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BREAKING THE CHAINS OF TUBERCULOSIS: QUANTIFYING THE EFFECTS OF LITERACY, POPULATION DENSITY, AND ACCESS TO IMPROVE SANITATION TO SUPPORT DEFENSE HEALTH AND SECURITY IN INDONESIA

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ABSTRACT

Background: Tuberculosis (TB) is a global health problem. It poses a significant burden worldwide, requiring urgent control measures and research for effective reduction, especially in Indonesia. **Objective:** Investigating the effects of literacy, population density, and access to improved sanitation on TB incidence can provide insights into the relationship between these factors. **Methods:** This study was conducted in Jakarta, Indonesia from June to July 2023, using secondary data from 2005 to 2021. It employed a quantitative cross-sectional design to examine the relationship between variables. Data were collected from the ASEAN database and analyzed using descriptive and path analysis techniques to determine variable effects and significance. The study found that the incidence of tuberculosis in Indonesia initially decreased from 2005 to 2020 but significantly increased in 2021. **Results:** Population density, adult literacy rate, and access to improved sanitation all showed positive trends. Population density has an effect on access to improve sanitation (p<0,001), and literacy rate (p<0,001). In the context of the incidence of tuberculosis, this variable is affected by access to improved sanitation (p=0,002) and literacy rate (p=0,010). Moreover, population density has an effect on the incidence of tuberculosis mediated by literacy rate (p=0,012), and by access to improve sanitation (p=0,002). Overall, the model had a very good fit based on the indicators. **Conclusion:** The final model showed that higher population density correlated with increased access to sanitation and literacy rate, while access to improved sanitation was associated with reduced tuberculosis incidence. Priority investments in sanitation infrastructure, especially in densely populated areas, along with improved access to sanitation facilities and targeted health education campaigns and collaboration across defense, health, and education sectors, are recommended to enhance tuberculosis prevention and control.

Keywords: *Tuberculosis; Indonesia; Health Security; Defense; Sanitation*

INTRODUCTION

Tuberculosis (TB) remains a significant global health problem, affecting millions of people worldwide. It is caused by the bacteria Mycobacterium tuberculosis and primarily affects the lungs but can also affect other parts of the body. TB is transmitted through inhaling respiratory droplets containing the bacteria[1]. The global burden of TB is substantial, with approximately a quarter of the world's population infected with TB bacteria. However, only a small percentage of those infected develop TB disease, which can be fatal if left untreated[2]. In 2020, an estimated 10 million people fell ill with TB, and around 1.5 million died from the disease[3]. These high incidence and mortality rates underscore the urgent need for effective control and prevention measures.

TB poses significant socioeconomic implications. It primarily affects individuals in their most productive years, leading to a loss of productivity and a potential economic burden on affected communities[4]. The disease can push households into poverty due to the cost of treatment and the economic impact of illness or death. The strain on healthcare systems, particularly in resource-limited settings, is considerable, as TB requires prolonged and intensive treatment[5]. Furthermore, the emergence of drug-resistant TB strains, such as multidrug-resistant TB (MDR-TB) and extensively drug-resistant TB (XDR-TB), poses additional challenges for diagnosis, treatment, and control efforts[6].

The burden of TB is exceptionally high in low- and middle-income countries, with most cases concentrated in regions such as South-East Asia, Africa, and the Western Pacific[7]. TB disproportionately affects adults, but all age groups are at risk. However, achieving global targets for reducing TB cases and deaths remains challenging, especially in Indonesia[8].

Indonesia has been identified as the country with the second highest TB burden in the world[9]. Additionally, in 2018, Indonesia had an estimated incidence of 845,000 TB cases and an estimated

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mortality of 93,000 TB cases, making it the third highest TB burden country[10]. TB remains a significant health problem in Indonesia, and efforts are being made to address and eliminate the disease.

Specific risk factors contribute to the transmission and spread of TB in Indonesia. These include overcrowded living conditions[11], poor access to healthcare[12], limited awareness and knowledge about TB[13], and suboptimal adherence to treatment regimens[14]. To address the TB situation in Indonesia, the government has implemented various initiatives, including the National Tuberculosis Program, which aims to improve case detection, increase access to treatment, and promote community awareness[15]. Efforts are being made to strengthen healthcare systems, enhance diagnostic capabilities, and provide quality care to TB patients.

