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Tuberculosis Risk Mapping in Yogyakarta, Indonesia : An Ecological Study

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Abstract

Environmental, demographics, geography, to health system-related aspects can influence the incidence of tuberculosis. The objectives of this study are to know the correlation between environmental, health services and population-related variables with tuberculosis incidence rate and map the tuberculosis risk distribution in 78 sub-districts in Daerah Istimewa Yogyakarta, Indonesia. This study is a cross-sectional study with an ecological approach and using a mapping approach. Variables in this study include population density, altitude, tuberculosis treatment success rate, health facilities, health personnel, education, and population growth rate. Data in this study were analyzed using univariate and bivariate (Rank Spearman) tests, then depicted on a map. There are correlations between population density, education, population growth rate, altitude, and health facilities with tuberculosis incidence rate (r = 0.663, 0.654, -0.495, -0.274, and -0.267). Tuberculosis treatment success rate and health personnel show no correlation with tuberculosis incidence rate (r = -0.020; -0.002). Strengthening of TB programs and cross-sectoral measures are needed to control TB, especially in high-risk areas. Research on other ecological-related factors and further spatial analysis can also be carried out to provide input for TB control.

INTRODUCTION

Tuberculosis (TB) is a communicable disease caused by Mycobacterium tuberculosis bacteria, and is known as one main cause of morbidities and health problems which in the year 2020 there were approximately 129 cases per 100,000 population in the world. TB is considered as the main cause of death from a single infectious pathogen and is above HIV/AIDS where there were 1.3 million deaths due to TB recorded in 2020 (WHO, 2021). An early detection to appropriate and adequate treatment are known to could help in preventing severity, disabilities, and even deaths from TB (Virenfeldt et al., 2014; WHO, 2021). Not only are the morbidity and mortality of TB still concerning, but also the ability of the bacteria that causes TB to remain latent in the human's body, a great number of asymptomatic carriers, and the potential for antibiotic resistance that continues to increase also make TB one important concern (Banuls et al., 2015).

Southeast Asia ranked 2nd as the continent with the highest TB incidence (211 per 100,000 population) after Africa in 2020, and Indonesia itself ranked 4th after the Philippines, Timor Leste, and Myanmar as one of the countries with the

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highest incidence of TB in Southeast Asia. In the year 2020, 3 of 1,000 people in Indonesia were estimated to be infected with TB and 11.28% people with TB in Indonesia died (WHO, 2021). In Daerah Istimewa Yogyakarta (DIY), TB is still one health problem that is a focus or priority. In 2020, there were 2,927 TB cases recorded in all health facilities in DIY which approximately 79 per 100,000 people are suffering from TB (Dinas Kesehatan Daerah Istimewa Yogyakarta, 2020). Furthermore, DIY is one of the provinces in Indonesia that is still facing problems or challenges related to the efforts and progress in achieving TB control program targets, of which are in relation to the detection and treatment of tuberculosis cases, which are known to be declining especially due to COVID-19.

COVID-19 Pandemic is known to affect the efforts in relation to TB control and countermeasures, of which is that there is a decline in TB case detection and notification. The World Health Organization stated that the decline is estimated to be at 18% by 2020 globally (Jain et al., 2020; Udwadia et al., 2020; WHO, 2021). The TB case notification rate in DIY also decreased from 107 per 100,000 population in 2019 to 80 per 100,000 population in 2020 (Dinas Kesehatan Daerah Istimewa Yogyakarta, 2019, 2020). This decline in the TB case finding needs to be a concern, given the possible impacts that it can increase the risk of TB and its spread as well as can lengthen the duration of exposure in the patients who are infectious due to undetected and untreated TB cases (Cheng et al., 2013; Narasimhan et al., 2013).

Living with HIV, diabetes mellitus, and malnutrition are some of the factors that can influence or affect the body's immune response that can increase man's risk of being exposed to and infected with TB (Diah Wahyuningsih, 2020; Narasimhan et al., 2013; Silva et al., 2018). In addition to individual-related factors, TB incidence in an area is also known to be influenced by the broader factors or conditions related to the area, such as environment, demographic, geography, to health system-related conditions (Cui et al., 2019; Li et al., 2019; Sifuna et al., 2019). Some of these related conditions include population growth rate, population density, inadequate environmental and housing conditions, poverty, low educational level, access to health services, as well as altitude. In relation to altitude, a study revealed that the incidence of TB increases three times in the areas with low altitude (Bie et al., 2021; Fitriani, 2013; Hassarangsee et al., 2015; Im & Kim, 2021; Mathema et al., 2017; Pratiwi et al., 2020; Tanrikulu et al., 2008).

