Ecological Factors Influencing Tuberculosis in Indonesia: Exploring the Interplay of Health Resources, Socioeconomic Status, Climatic Factors, and Consumption Patterns

Sayifullah Sayifullah[1]*, Andi Kustanto[1], and Jabbar Ul-haq[2]

[1] Department of Economics, Universitas Sultan Ageng Tirtayasa, Indonesia
[2] Department of Economics, University of Sargodha, Pakistan
* Sayifullah, corresponding author. Email: sayifullah@untirta.ac.id
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Abstract

The elimination of tuberculosis (TB) in Indonesia is a challenging task due to its persistent increase in incidence, making it one of the primary infectious diseases that cause death. Until now, its handling has not been optimal. In this study, we take an ecological approach to discussing TB cases that can offer a comprehensive perspective, but only some studies still discuss this approach in Indonesia. This study aims to investigate various ecological factors—health resources, socioeconomic status, climatic factors, and consumption patterns—to provide an understanding of TB cases. We collected data on TB cases and ecological factors in 34 provinces in Indonesia from 2005 to 2020, leading to the development of a study by combining 41 tertiary and four secondary indicators. We compiled a panel dataset using a fixed-effects model to select and assess ecological factors associated with TB cases. This study revealed that those that showed a statistically significant correlation to the increase in TB cases were influenced by the number of TB cases treated, sanitarians, toddler obesity, income inequality, precipitation, rainy days, and temperature. In contrast, nutritionists, health insurance, population, and access to protein sources showed statistically significant correlations to the decline in TB cases. This study provides an overview of various ecological factors that influence TB cases in Indonesia, and the results of this study can be a basis for the government to create evidence-based policies to accelerate the handling of TB cases so that elimination by 2030 can be achieved.

Keywords

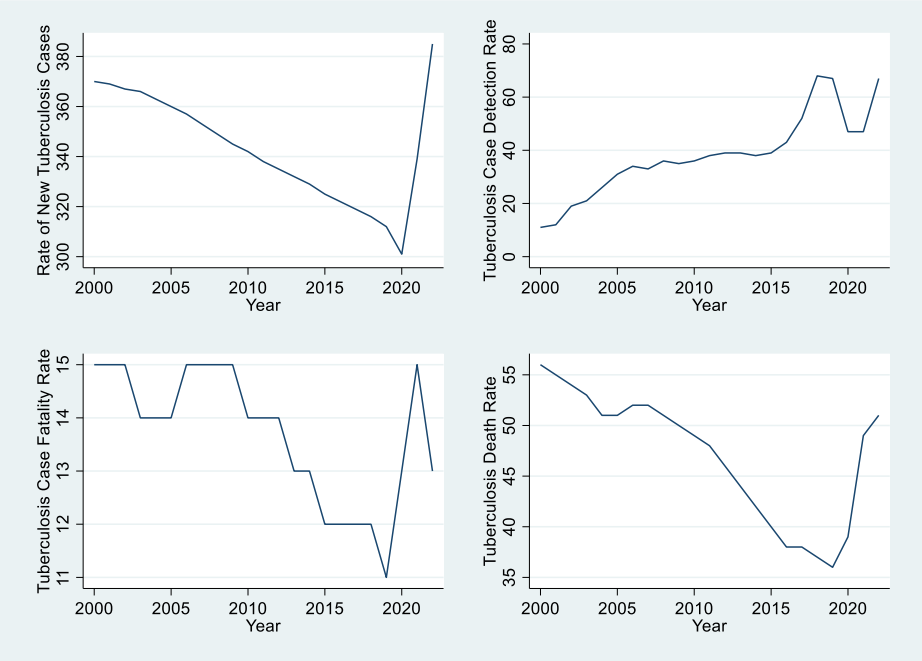
Climatic factors; consumption patterns; health resources; socioeconomic status; tuberculosis cases

Introduction

Tuberculosis (TB) is an infectious disease that infects the lungs caused by the bacteria *Mycobacterium tuberculosis*, and the spread of these bacteria occurs through the air from individuals infected with the virus (Liyew et al., 2024). Tuberculosis cases have become a public health challenge at the global level as a cause of morbidity and mortality and high health costs that must be borne by the country (Moule & Cirillo, 2020; Ong et al., 2020; Quan et al., 2022), according to the World Health Organization (WHO) (2020), which revealed that the number of deaths due to TB virus infection is often related to HIV cases. As many as 10 million people have been exposed to the TB virus, and 1.5 million people died from TB in 2018. It has been implemented in the Sustainable Development Goals (SDGs) so that international leaders have initiated TB prevention and transmission measures focused on achieving TB elimination by 2030 (Uplekar et al., 2015). Southeast Asia is the region with the highest TB prevalence at 44%, followed by Africa at 25%. The Western Pacific region has 18% of the lowest TB prevalence in Europe at 2.5%, followed by America at 2.9% and the Eastern Mediterranean at 8.2% (Chakaya et al., 2021). To reduce cases of death due to TB, a campaign program has been carried out at the global level, the message of which is that deaths caused by this infectious disease will be one per million people by 2050 (Kustanto, 2020).