The statistics and trends related to TB in Indonesia highlight the urgent need for continued research, and sustained efforts to control the disease effectively. The rationale for investigating the effects of literacy, population density, and access to improved sanitation on tuberculosis (TB) incidence can be understood by considering the relationship between these factors and the spread of TB. By conducting such investigations, researchers aim to identify key factors that can inform public health strategies, policy-making, and resource allocation to control and reduce TB incidence effectively.

METHODS

Study Setting

The study was carried out in Jakarta, Indonesia, spanning from June 2023 to July 2023. The data utilized in this study was derived from secondary sources, specifically the database spanning from 2005 to 2021.

Study Designs

This study employs a quantitative approach and adopts a cross-sectional design to examine a diverse range of subjects across multiple years spanning from 2005 to 2021. The utilization of a cross-sectional study design enables the researcher to examine the concurrent relationship between the observed variables. Within the scope of this investigation, scholars have the capacity to examine alterations and patterns that manifest in the observed variables throughout the designated duration.

Study Variables

The variables in this study consisted of exogenous variables: population density (X), intervening variables in the form of adult literacy rate (Z1), and proportion of population with access to improved sanitation (Z2), and endogenous variables, namely incidence of tuberculosis (Y).

Table 1. Study Variable

Variable		Description	Scale
Exogen Variable	X	Population Density	per Sq. Km
Intervening Variable	Z_1	Adult Literacy Rate	in percent
	Z_2	Proportion of Population with Access to Improved Sanitation	in percent
Endogen Variable	Y	Incidence of Tuberculosis	per 100,000 population

Design Models

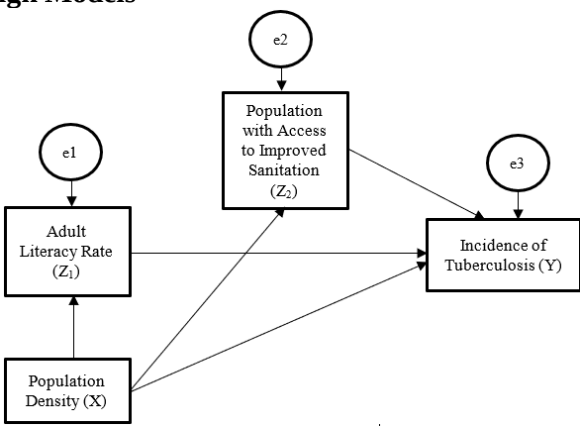

Figure 1. Design Model

The present model comprises of one exogenous variable, two intervening variables, and one endogenous variable. The hypotheses associated with this model are as follows:

H_1: Population density (X) has direct effect to Population with Access to Improved Sanitation (Z_2)
H_2: Population density (X) has direct effect to Literacy Rate (Z_1)
H_3: Access to Improved Sanitation (Z_2) has direct effect to Incidence of Tuberculosis (Y)
H_4: Population density (X) has direct effect to Incidence of Tuberculosis (Y)
H_5: Literacy Rate (Z_1) has direct effect to Incidence of Tuberculosis (Y)

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H_6: Population density (X) has indirect effect to Incidence of Tuberculosis (Y) moderating by Literacy Rate (Z_1)

H_7: Population density (X) has indirect effect to Incidence of Tuberculosis (Y) moderating by Population with Access to Improved Sanitation (Z_2)

Data Collection and Analysis

The data was acquired from the ASEAN database. The data presented in this study is the result of a collaborative endeavor involving the Statistics Division of the ASEAN Secretariat (ASEANstats) and the National Statistical Offices of the ASEAN Member States, operating within the framework of the ASEAN Community Statistical System (ACSS). The data underwent analysis through descriptive and path analysis techniques in order to ascertain the impact and statistical significance of the variables.

RESULTS

According to the findings of the analysis, there was an initial decline in the prevalence of tuberculosis in Indonesia between the years 2005 and 2020. In the year 2020, the incidence rate of cases amounted to 301 per 100,000 individuals. However, there was a notable increase in the subsequent year of 2021, with the incidence rate rising to 354 cases per 100,000 individuals.