Mapping of disease can be beneficial for surveillance purposes including for taking preventive actions in potentially high-risk areas (Nayak et al., 2021). A disease mapping known as surface mapping utilizes aggregate data to produce information on maps. One type of surface mapping that is widely used is choropleth map, which usually the disease's statistical data such as prevalence, incidence rate, etc. are processed and visualized into maps (Lin & Wen, 2022). Mapping has been used as a way to display the result of the analysis of infectious diseases' risk, such as the risk of COVID-19 (Mufti & Siwiendrayanti, 2021). In relation to TB, mapping, spatial analysis, to clustering of TB have been broadly used to identify the pattern of its distribution as well as the areas at risk of TB, especially the risks related to climate, meteorological, geography, demographic, and socioeconomic factors (Bie et al., 2021; Tadesse et al., 2018; Utomo et al., 2022; Yu et al., 2020).

Given the facts that TB is still a priority in DIY, the importance of optimization of TB control and countermeasures, as well as reviewing the diverse conditions of DIY in its administrative areas, an area-based study regarding TB incidence and the potential related factors such as demographic, geography, to health service-related aspects is needed to help in identifying the risk of TB in each region in DIY. This study aims to know the correlation between population density, altitude, TB treatment success rate, health facilities, health personnel, education, and population growth rate with the incidence rate of TB and map the TB risk distribution, which later on the results of this study can be used as inputs for the policy makers or the related parties as a means of TB control efforts in DIY especially in areas that are at high-risk.

METHOD

This study is a cross-sectional study with an ecological approach and using a mapping approach, which focuses on environmental both physical and social, to population-related aspects. The population in this study is all the sub-districts in all regencies/municipalities in Daerah Istimewa Yogyakarta (DIY). The sample in this study is determined using total sampling since this study is an ecological study with the unit analysis for sub-districts in DIY, thus the sample in this study is all 78 sub-districts in DIY. This study has obtained an ethical clearance from the Komisi Etik Penelitian Kesehatan UNNES (Health Research Ethics Commission of UNNES) with the ethical

numbers 477/KEPK/EC/2022.

The dependent variable in this study is tuberculosis incidence rate (TB IR) in each sub-district in 2020. average altitude (m above sea level (a.s.l)), TB treatment success rate (percentage of patients that are recovered and had a complete treatment), health facilities (number of hospitals, polyclinics, primary healthcare centers, sub-primary healthcare centers to 10,000 population), health personnel (number of physicians and nurses to 10,000 population), education (percentage of people with 12 years of compulsory education to total numbers of population), and population growth rate (annual population growth rate from 2010-2020 in percentage), which all these variables are aggregate data at the sub-district level. All the data in this study are sourced from secondary data, specifically data in the year 2020, where data related to TB namely TB incidence rate and TB treatment success rate was obtained from DIY Provincial Health Office, data related to education was obtained from DIY Regional Secretariat Governance Bureau, while data related to population density, altitude, health facilities, and health personnel were obtained from the Central Bureau of Statistics. This study could prone to ecological bias if it's interpreted at the individual level, thus the results in this study must only be interpreted at the sub-district level.

Statistical analyses primarily performed in this study include univariate and bivariate analyses. The univariate analysis is intended to get the descriptive picture of the studied variables, while the bivariate analysis is carried out to know the correlation between the dependent and independent variables using the Rank Spearman test. The Rank Spearman Test is used because the data of the dependent variable and some of the independent variables in this study are not normally distributed. The normality test is performed using the Kolmogorov-Smirnov test and the variables that are not normally distributed include TB IR as the dependent variable, while some of the independent variables that are not normally distributed are altitude, TB treatment success rate, population density, health personnel, and population growth rate. The univariate and bivariate analyses performed using the Statistical Package for the Social Sciences (SPSS) 25. A mapping approach is also carried out to depict the distribution of risk of TB incidence based on the variables that are significantly correlated with TB, using Quantum Geographic Information System (QGIS) version 3.22.11 software.