Based on the WHO data (Dattani et al., 2022), Figure 1 shows an interactive graph of TB in Indonesia. Tuberculosis cases in Indonesia each year show fluctuations in both the incidence rate and the death rate from TB from 2000 to 2022 amid the COVID-19 pandemic, and the government has carried out several public health interventions to address this case. In 2000, there were an estimated 370 TB cases per 100,000 population, which increased to 385 cases in 2022. The government has launched several programs to address diagnosed and treated TB cases, which showed 11 in 2000 and increased by around 67 in 2022. The number of TB-related deaths in 2000 was 15 and decreased to 13 cases in 2022. Meanwhile, the death rate from TB per 100,000 population was recorded at 56 cases in 2020 and decreased to 51 cases in 2022.

Figure 1: Interactive Charts on TB in Indonesia, 2000–2022



Tuberculosis is one of Indonesia's significant public health challenges because the number of cases continues to increase every year, and it is also recorded as a country facing a high global TB burden (Chakaya et al., 2021). According to the WHO (2020), Indonesia contributes 10% of all TB cases globally, making it one of the significant contributors after India and China. Climate change, population density, and limited access to health services are significant factors in Indonesia's high number of TB cases (Kustanto, 2020). Poor air ventilation quality and slums in densely populated areas are health problems in indoor environments because they can cause the spread of TB bacteria through the air (Kustanto, 2020; Rachmat et al., 2022). The COVID-19 pandemic has significantly impacted TB management in Indonesia, slowing down efforts to detect, treat, and prevent TB because, during the pandemic, the government diverted many health resources to handling COVID-19, thus affecting health services for other diseases, including TB (Rachmat et al., 2022).

In the current global landscape, TB prevention and treatment continue to face significant barriers, such as drug resistance, limited access to health services, lack of public awareness, socioeconomic status, climatic factors, consumption patterns, and weak health systems (Liyew et al., 2024). Eliminating the TB epidemic is a key goal in the SDGs, and it is targeted to be achieved by 2030. The other goals are critical for a country to achieve prosperity and equality. According to the WHO (2020), Indonesia is among the countries with the highest TB cases in the world, with an estimated 845,000 cases and 98,000 TB deaths, equivalent to 11 deaths per hour. Tuberculosis cases are also widely associated with health problems such as malnutrition, smoking habits, diabetes mellitus, and HIV (Girishbhai Patel et al., 2024; Humphrey et al., 2020; Indarto et al., 2020; Noviyani et al., 2021). The Ministry of Health (2021) revealed that as many as 67% of TB cases have been identified and treated, as many as 283,000 people died from untreated TB cases, and family members around them during close contact while still alive were very susceptible to contracting TB bacteria.

One potential mediator in the increase in TB cases is socioeconomic conditions (Alene et al., 2019; Fang et al., 2019; Wardani & Wahono, 2018). These conditions can be seen from aspects of inadequate nutritional intake, unhealthy residential environments, limited access to health services, unemployment, low per capita income, and low education that are related to the increase in TB cases (Kustanto, 2020; Myers et al., 2006; Pelissari & Diaz-Quijano, 2017; Ploubidis et al., 2012). Long-term abuse of hazardous substances such as alcohol or drugs can also weaken the immune system and make people susceptible to TB (Humphrey et al., 2020). House conditions with a dense number of family members also have a risk of exposure to the TB virus through the air due to prolonged close contact with people who have previously been infected with the TB virus (Clark et al., 2002; Kustanto, 2020; Millet et al., 2013; Pedro & De Oliveira, 2013).

Increasing temperatures and high rainfall are two of the causes of climate change that have had a broad impact on health (Abbass et al., 2022; Rocha et al., 2022), which is also related to TB cases (Beiranvand et al., 2016; Chang et al., 2024; Hasan, 2019; Li et al., 2021; Qin et al., 2022; Wang et al., 2024; Xiao et al., 2018). Current public health and ecosystem conditions are an environmental syndrome due to climate change that impacts TB (Álvaro-Meca et al., 2016; Butler & Hanigan, 2019). High air pollution increases individuals' susceptibility to TB infection, which can be transmitted through the air (Huang et al., 2020).

High TB cases are often found in individuals who live in densely populated areas with poor ventilation and inadequate sanitation conditions (Kharwadkar et al., 2022; Kustanto, 2020). A history of previous illnesses makes individuals susceptible to contracting the TB virus (Haiqing Cai et al., 2020). Individuals who have a smoking habit are also susceptible to

contracting the TB virus (Burusie et al., 2020) because the condition of the lungs that are no longer in good condition and the immune system that is no longer extended prime can also increase the risk of contracting TB (Huang et al., 2020). In addition, health factors in individuals with diabetes mellitus are also susceptible to TB bacteria (Koo, 2013). Consuming alcohol (Munch et al., 2003) and cases of malnutrition can also worsen the body's condition because a body that lacks nutrition cannot have an immune system to fight TB bacteria (Cai et al., 2020; Li et al., 2023; VanValkenburg et al., 2022).