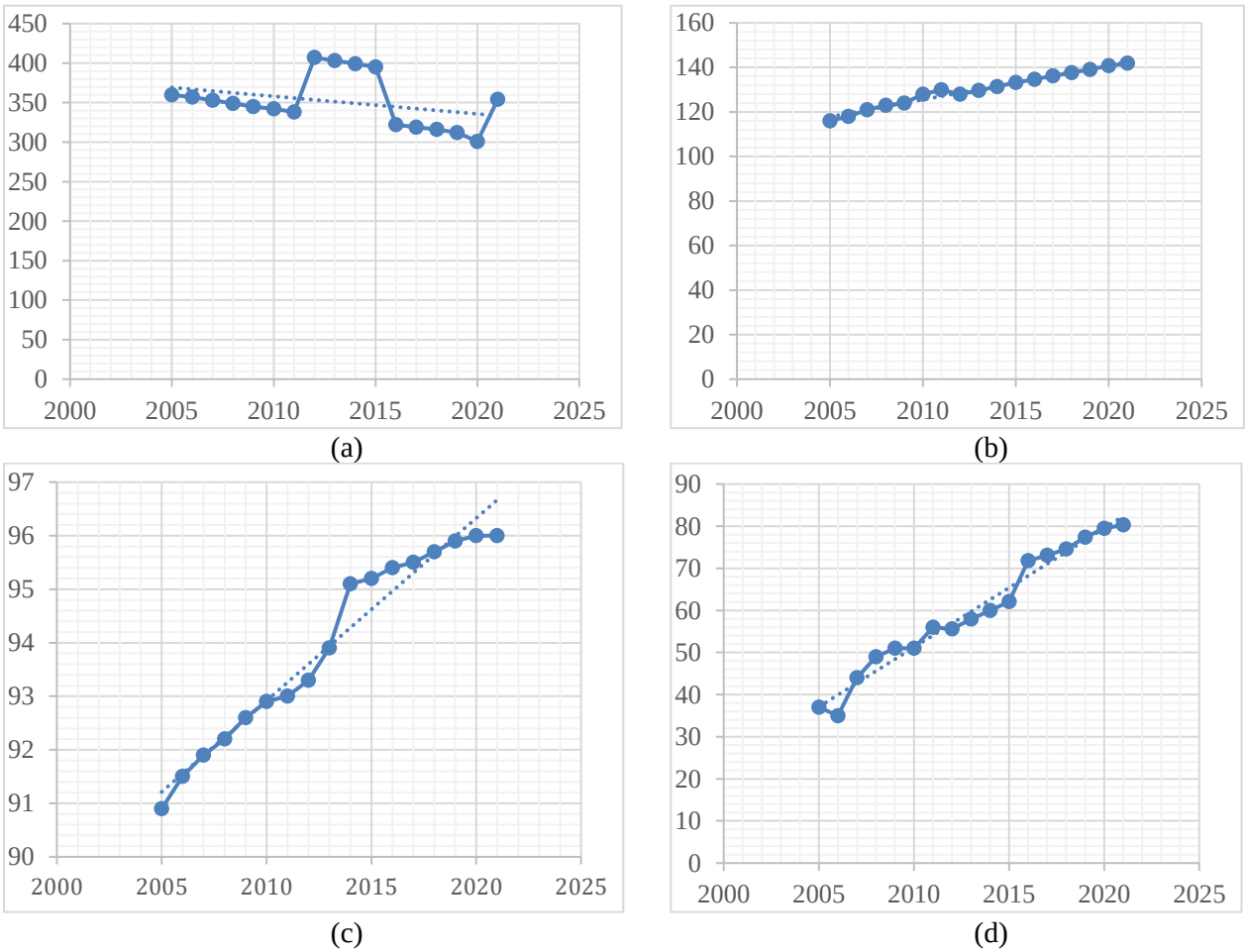

Figure 2. The trends of: (a) Tuberculosis Incidence; (b) Population Density; (c) Adult Literacy Rate; and (d) Proportion of Population with Access to Sanitation in Indonesia 2000-2021

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The population density has exhibited a consistent upward trend from 2005 to 2021. As of 2021, the population density stands at 141.84 individuals per square kilometer. Moreover, there was a notable increase in the adult literacy rate, reaching 96%. Additionally, the proportion of the population with access to sanitation also experienced growth, reaching 80.3%.