The determination and depiction of the risk map carried out by giving scores on each variable as well as determining interval for each classification for the variables whose the boundary of the classification have not been known yet, then later the scores will be processed using risk assessment formula to know the risk of TB of each sub-district if seen from the variables found to be correlated with TB in this study. The interval formula is as follows.

$$Interval = \frac{Highest\ value - Lowest\ value}{Number\ of\ classes}$$

Below is the risk assessment formula to determine the risk of TB of each sub-district based on the correlated variables found in this study. Hazard is the score of TB incidence rate of each sub-district. Between the variables of population density, altitude, TB treatment success rate, education, and population growth rate that are found to be correlated with TB IR in this study will be included in the vulnerability aspect. Meanwhile, the capacity is related to the health service aspects in relation to TB management including health facilities and health personnel aspects, which in this study the capacity will be determined by the health service-related variable that is correlated with TB IR.

$$Risk = Hazard\ x\ \frac{Vulnerability}{Capacity}$$

The scoring of each variable will be depending on the classification based on the interval, the direction of correlation, as well as depending on whether the variable is included in hazard, vulnerability, or capacity. There will be three classes or categories for the classification namely low, moderate, and high. The score for low is one, moderate is two, and high is three for variables categorized as hazard, capacity, and vulnerability if the risk is positively correlated with TB. For altitude variable, if the altitude shows a significant correlation with TB IR, it will be classified into two classes namely low with the score two when the altitude is ≤750 meters, and high with the score one if the altitude is >750 meters, as a study has proven that an area with the altitude of 750 meters and below has a three times higher risk of having a high incidence of TB. Meanwhile, for variables as vulnerability, if the risk is negatively correlated with TB, the score will be three for low, two for moderate, and one for high.

RESULT AND DISCUSSION

Daerah Istimewa Yogyakarta (DIY) has 78 sub-districts within its administrative area. Based on the TB case data throughout DIY recorded in the Sistem Informasi Tuberkulosis (tuberculosis

information system) that abbreviated as SITB and after the filtering process of the patients who are domiciled and have complete addresses in DIY, there are 2,718 TB cases throughout all 78 sub-districts in DIY in 2020. Gondomanan Sub-District (Yogyakarta City) is the sub-district with the highest TB incidence rate (25.8 per 10,000 population), while the sub-district with the lowest TB incidence rate (TB IR) is Ngawen Sub-District (1.47 per 10,000 population) in Gunungkidul Regency, and the median (IQR) of TB IR per 10,000 population in DIY showed at the numbers of 6.92 (4.31). Figure 1 depicts the map of the TB IR distribution in DIY in the year 2020.