Nutritional status and TB are significantly interrelated, where TB infection can cause weight loss, malabsorption, and chronic fatigue that worsen the response to treatment (Gupta et al., 2009). As happened in the Malawi cases of smokers and pulmonary TB, cause malnutrition, lack of appetite, and increased catabolism (Pednekar & Gupta, 2007). Cases of malnutrition in TB patients are closely related to an increased risk of relapse to death (Kouhpayeh, 2022; Semba et al., 2010; Zachariah et al., 2017). Meeting proper nutritional needs is essential to support the healing process in TB patients, and adequate nutritional intake, especially protein, can strengthen the body's immunity, accelerate recovery, and prevent complications (Girishbhai Patel et al., 2024; Kubiak et al., 2019).

Several studies we have presented previously provide varying findings on how ecological factors such as health resources, socioeconomic status, and climatic factors are interrelated and contribute significantly to TB cases. In this study, we want to fill in a small part of the previous study by discussing how protein consumption can reduce TB cases (Karyadi et al., 2002; Kustanto, 2020; Kusumaningrum et al., 2023; Noviyani et al., 2021; Putra et al., 2022; Sihaloho et al., 2019, 2020; Tosepu et al., 2024; Wardani & Wahono, 2018). Good nutritional intake is an essential factor in the healing process for individuals infected with the TB virus because it will build strong body immunity, speed up the recovery period, and prevent disease complications. The repair of body cells damaged by the TB virus can be improved by consuming protein sources because it can increase low serum albumin levels, which TB patients often experience in this condition.

The problem of high TB cases in Indonesia can be discussed from a health perspective and through an ecological approach, which can significantly contribute to understanding its relationship to population studies and social sciences. For this reason, we will identify ecological factors such as health resources, socioeconomic status, climate, and consumption patterns that influence TB cases in Indonesia. In addition, integrated health policies and multidisciplinary approaches are key to developing effective and sustainable TB prevention and control strategies. The results of this study will be analyzed, as an effective TB control effort must consider all of these aspects to reduce TB cases and prevent the spread of this disease.

The study period we conducted was quite long, combining panel data in 34 provinces in Indonesia from 2005 to 2020. Integrating ecological factors in population studies and social sciences is a multidisciplinary approach that can provide a comprehensive understanding of the complex TB problem. The local context, namely Indonesia, shows the relevance of locality as a country experiencing an increase in TB cases so that the results of this study can be useful, especially in formulating effective and sustainable policies and strategies to reduce the TB problem in Indonesia and in other countries with similar situations and conditions to implement public health interventions by modifying those described by the WHO, increasing economic development for the welfare of society as a whole, and addressing climate change in order to reduce the spread of TB in Indonesia.

Methods

Study design, population, and variables

Several ecological factors influencing the number of TB cases were selected. Then, a panel data model combining time series and cross-unit data was constructed to increase the precision of model estimation (Baltagi, 2015). The panel data method is more effective in overcoming the problems of autocorrelation, heteroscedasticity, standard error, and degrees of freedom. This study used a regression technique in panel data, namely the random effect model (REM), which assumed no correlation between unobserved and independent variables. This is different from the fixed effect model (FEM), which assumes an arbitrary relationship between the two variables. To determine the appropriate regression model between REM and FEM, the Hausman test, which observed the correlation between unobservable and independent variables, was used (Baltagi, 2015).

Given the high rate in Indonesia, ecological studies on the number of TB cases are fascinating and crucial. To better plan public health initiatives, panel data methods in environmental studies of TB can offer insightful information on the disease progression and influencing factors. This study analyzed the Indonesian Health Profile, Welfare Statistics, and Statistical Year Book dataset published by the Indonesian Ministry of Health and Statistics. The secondary data used consists of 34 provinces in Indonesia as a cross-section and time series for 14 years from 2005–2020.

Panel data methods were employed, incorporating four distinct models:

1. **Health Resources Model**: This model examined the impact of health resources on TB cases. Variables included the number of completed TB treatments, HIV prevalence, general practitioners, nurses, sanitarians, nutritionists, public health centers, hospitals, health expenditure, insurance coverage, hospital bed availability, the percentage of smokers aged 15 and older, and toddler obesity.
2. **Socioeconomic Status Model**: This model analyzed how socioeconomic factors influenced TB cases. Variables included GRDP per capita, population, population density, sanitation coverage, mean years of schooling, unemployment rate, percentage of the poor population, urban slum households, the gender inequality index, literacy rates, and the percentage of households with access to adequate housing, improved drinking water, proper toilet facilities, and income inequality.
3. **Consumption Model**: This model investigated the relationship between dietary factors and TB cases. Variables included the consumption of fresh fish and shrimp, canned fish and shrimp, beef, chicken (broiler and local), chicken eggs, soybean curd, and fermented soybean cake.
4. **Climatic Model**: This model explored the effects of climatic factors on TB cases. Variables included precipitation, rainy days, temperature, humidity, wind speed, sunshine duration, and atmospheric pressure.

These models collectively provide a comprehensive framework for understanding the ecological and systemic factors contributing to TB in Indonesia, offering a solid foundation for evidence-based public health interventions.

