pencegahan penyakit tuberkulosis. *Jurnal Kesehatan Tambusai, 5*(1), 1252–1273.

Saputra, F. F., Wahjuni, C. U., & I. M. (2020). Spatial modeling of environmental-based risk factors of tuberculosis in Bali Province: An ecological study. *Jurnal Berkala Epidemiologi.* https://doi.org/10.20473/jbe.V8I12020.26-34

Siame, L., & Chama, G. C. (2025). Correlates of tuberculosis in children under the age of 15 years. *PLOS ONE, 20*(2), 1–8.

Srisantyorini, T., Nabilla, P., Herdiansyah, D., & Fajrini, F. (2019). Analisis spasial kejadian tuberkulosis di wilayah DKI Jakarta tahun 2017–2019. *Jurnal Kedokteran dan Kesehatan, 18*(2), 131–138. https://doi.org/10.24853/jkk.18.2.131-138

Stadnytskyi, V., Anfinrud, P., & Bax, A. (2021). Breathing, speaking, coughing or sneezing: What drives transmission of SARS-CoV-2?. *Journal of Internal Medicine*, *290*(5), 1010-1027. https://doi.org/10.1111/joim.13326

Sudana, D., Emanuel, A. W., & Fornia, A. S. (2020). Applying social-gamification for interactive learning in tuberculosis education. *International Journal of Advanced Computer Science and Applications, 11*(3). http://dx.doi.org/10.14569/IJACSA.2020.0110342

Swalehe, H. M., & Obeagu, E. I. (2024). Tuberculosis: Current diagnosis and management. *Elite Journal of Public Health*, *2*(1), 23-33.

Tamiima, L. (2022). *Analisis spasial dan temporal kasus tuberkulosis di Kabupaten Sarolangun tahun 2015–2021*. Universitas Jambi.

Vonasek, B., Ness, T., Takwoingi, Y., Kay, A. W., van Wyk, S. S., Ouellette, L., ... & Mandalakas, A. M. (2021). Screening tests for active pulmonary tuberculosis in children. *Cochrane Database of Systematic Reviews*, (6). https://doi.org/10.1002/14651858.cd013693.pub2

Wijaya, M. S., Mantik, M. F., & Rampengan, N. H. (2021). Faktor risiko tuberkulosis pada anak. *e-CliniC, 9*(1). https://doi.org/10.35790/ecl.v9i1.32117

World Health Organization. (2020). *Global tuberculosis report 2020.* World Health Organization.

Wu, Y., Huang, M., Wang, X., Li, Y., Jiang, L., & Yuan, Y. (2020). The prevention and control of tuberculosis: An analysis based on a tuberculosis dynamic model derived from the cases of Americans. *BMC Public Health, 20*(1), 1173. https://doi.org/10.1186/s12889-020-09260-w

Wulanda, A. F., & Delilah. (2021). Efektivitas imunisasi BCG terhadap kejadian tuberkulosis anak di Kabupaten Bangka: Effectiveness of BCG immunization against children's tuberculosis incidence in Bangka Regency. *Jurnal Kesehatan Poltekkes Kemenkes RI Pangkalpinang, 9*(1), 37–41. https://doi.org/10.32922/jkp.v9i1.333

Yang, T. L., Lee, C. M., Lee, K. L., Yen, T. Y., Lu, C. Y., Lee, P. I., ... & Chang, L. Y. (2021). Clinical features of tuberculosis and Bacillus Calmette-Guérin (BCG)-associated adverse effects in children: a 12-year study. *Journal of the Formosan Medical Association*, *120*(1), 443-451. https://doi.org/10.1016/j.jfma.2020.06.012

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