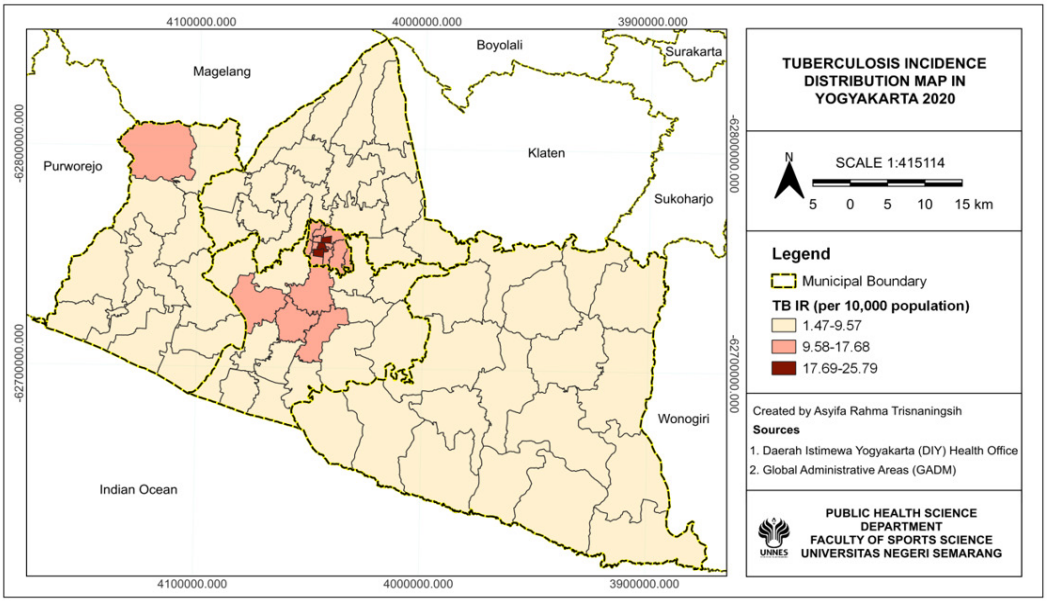

Figure 1. Mapping of TB Incidence Rate in Yogyakarta, 2020

In DIY, the average of health facilities to serve 10,000 population in each sub-district is 1.87 (SD = 0.69). In relation to education, it can be seen from Table 1 that the average of people who have completed 12 years of compulsory education is 38.90% (SD = 14.45). The median (IQR) of population density in DIY is 1,311.09 (2,844.5) people/km2, with Ngampilan Sub-District (Yogyakarta City) has the highest population density among all the sub-districts (23,048.75 people/km^2) and Girisubo Sub-District as the sub-district with the lowest population density (258.96 people/km^2). Geographical conditions including the altitude of the areas in DIY are vary, which the highest altitude of 634 m a.s.l is in Turi Sub-District in the Sleman Regency area and Panjatan Sub-District in Kulon Progo Regency is the sub-district with the lowest altitude (7 m a.s.l), while the median (IQR) of the altitude in DIY showed at the numbers of 134.45 (149.5) m a.s.l.

The median (IQR) of the TB treatment success rate in DIY are 89.83% (9.82%), with some sub-districts have reached a 100% of TB treatment success rate which those sub-districts are Srandakan Sub-District (Bantul Regency), as well as Panggang, Purwosari, Tepus, and Ngawen Sub-Districts that are located in the Gunungkidul Regency. Meanwhile, sub-districts with the lowest TB treatment success rate are Panjatan and Kalibawang Sub-Districts which both are part of Kulon Progo Regency, where the TB treatment success rate in both sub-districts are shown in the number of 74.07%.

Population growth rate in DIY showed the median (IQR) of 0.92% (0.66%), with the highest of 1.51% in Sleman Sub-District (Sleman Regency) and the lowest in Depok Sub-District (Sleman Regency) with the population growth rate of -3.2%. In addition to health facilities, this study also covers health personnel as one of the aspects related to health service. From Table 1, it can be seen that the median number of health personnel to serve 10,000 people in DIY is 5.79, with an interquartile range of 5.92.

This study primarily examines the correlation between population density, altitude, TB treatment success rate, health facilities, health personnel, education, and population growth rate with the incidence rate of tuberculosis at the sub-district level in DIY using the Rank Spearman test because the normality test results showed that some of the variables, including the dependent variable, are not normally distributed ($p<0.05$). Based on the results of the bivariate

Table 1. Univariate Analysis Results of TB IR, Population Density, Altitude, TB Treatment Success Rate, Health Facilities, Health Personnel, Education, and Population Growth Rate variables at the Sub-District Level in Yogyakarta, 2020

Variable (Normal Distribution)	Central Tendency			Dispersion Measure	
	Mean	Median	Mode	Standard Deviation	Variance
Health Facilities (per 10,000 population)	1.87	1.87	2.30	0.69	0.48
Education (% of people with 12 years of compulsory education)	38.89	40.22	43.87	14.45	208.99
Variable (Non-Normal Distribution)	Central Tendency			Dispersion Measure	
	Median	Mode	Min-Max	Range	Interquartile Range (IQR)
TB Incidence Rate (per 100,000 population)	6.92	5.77	1.47-25.80	24.33	4.31
Population Density (per km^2)	1311.09	258.96	258.96-23048.75	22789.79	2844.55
Altitude (m a.s.l)	134.45	19	7-634	627	149.5
TB Treatment Success Rate (%)	89.83	100	74.07-100	25.93	9.82
Health Personnel (per 10,000 population)	5.79	3.02	2.07-111.62	109.55	5.92
Population Growth Rate (% of annual population growth rate)	0.92	0.93	-3.20-1.51	4.71	0.66

Sources: DIY Provincial Health Office, DIY Regional Secretariat Governance Bureau, Central Bureau of Statistics

analysis in Table 2, it can be known that population density, altitude, health facilities, education, and population growth rate are all having a significant correlation to tuberculosis incidence rate in the sub-districts in DIY. Population density and education are having a strong positive correlation with the incidence of TB at the sub-district level in DIY. On the other hand, altitude and health facilities both have a weak correlation strength and a negative correlation direction with TB IR in the sub-districts in DIY. Population growth rate also shows a negative correlation with TB IR with a moderate correlation strength. Meanwhile, TB treatment success rate and health personnel show no correlation with the incidence rate of TB at the sub-district level in DIY.