Statistical analysis

This study adopted a comprehensive method in line with a previous investigation focused on home conditions, household income, and education level, using a single model that explained home environmental factors and social determinants of TB cases (Khaliq et al., 2015). Meanwhile, in this study, four models were used to analyze the influence of health resources, socioeconomic status, climatic factors, and consumption patterns on the number of TB cases using the panel data method:

$$TB_{it} = \beta_0 + \beta_1 TTB_{it} + \beta_2 HIV_{it} + \beta_3 Physician_{it} + \beta_4 Nurses_{it} + \beta_5 Sanitarian_{it} + \beta_6 Nutritionist_{it} + \beta_7 PHC_{it} + \beta_8 Hospitals_{it} + \beta_9 HS_{it} + \beta_{10} Insurance_{it} + \beta_{11} Beds_{it} + \beta_{12} Smoked_{it} + \beta_{13} Obesity_{it} + \varepsilon_{it} \quad (1)$$

$$TB_{it} = \beta_0 + \beta_1 GRDP_{it} + \beta_2 Population_{it} + \beta_3 Density_{it} + \beta_4 Sanitation_{it} + \beta_5 MYS_{it} + \beta_6 Unemployment_{it} + \beta_7 Poverty_{it} + \beta_8 Slums_{it} + \beta_9 Gender_{it} + \beta_{10} Literacy_{it} + \beta_{11} Housing_{it} + \beta_{12} Water_{it} + \beta_{13} Toilet + \beta_{14} Inequality_{it} + \varepsilon_{it} \quad (2)$$

$$TB_{it} = \beta_0 + \beta_1 FFS_{it} + \beta_2 CFS_{it} + \beta_3 CBM_{it} + \beta_4 Chicken_{it} + \beta_5 Eggs_{it} + \beta_6 Tofu_{it} + \beta_7 Tempeh_{it} + \varepsilon_{it} \quad (3)$$

$$TB_{it} = \beta_0 + \beta_1 Precipitation_{it} + \beta_2 Rainy_{it} + \beta_3 Temperature_{it} + \beta_4 Humidity_{it} + \beta_5 Wind_{it} + \beta_6 Sunshine_{it} + \beta_7 Atmospheric_{it} + \varepsilon_{it} \quad (4)$$

Results

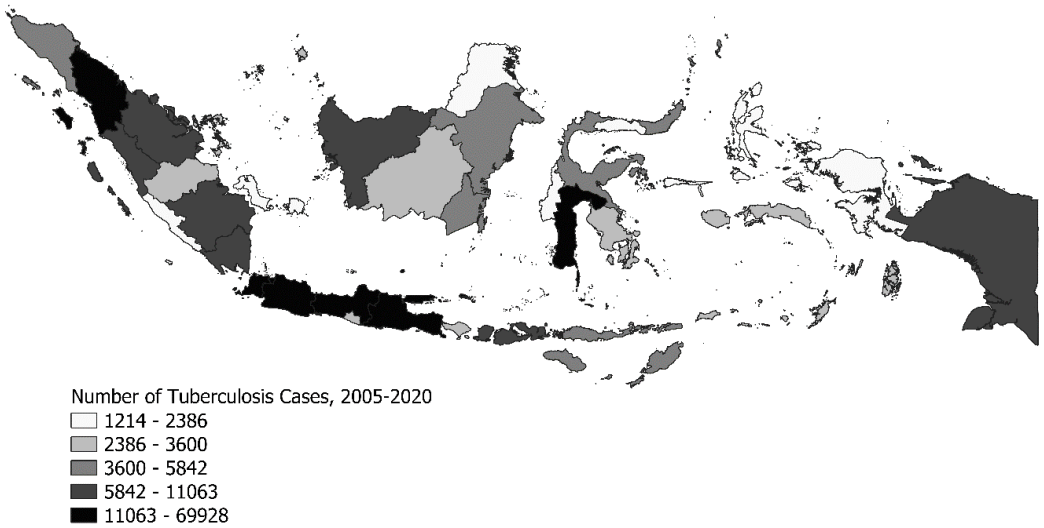
Table 1 shows summary statistics results, which describe the variables of health resources, socioeconomic status, consumption, and climate conditions. The average number of TB cases in Indonesia from 2005 to 2020 was 10,373. Consequently, Indonesia is ranked third on the list of 30 countries with the highest TB burden in the world. This suggests a high number of cases, both new and recurrent. With such an average number of cases, progressive steps are needed to overcome this infectious disease, especially if Indonesia wants to achieve the target of eliminating TB by 2030.