Based on the statistical analysis results, there is a significant positive correlation (r = 0.663;

Table 2. Correlation between TB IR with Population Density, Altitude, TB Treatment Success Rate, Health Facilities, Health Personnel, Education, and Population Growth Rate at the Sub-District Level in Yogyakarta, 2020

Variable	r	p-value
Population Density (per km^2)	0.663**	<0.001
Altitude (m a.s.l)	-0.274*	0.015
TB Treatment Success Rate (%)	-0.020	0.864
Health Facilities (per 10,000 population)	-0.267*	0.018
Health Personnel (per 10,000 population)	-0.002	0.989
Education (% of people with 12 years of compulsory education)	0.654**	<0.001
Population Growth Rate (% of annual population growth rate)	-0.459**	<0.001

**) Significant at 0.01; *) Significant at 0.05

p<0.001) between population density and the incidence of TB at the sub-district level in DIY. It means that the higher the population density in a sub-district, the higher the TB IR in that sub-district. In DIY, Ngampilan, Gedongtengen, and Danurejan Sub-Districts that respectively ranked first to third as the sub-districts with the highest population density are relatively having moderate to high TB incidence rate. The positive correlation between population density and incidence of TB is in line with the results of studies conducted in Kenya, Malaysia, Algeria, China, and South Jakarta City in Indonesia, which also found a positive correlation between population density and TB. Some of these studies also showed that the incidence of TB is seen mostly in the populous urban areas (Li et al., 2019; Mohidem et al., 2021; Selmane & L'hadj, 2021; Sifuna et al., 2019; Wulandari, 2012). Population density in relation to TB here is not merely about the number of the population density that can be considered as a factor that causes TB, but rather an area that is densely populated can contribute to the spread of tuberculosis (Selmane & L'hadj, 2021). Because, population density is generally associated with the environmental and housing conditions that are inadequate and do not meet the health-related requirements, in which it can make it easier for infectious diseases, including TB, to spread (Achmad, 2010; Li et al., 2019). With regards to housing, Low et al., 2013, stated that housing characteristics including the type of housing and residential or housing floor levels can affect the incidence of TB, in which areas with inadequate conditions of housing such as densely populated public housing and being in the ground level of housing showed a higher TB incidence. In addition to that, population density can also provide a space for the bacteria that causes TB to spread through contact between individuals that transmit the disease and prone individuals that is also getting higher (Harling & Castro, 2014).

Geographical conditions, including altitude, are known to influence the occurrence of diseases, of which is TB. Conditions related to humidity, temperature, and density of oxygen that can be varied by altitude are known to affect the viability of the bacteria that causes TB (Achmad, 2010). This study shows that there is an inverse correlation between altitude and TB incidence at the sub-district level in DIY (r = -0.274; p<0.05), where it can be interpreted that the TB incidence is tend to be higher in the sub-districts with low altitudes, which Gondomanan Sub-District, for instance, a sub-district with the highest TB incidence has an average altitude that is relatively low. This finding, that is an inverse correlation between altitude and tuberculosis incidence, is in accordance with the study results in Si Sa Ket Province in Thailand, Bukittinggi City in Indonesia, and Aguascalientes City in Mexico (Haq et al., 2019; Hassarangsee et al., 2015; Pérez-Guzmán et al., 2014). A study in Turkey also revealed that the areas with lower altitudes, specifically in the areas with altitudes ≤750 m, have a 3.28 times greater risk of having a high incidence of tuberculosis than the areas with higher altitudes (Tanrikulu et al., 2008).

The further and specific explanation regarding the correlation between altitude and tuberculosis in an area is still not clearly known and has not been studied further. However, the variety of TB incidence by altitude could possibly be explained by the environmental and climate-related conditions that are also varied by altitude that can provide space for the growth and transmission of the bacteria that causes TB, for example conditions related to oxygen pressure to the intensity of UV light. Oxygen pressure tends to be low in the highland areas which known to inhibit the growth rate of the TB-causing agent, while on the other hand, the high oxygen pressure in the lowland areas can prompt the Mycobacterium tuberculosis to multiply in the lungs according to Maylan et al., 1992 on Hassarangsee et al., 2015.

In areas with higher altitudes, population density is usually lower and people in these areas tend to not stay in an indoor setting for a long period of time. Other than that, immunity towards disease-causing organisms including the Mycobacterium tuberculosis can be influenced by several factors, one of which is vitamin D. In high altitude areas, exposure to UV-B light is known to be higher, which may lead to higher vitamin D levels that might increase the body's immune response and help in lowering the risk of TB exposure and even TB reactivation (Gelaw et al., 2019; Olender et al., 2003). In relation to the UV-B light, a study conducted by Boere et al., 2017, also found that the incidence of tuberculosis is 78% lower in the areas that are exposed to high UV-B light. It is important to mention that this study uses the average altitude of each sub-district and the average altitude on each sub-district in DIY tends to be low, which may explain the inverse correlation between altitude and TB incidence if reviewed from the previous studies.

Efforts in relation to TB control and countermeasures cannot be separated from the health service aspects, in which health service aspects are closely linked with the detection and treatment of TB cases, and among those is access to health

facilities (Kementerian Kesehatan RI, 2016). Health facilities in this study include hospitals, polyclinics, primary healthcare centers, and sub-primary healthcare centers. This study found that sub-districts with a higher ratio of health facilities to the population have a lower incidence of TB ($r = -0.268$; $p<0.05$). A study from Brazil also revealed the same finding, where areas that are having a generous number of health facilities tend to have a lower TB incidence (Harling & Castro, 2014). Some of the sub-districts in DIY, for instance, the Sub-Districts of Pakualaman (Yogyakarta City), Samigaluh (Kulon Progo Regency), Girisubo and Patuk (Gunungkidul Regency) are having a high ratio of health facilities to population in the area, and all of them are having a relatively moderate to low incidence of TB. The health facilities aspect in this study plays role as the capacity in the risk assessment, which the higher the health facilities ratio to the population in a sub-district, the better the capacity is.

The availability of health personnel is also vital in the tuberculosis control and countermeasures besides access to health facilities. In regard to the health personnel aspect, this study reveals that there is no correlation between health personnel in a sub-district with the occurrence of TB in the related sub-district in DIY ($r = -0.002$; $p = 0.989$). On the contrary, a study conducted by Li et al., 2019 in China pointed out that there is an inverse association between health personnel and tuberculosis occurrence, where if there is an adequate, moreover high, number of health personnel in an area, it can strengthen the health system in the area and resulting in the decreasing risk of tuberculosis in the related area. The availability of health personnel in relation to TB control and countermeasures also plays role in TB treatment, especially regarding their roles in providing counselling, education, as well as ensuring the compliance and continuity of the treatment (Herawati et al., 2020).

TB treatment is one of the aspects in the control and countermeasure efforts of tuberculosis, especially in relation to the detection and management of TB cases. TB cases management, including treatment of TB patients, is carried out with the aim of breaking the chain of transmission in the community as well as to prevent severity, disability, and deaths due to TB (Kementerian Kesehatan RI, 2016; Virenfeldt et al., 2014). The statistical analysis results in this study show that there is no correlation between the TB treatment success rate and the incidence of TB at the sub-district level in DIY ($r = -0.020$; $p = 0.860$). This finding is in line with a study by Utomo et al., 2022, in East Java, yet in contrast with the result of a study conducted in China, which found that there is a significant negative association between TB treatment success rate with the incidence of TB, in which the TB treatment success rate that is low allow the possibility for the source of TB infection to stay a longer term in the community (Cui et al., 2019).

Given the facts that the ratio of health personnel that is still not evenly adequate in all sub-districts and health personnel is an important aspect of TB countermeasures, the efforts in empowering and optimizing the health personnel in DIY for TB countermeasures are needed. The optimization of health personnel can be a means to increase the TB case findings as well as efforts in relation to TB treatment, since the data in this study shows that 38 (48.72%) of all sub-districts in DIY are still having TB treatment success rate below the target (90%).

Another aspect that is closely linked to the incidence of tuberculosis is education. In this study, education is described as the percentage of people in each sub-district that have completed the 12 years of compulsory education. The statistical analysis results indicate that there is a positive correlation between the percentage of people in each sub-district that have finished the 12 years of compulsory education with the TB incidence rate at the sub-district level ($r = 0.655$; $p<0.001$), which the higher the percentage of people that finished 12 years of compulsory education of a sub-district, the higher the TB incidence in that sub-district. The Sub-Districts of Pakualaman, Gondokusuman, and Ngampilan (Yogyakarta City), for instance, are all having a high percentage of people that finished 12 years of compulsory education and are having a relatively moderate to high incidence of TB. This finding is in contrast to previous studies in Brazil, Sichuan Province, and India that found a correlation between education and tuberculosis incidence, in which the higher the years of education completed by the residents in a region, the lower the incidence of tuberculosis in the region (Gehlen et al., 2019; Mazumdar et al., 2019; Xia et al., 2020). Nevertheless, a study in Portugal revealed the same finding as this study's, in which the risk of tuberculosis is seen to be higher in the regions with the residents that are having a higher level of education (Apolinário et al., 2017). This insight of a positive correlation between education level and tuberculosis incidence is assumed to be due to lower suspicion of TB occurrences and diagnostics toward people with a higher educational level and there is also a finding that there is a delay of reported

TB diagnosis among people with higher level of education, specifically who are having university degrees, which as a result could prolong the period of transmission in the community. The positive direction of the correlation between tuberculosis incidence rate and education in this study denotes that the educational aspect that is good in an area does not always guarantee the area to have a lower risk of tuberculosis. In addition, the inconsistent results of several studies regarding this matter can also explain that the incidence of tuberculosis in an area cannot be driven by one specific factor only, for instance education aspect only, but it is also influenced by other determinants such as socioeconomics, demographic, and other conditions (Gehlen et al., 2019).