Table 1: Summary Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Number of TB cases	531	10,373.28	15,440.08	648.00	12,3021.00
Number of TTB cases	402	2,754.54	7,019.33	3.00	69,774.00
Number of HIV cases	368	1,046.91	1,628.47	1.00	395.00
Number of physicians	535	490.38	499.95	34.00	2,866.00
Number of nurses	535	2,756.50	2,386.03	226.00	15,178.00
Number of sanitarians	535	282.57	226.84	15.00	1,162.00
Number of nutritionists	535	271.67	249.82	8.00	1,597.00
Number of PHCs	535	276.82	239.07	41.00	1,083.00
Number of hospitals	203	62.82	76.13	1.00	395.00
Health spending	203	23,954.73	11,148.74	6,507.00	68,634.00
Insurance	498	67.77	24.29	10.09	228.15
Number of hospital beds	402	7,911.187	10,292.81	217.00	54,137.00
Smoked	204	29.10	3.18	20.50	36.56

Variable	Obs.	Mean	Std. Dev.	Min	Max
Toddler obesity	102	5.61	2.27	1.46	13.20
GRDP per capita	536	34,332.26	27,879.25	7,105.00	174,137.00
Population growth	531	7,369.28	10,551.71	682.80	54,472.00
Population density	537	681.17	2,453.98	2.00	15,900.00
Sanitation	501	57.21	18.74	9.06	96.96
Mean years of schooling	371	8.06	1.00	5.59	11.13
Unemployment rate	531	6.47	2.92	1.40	18.91
Poverty rate	468	12.72	7.11	3.42	40.78
Slums	102	10.96	6.35	2.74	42.73
Gender inequality	370	66.77	6.76	47.88	83.20
Literacy rate	237	95.86	4.86	70.78	99.87
Income inequality	499	0.35	0.04	0.23	0.50
Housing	204	80.00	19.96	26.16	99.49
Improved drinking water	402	66.08	16.02	22.32	99.84
Toilet	497	66.73	13.69	28.83	93.55
Fresh fish and shrimp	236	42,638.27	17,139.04	8,344.00	92,312
Canned fish and shrimp	236	5,725.65	3,120.88	1,084.00	15,801.00
Cow buffalo meat	236	2,666.05	2,294.19	132.00	18,205.00
Broiler/local chicken meat	236	13,476.46	6,656.25	2,063.00	28,119.00
Chicken eggs	236	10,880.28	3,470.98	2,891.00	19,163.00
Soybean curd	236	3,774.15	1,392.52	1,035.00	7,489.00
Fermented soybean cake	236	3,900.64	1,715.08	645.00	9,059.00
Precipitation	494	2,280.20	963.42	1.50	5,652.00
Rainy	468	182.76	54.24	2.00	304.00
Temperature	504	26.97	2.35	0.00	30.04
Humidity	480	82.18	34.95	0.00	836.00
Wind	464	3.70	6.89	0.07	144.00
Sunshine	472	59.47	12.25	13.30	100.00
Atmospheric	472	1,006.43	14.77	921.40	1,014.80

Figure 2: The Average Number of TB Cases in 34 Provinces in Indonesia, 2005–2020



Indonesia stands out as one of the countries grappling with several TB cases, ranking third globally after India and China. Figure 2 illustrates the average number of tuberculosis (TB) cases across 34 provinces in Indonesia during the study period from 2005 to 2020. Data

collected over the period from 2005 to 2020 revealed 10,373 cases of TB. The analysis highlights that during this timeframe, West (699,287), East (44,449), and Central Java (40,136) were the provinces with the number of cases. In contrast, North Kalimantan (1,214), North Moluccas (1,372), and West Sulawesi (1,500) recorded the numbers. Population dynamics, healthcare infrastructure quality, and public health interventions influence the fluctuation in TB cases in Indonesia. Efforts to combat TB in the country have been ongoing through initiatives like the National TB Program to enhance diagnosis and treatment accessibility. The number of cases reported in the provinces can vary each year. Generally populated provinces like West Java and Central Java tend to report numbers due to their large populations. West Java has the highest number of TB cases in Indonesia due to various challenges in the prevention program, including suboptimal multi-sector participation, poor implementation of minimum service standards, under-reporting of cases, and the need for quality service and improved TB treatment.

In this ecological study, four models were used to test the influence of health resources, socioeconomic status, climatic factors, and consumption patterns on the number of TB cases in Indonesia using panel data methods. The F and Hausman tests selected the panel data testing methods on models 1 to 4. First, the F test was used to determine whether the more appropriate method was using pooled least squares (PLS) or FEM. If the F-statistic value is significant, it means that there is a variation that FEM can explain, so it is continued with the Hausman test to choose between FEM or REM (Baltagi, 2015). The significant Hausman test results (probability value < α) indicate that FEM is more appropriate because there is a correlation between REM and the independent variables (Baltagi, 2015).

In Table 2, the F test results show that models 1 to 4 have significance in cross-section and cross-section/period fixed effects but are not significant in period fixed effects. This indicates that FEM with cross-section fixed effects is the most appropriate method for processing panel data in these models. Furthermore, the Hausman test results that are significant in all models make FEM the better choice over REM because REM residuals and independent variables are linked. Therefore, the FEM method with cross-section fixed effects is chosen as the best approach to estimate models 1 to 4. From the explanation that has been presented previously, the Chow and Hausman test results in Table 2 show that the four models proved effective using the FEM method.