Population growth rate has been seen as one of the population-related aspects that can influence the TB incidence. The results of this study reveal that there is a significant inverse correlation between population growth rate and TB incidence rate ($r = -0.495$; $p<0.001$), where the lower the population growth rate in a sub-district, the higher the TB incidence. This result is in line with a study conducted by Im & Kim, 2021 in South Korea that there is an inverse relationship between population growth rate in an area with the TB incidence in that area, where it is found that there is a decrease of -1.55 in the TB incidence rate as there is an increase of one percent in the population growth rate. In this study, sub-districts that are having a high risk are majority in or near the city areas, which have an already high TB incidence within the area and have a relatively low to moderate ratio of health facilities to the population that could explain the inverse correlation between the population growth rate and TB incidence rate, which Gondomanan Sub-District, for example, is an area at the 6th lowest of population growth rate in DIY yet has a highest TB incidence rate.

Table 3. Classification of TB IR, Population Density, Altitude, Education, Population Growth Rate, and Health Facilities

Variable	Classification	Boundary	Score
Hazard			
TB Incidence Rate (per 100,000 population)	Low	$1.47 \leq X \leq 9.57$	1
	Moderate	$9.58 \leq X \leq 17.68$	2
	High	$17.69 \leq X \leq 25.8$	3
Vulnerability			
Population Density (per km^2)	Low	$258.96 \leq X \leq 7855.55$	1
	Moderate	$7855.56 \leq X \leq 15452.15$	2
	High	$15452.16 \leq X \leq 23048.75$	3
Altitude (m a.s.l)	Low	≤ 750	2
	High	>750	1
Education (% of people with 12 years of compulsory education)	Low	$8.78 \leq X \leq 29.35$	1
	Moderate	$29.36 \leq X \leq 49.93$	2
	High	$49.94 \leq X \leq 70.52$	3
Population Growth Rate (% of annual population growth rate)	Low	$-3.2 \leq X \leq -1.64$	3
	Moderate	$-1.63 \leq X \leq -0.07$	2
	High	$-0.06 \leq X \leq 1.51$	1
Capacity			
Health Facilities (per 10,000 population)	Low	$0.28 \leq X \leq 1.42$	1
	Moderate	$1.43 \leq X \leq 2.57$	2
	High	$2.58 \leq X \leq 3.73$	3

The given information regarding population density, altitude, education, population growth rate, and health facilities that have correlation with the incidence of TB in DIY can be utilized as one of the ways to map the sub-districts that are at risk of TB. The risk mapping in this study is carried out by giving scores until calculating the risk based on TB IR and the variables that showed a significant correlation using risk assessment that includes three aspects of hazard, vulnerability, and capacity. Based on the statistical analysis results and what is stated in the method, the hazard is TB IR, and the vulnerability

includes population density, altitude, education, and population growth rate. Meanwhile the capacity is health facilities variable as it is the health service-related variable that is correlated with TB IR in this study.

Based on the scoring of all combined correlated variables with IR TB, the minimum score is 1.67 while the maximum score is 27. A sub-district is classified into low if the score is ranged between $1.67 \leq X \leq 10.10$, moderate if $10.11 \leq X \leq 18.55$, and high if the score is ranged between $18.56 \leq X \leq 27$. The distribution of tuberculosis risk map seen from all combined IR TB correlated-variables including population density, altitude, education, and population growth rate at the sub-district level in DIY is shown in Figure 2. Viewed from all combined aspects, the sub-districts in DIY that are having a high risk of tuberculosis are located in the administrative areas of Yogyakarta City (Danurejan, Kraton, and Ngampilan Sub-Districts). The three sub-districts are all having a high population density, low altitude, high percentage of people in the sub-district that are completed 12 years of compulsory education, and relatively having a moderate to high population growth rate. In addition to that, the three sub-districts also have a relatively low ratio of health facilities to the population in the sub-district, which could possibly contribute to the ability and capacity of the sub-district in the TB control and countermeasures. Meanwhile, the sub-districts at moderate risk of TB are Sewon Sub-District (Bantul Regency), also Gondomanan, Jetis, Mergangsan, Mantrijeron, and Tegalrejo Sub-Districts (Yogyakarta City).