Table 2: The Result of the Chow and Hausman Test

Model 1			
Chow test			
	Statistic	Prob.	Conclusion
Cross-section Chi-square	56.903601	0.0060	Fixed Effect Model (FEM)
Hausman test			
	Chi-Sq. Statistic	Prob.	Conclusion
Cross-section random	25.341219	0.0208	Fixed Effect Model (FEM)
Model 2			
Chow test			
	Statistic	Prob.	Conclusion
Cross-section Chi-square	204.642844	0.0000	Fixed Effect Model (FEM)
Hausman test			
	Chi-Sq. Statistic	Prob.	Conclusion
Cross-section random	117.848229	0.0000	Random Effect Model (REM)

Model 3			
Chow test			
	Statistic	Prob.	Conclusion
Cross-section Chi-square	522.074471	0.0000	Fixed Effect Model (FEM)
Hausman test			
	Statistic	Prob.	Conclusion
Cross-section random	25.066936	0.0007	Random Effect Model (REM)
Model 4			
Chow test			
	Statistic	Prob.	Conclusion
Cross-section Chi-square	811.273626	0.0000	Fixed Effect Model (FEM)
Hausman test			
	Statistic	Prob.	Conclusion
Cross-section random	174.494737	0.0000	Random Effect Model (REM)

Tuberculosis is a substantial public health challenge in Indonesia as well as numerous other developing countries. Despite the historical recognition, TB continues to present a substantial obstacle. Therefore, we conducted a study that explores and quantitatively analyzes the influence of ecological factors on TB cases. Table 3 is an overview of the findings of this study, which shows that TB cases are associated with various ecological factors, including health resources, socioeconomic status, climatic factors, and consumption patterns in 34 provinces in Indonesia during the period 2005–2020. Tuberculosis cases showed an increasing trend influenced by various factors such as the number of TB cases treated, sanitarians, toddler obesity, income inequality, precipitation, rainy days, and temperature. Nutritionists, health insurance, population, and access to protein sources influenced the decrease in TB cases. However, to provide a more comprehensive picture in this results section, it is also important to highlight the current condition of TB cases in Indonesia.

Based on data from the Ministry of Health, TB cases in Indonesia are estimated to reach 1,060,000 cases and 134,000 deaths due to TB per year (17 people die from TB every hour) in 2023 (Ramadhan, 2024). Previously, in 2020, Indonesia was ranked third in the number of TB cases, with 824,000 cases; India was ranked first (2.59 million cases), and China second (842,000 cases) (Kustanto, 2020). In 2021, India was still ranked first with 2.95 million TB cases, Indonesia rose to second place (969,000 cases), and China fell to third place (780,000 cases) (Ramadhan, 2024). Thus, Indonesia contributed to 9.2 percent of global TB cases. This increase is not positive news but reflects serious challenges in TB control efforts in Indonesia. The problem currently facing Indonesia is that many TB cases are found, but the discovery of TB cases in the community could be more optimal. It is an important concern because the reported incidence rate of infectious diseases indicates an influence on public health and distribution. The Stop TB Partnership Indonesia Program Manager Nurliyanti said that the gap in TB cases that has not been found is one of the causes of the increasing number of TB cases in Indonesia (Ramadhan, 2024). The slowdown in TB case discovery can be seen from the comparison of case discovery in the previous year, and this is one of the challenges in handling TB in Indonesia, namely that there is still a gap in terms of case discovery and reporting to the quality of service.

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Table 3: Ecological Factors Related to The Number of TB Cases: Fixed Effect Estimations

Dependent variable	**Number of TB cases**			
Independent variable	**Model (1)**	**Model (2)**	**Model (3)**	**Model (4)**
Number of TTB cases	2.434250*** (0.190088)			
Number of HIV cases	0.360654 (1.036591)			
Number of physicians	-0.310812 (2.032648)			
Number of nurses	0.276681 (0.277346)			
Number of sanitarians	0.276681** (0.277346)			
Number of nutritionists	-6.210089** (2.442414)			
Number of PHCs	60.33908 (40.48569)			
Number of hospitals	-62.09512 (51.97852)			
Health spending	0.054231 (0.034780)			
Insurance	-46.73032*** (16.88973)			
Number of hospital beds	0.445902 (0.558846)			
Smoked	-26.47125 (83.33402)			
Toddler obesity	125.2102*** (42.33986)			
GRDP per capita		0.124137 (0.085093)		
Population growth		-0.046384*** (0.023446)		
Population density		15.95155 (12.62541)		
Sanitation		18.28895 (22.80007)		
Mean years of schooling		-776.0644 (2939.897)		
Unemployment rate		-25.70551 (545.0003)		
Poverty rate		-1,149.496 (890.6708)		
Slums		40.31916 (58.37383		
Gender inequality		-11.26699 (0.8240)		
Literacy rate		480.9987 (360.2528)		
Income inequality		5,9163.78*** (21253.39)		
Housing		-36.76737** (17.14675)		