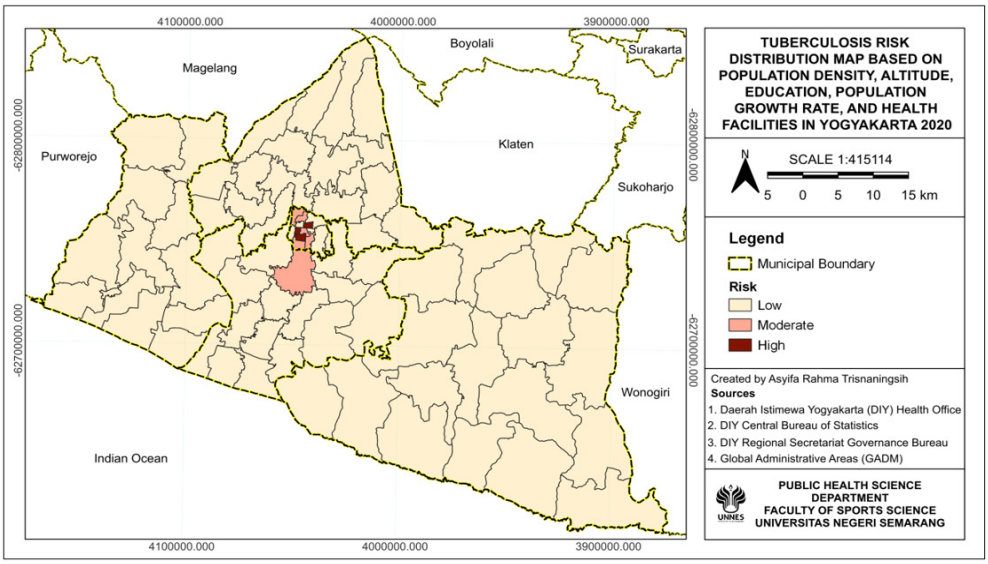

Figure 2. Mapping of TB Risk Distribution based on Population Density, Altitude, Education, Population Growth Rate, and Health Facilities in Yogyakarta, 2020

The obtained information regarding the distribution of sub-districts at risk of TB can be utilized as an input for TB control and countermeasures, especially in the TB case finding such as by carrying out an active case finding in the potentially high-risk areas, which may include actively carry out screening from houses to houses, close-contact or household tracing and investigation, as well as screening in the high-risk population. In addition to active case finding can help in finding and detecting new cases, it can also help in preventing the catastrophic costs resulting from TB to happen (Gurung et al., 2019; Shewade et al., 2018).

It is necessary to mention that this study is using an ecological approach with the unit analysis at the sub-district level. Thus, the results in this study could not and must not be interpreted or generalized at the individual level. Another limitation in this study is that there are still many ecological-related variables that are potentially correlated with the incidence of TB in an area that are not included in this study due to the limitation of data availability and accessibility. Therefore, further mapping and spatial analyses in relation to tuberculosis incidence in an area might be conducted with a more comprehensive approach and examine more variables such as other socio-economics variables, climate-related variables, until variables related to TB comorbidity such as HIV, to add more findings and insights regarding the mapping and spatial analysis of areas at risk of TB.

CONCLUSION

Ecological approach, as used in this study, can be utilized as a way to discover the distribution of tuberculosis at the population level in relation to environmental both physical and social, to population-related aspects. Population density, education, altitude, population growth rate, and health facilities aspects are all found to have a correlation with the incidence rate of tuberculosis at the sub-district level in Daerah Istimewa Yogyakarta. Population density and education show a positive correlation with the incidence rate of tuberculosis, while altitude, population growth rate, and health facilities have an inverse correlation with the tuberculosis incidence rate. Tuberculosis risk distribution viewed from these five significant aspects denotes that sub-districts at high risk of tuberculosis are found to be in the Yogyakarta City.

Insights regarding the high risk areas as well as aspects in relation to a specific area that can increase the risk of that area to tuberculosis incidence can be put to use as inputs for tuberculosis control and prevention measures. These measures can be related to case detection and finding as well as the strengthening of tuberculosis prevention programs, also establish cross-sectoral cooperation as to aspects that are related to tuberculosis incidence, especially in the high-risk areas. This study also sheds light on the potential of further mapping and spatial analysis studies, such as by adding socioeconomics, environmental, meteorological and other variables, to studies about TB clustering.

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