Dependent variable	**Number of TB cases**			
Independent variable	**Model (1)**	**Model (2)**	**Model (3)**	**Model (4)**
Improved drinking water		98.93029 (56.38495)		
Toilet		123.0127 (138.0265)		
Fresh fish and shrimp			-0.077314** (0.036357)	
Canned fish and shrimp			-0.625269*** (0.147498)	
Cow buffalo meat			-0.752901*** (0.203210)	
Broiler/local chicken meat			-0.153585*** (0.096099)	
Chicken eggs			-0.320809** (0.148299)	
Soybean curd			-0.983175** (0.467661)	
Fermented soybean cake			-1.021025** (0.477743)	
Precipitation				0.245303* (0.140814)
Rainy days				6.121418** (2.048617)
Temperature				665.7643*** (96.55439)
Humidity				-0.549450 (2.209264)
Wind				-41.70548 (36.15328)
Sunshine				-11.83438 (7.376266)
Atmospheric				27.91045 (27.72401)
Constant	-14,564.10 (12,192.05)	-70,657.80 (46,911.61)	5,240.285*** (1,078.676)	-34,085.64 (28,481.98)
Number of Observations	102	101	236	411
R-squared	0.994249	0.988446	0.917127	0.871652
Adjusted R-squared	0.989439	0.978200	0.900127	0.857776
F-Statistic	206.7132	96.47027	53.94964	62.81945
Prob (F-Statistic)	0.000000	0.000000	0.000000	0.000000

*Note: Standard errors in parentheses; significance level ***p < .01, **p < .05, *p < .1*

Discussion

Panel data regression results are presented in Table 3, with the estimation result referring to model Equations 1, 2, 3, and 4. This study tested the influence of 41 ecological variables on TB cases in Indonesia from 2005 to 2020. These variables include the effect of health resources, socioeconomic status, consumption, and climate change on the number of TB cases using the panel data method, and the best model used was FEM. The study results in Table 3 show that the number of TB cases is influenced by the number of TB patients who receive treatment. Treatment of TB patients until complete can reduce the number of cases and stop the spread of pathogens (Kustanto, 2020).

However, the problems often faced by TB patients are failure during treatment therapy, sociodemographic and socioeconomic problems, knowledge and perception, and the effects of TB treatment (Fang et al., 2019). With a long treatment period of around 6–8 months, accompanied by the consumption of various other drugs and also the side effects felt by TB patients, it causes patient non-compliance during the treatment process (Wong et al., 2013). Non-compliance with treatment makes TB patients face drug resistance and frequent relapses of the disease and can also result in death (Dodd et al., 2023; Marais, 2016; Ukwaja et al., 2013; Vos et al., 2020). Older TB patients and limited access to health facilities and services are some of the obstacles to TB treatment (Kustanto, 2021a; Ukwaja et al., 2013).

The number of sanitarians has caused an increase in TB cases. When there is an increase in the involvement of sanitation experts in the community, it can increase the detection and reporting of TB cases so that the number of TB cases appears to increase even though sanitation efforts help reduce the spread of TB cases. The number of sanitarians can be a way to prevent the spread of disease, promote healthy and clean living, provide knowledge about managing household waste, and monitor the quality of clean and proper water (Kustanto, 2020; Mariana et al., 2020).

The number of nutritionists has shown a significant influence on the decline in the number of TB cases. Nutritionists spread across several health centers and present in the community can help improve patients' nutritional status, strengthen the immune system, improve patient recovery and endurance through a balanced diet and nutritional interventions, and support patients' compliance during the treatment process so that the decline in TB cases can be effective (Adhanty & Syarif, 2023; Kustanto, 2020).

The coverage of national health insurance membership significantly impacts reducing TB cases. This condition concerns using national health insurance to increase access to health services for patients with chronic diseases and long treatment periods (Skinner et al., 2014). In several countries with lower middle economic status, national health insurance can motivate increased curative and preventive health services and also protect against the high costs incurred by patients because they can be assisted by contributions paid by national health insurance participants (Nshakira-Rukundo et al., 2021; Rachmat et al., 2022; Setyadi et al., 2023). A study conducted by Wells et al. (2019) also revealed the same thing: that health insurance has a significant influence on TB treatment. In addition, comprehensive health insurance allows people to get health services, such as diagnosis and treatment, so that it can reduce TB cases (Adhanty & Syarif, 2023). With health insurance, TB patients can receive early and complete treatment, which is important to suppress the spread of TB bacteria (Ferreira et al., 2023).

Socioeconomic status, such as education, employment, income, and nutritional status of people in developed and developing countries, are often associated with TB incidence (Kustanto, 2020). Nutritional problems such as obesity in toddlers are a common problem in children and are a danger sign for the child's future (Kustanto, 2021b). Obesity is a growing nutritional problem associated with various chronic degenerative conditions that have become a global epidemic, with at least 2.8 million people dying each year due to overweight problems (WHO, 2021). The case of obese toddlers is an alarm that signals that this nutritional problem is an enemy that must be addressed seriously (Kustanto et al., 2024). The results of this study show that the problem of obesity in toddlers is closely related to the increase in TB cases. As reported by the Kompas Daily newspaper, children are also susceptible to TB, and based on data from the Ministry of Health in 2021, 9.7% of cases occurred in children aged 0–14 (Pancawati, 2023).

Although intuitively, areas with a large population and population density can increase the transmission of TB cases, as stated in Kustanto (2020), in this study, we found that this affected reducing TB cases. We assess that increasing population is often accompanied by strengthening the health system because the central and regional governments have implemented many TB control programs and shown that good public health management can overcome the challenges posed by increasing population and population density (Rachmat et al., 2022; Setyadi et al., 2023). Adequate and affordable housing has a significant impact on reducing TB cases because in a decent place to live, the house's occupants have good ventilation quality, and the occupants are not too dense, which can inhibit the spread of TB bacteria (Lee et al., 2022). Residents with decent housing reflect general welfare, contributing to a stronger immune system (Kustanto, 2020, 2021a).

Tuberculosis disease is not only detrimental to public health but also socioeconomically detrimental, and a large number of TB sufferers, the country also bears the burden of these losses (Dye et al., 2009; Hargreaves et al., 2011; Költringer et al., 2023; Lönnroth et al., 2009; Obuku et al., 2012; Ploubidis et al., 2012; Schmidt, 2008). Socioeconomic factors such as income inequality can limit access to health services and worsen socioeconomic conditions, thereby increasing the risk and cases of TB (Alene et al., 2019; Cui et al., 2019; Khaliq et al., 2015; Sihaloho et al., 2019, 2020; Wardani & Wahono, 2018). We found in this study, which shows that income inequality has a significant effect on the increase in TB cases because people with low incomes are often found to have poor housing and limited access to health services, which increases the risk of TB infection and spread (Aini, 2020; Ploubidis et al., 2012). This income inequality also affects the ability of individuals to receive adequate treatment and adhere to treatment regimens, thereby worsening the spread and control of TB (Kustanto, 2020). Socioeconomic problems such as transportation costs, accommodation, nutrition, and loss of income due to inability to work and high financial burdens can cause patients not to get a diagnosis, not start treatment, or even stop treatment. These conditions will have a high risk of transmitting the disease to others and can develop into multidrug-resistant (MDR) TB (Widyawati, 2019).

Tuberculosis patients' recovery and TB risk can decrease, one of which is influenced by a good protein consumption pattern (Dadgostar, 2019; Lee et al., 2020). The need for sufficient protein sources from foods such as meat, eggs, and nuts can support the immune system and repair body tissues damaged by TB bacteria. This study found that protein consumption, such as chicken, buffalo meat, eggs, tofu, and tempeh, can help recover from TB because good nutrition is very important to support the immune system in fighting pathogens (Li et al., 2022).

Climatic factors such as average rainy days, temperature, and rainfall affect the increase in TB cases (Li et al., 2021; Qin et al., 2022; Xiao et al., 2018). Average rainy days can affect room humidity in densely populated residential conditions because it can facilitate the spread of TB bacteria, especially in homes with poor ventilation and sanitation (Kustanto, 2020). Tuberculosis transmission can also occur over a long period because the bacteria stick to the room (Naranbat et al., 2009). During the rainy season, a person's activities are often more indoors (Wagner et al., 2019), and this can be dangerous if the room is humid, and poor ventilation can increase the risk of spreading the TB virus. Suppose family members are living in the same residence as TB sufferers. In that case, it is better to remain vigilant so as not to be exposed to the TB virus and to support family members so that they continue to undergo treatment to be free from it (Rachmat et al., 2022).

Tuberculosis cases can also be influenced by temperature because when in a room with poor ventilation conditions, temperature fluctuations affect the transmission of the TB virus, especially during the rainy season because there is increased humidity and lack of sunlight (Liyew et al., 2024). This increased frequency of indoor activities increases the likelihood that healthy individuals are exposed to tubercle bacilli that cause TB disease that can be shed by infected individuals indoors for a longer duration (Ackley et al., 2019; Bălă et al., 2021; Chopra et al., 2023; Mamahlodi, 2019).

Limitations

The 15-year period from 2005 to 2020 is sufficiently long and adequate to conduct a quantitative study of TB cases in Indonesia by considering several ecological factors. However, we realize that our study has limitations. The limitations of this study used a quantitative approach using macro data from ecological factors such as health resources, socioeconomic status, climatic factors, and consumption patterns at the provincial level in Indonesia. It is hoped that in future studies, if they want to use macro data, they can add the latest data from ecological factors and TB cases and can also be more systematic in exploring using a qualitative approach and analyzing it using a quantitative approach such as the socio-cultural context that may affect TB cases, because in our opinion, considering these factors can increase public awareness of TB, reduce stigma, and encourage more supportive behavior in the prevention and treatment of TB.

Conclusion

This study examines ecological factors such as health resources, socioeconomic status, climatic factors, and consumption patterns on TB cases in 34 provinces in Indonesia from 2005 to 2020. The results of this study indicate that several ecological factors have played an important role in TB cases. Tuberculosis patients who receive treatment, sanitation experts, toddler obesity, income inequality, precipitation, rainy days, and temperature play a role in increasing TB cases. Nutritionists, health insurance, population, and access to protein sources show a relationship to decreasing TB cases. Therefore, designing comprehensive policies at the population level is crucial to reducing TB cases. Implementing public health interventions through treatment efforts, preventive vaccinations, and the provision of health services can help accelerate the elimination of TB by 2030. In addition, the government is expected to ensure the equitable distribution of health resources, increase economic development,

maintain the stability of affordable protein source prices to meet community needs and address climate change that can affect TB ecology and pathogens.

Ethical statement

This study was approved by the Universitas Ngudi Waluyo Research Ethics Committee (Reference No: 364/KEP/EC/UNW/2024). The authors have fully addressed all ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, and more.

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