Table 2. First Phase of Path Analysis

Direct Effect	**Path Coefficients**	**S.E**	**P**	**R^2**
Access to Improve Sanitation ← Population Density	1,818	0,081	<0,001	0,970
Literacy Rate ← Population Density	0,217	0,014	<0,001	0,939
Incidence of Tuberculosis ← Access to Improve Sanitation	-6,204	2,536	0,014	
Incidence of Tuberculosis ← Population Density	3,001	5,035	0,551	0,480
Incidence of Tuberculosis ← Literacy Rate	30,891	14,801	0,037	
Indirect Effect	**Path Coefficients**	**S.E**	**Sobel Test**	**P**
Incidence of Tuberculosis ← Literacy Rate ← Population Density	-4,565	3.241	2.068	0.039
Incidence of Tuberculosis ← Access to Improve Sanitation ← Population Density	-4,565	4.64	-2.432	0.015

According to the findings presented in Table 2, all variables exhibit a statistically significant direct effect ($p < 0.05$), except for the population density variable, which does not demonstrate a significant relationship with the other variables ($p = 0.551$). Upon conducting the Sobel calculation, it is evident that the indirect effect demonstrates a statistically significant association between population density and tuberculosis incidence, mediated by both literacy and sanitation.

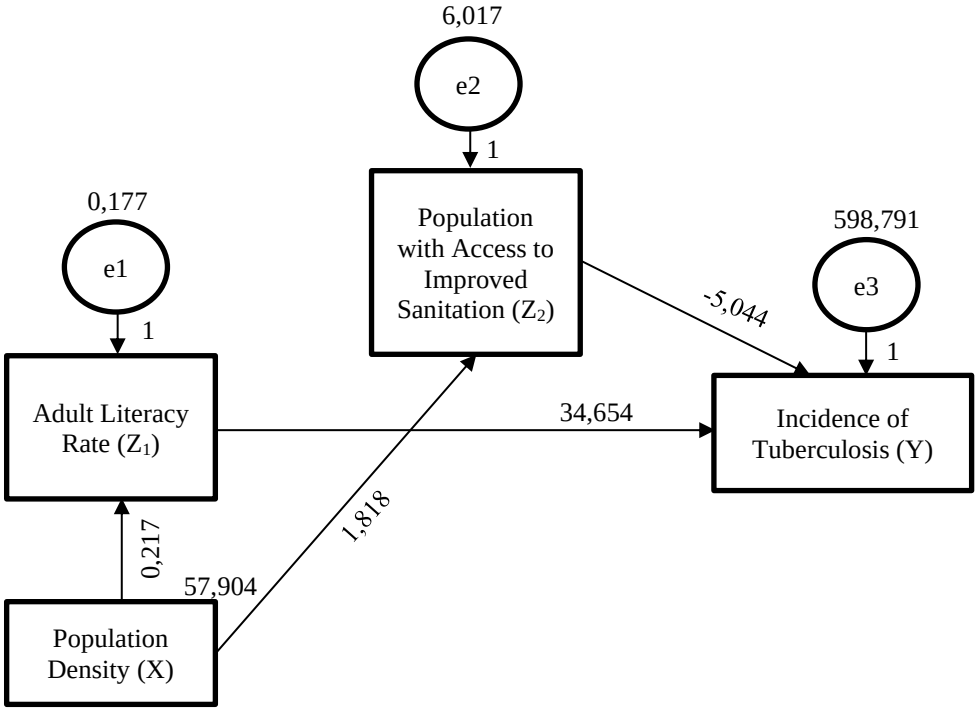

Figure 3. Fit Model

The model depicted in Figure 3 is the result of selecting the path model based on the significance of the variable. Although no variables were excluded, the research model did not incorporate the relationship between population density and the incidence of tuberculosis.

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Table 3. Final Phase of Path Analysis

Direct Effect	**Path Coefficients**	**S.E**	**P**	**R^2**
Access to Improve Sanitation ← Population Density	1,818	0,081	<0,001	0,970
Literacy Rate ← Population Density	0,217	0,014	<0,001	0,939
Incidence of Tuberculosis ← Access to Improve Sanitation	-5,044	1,644	0,002	0,465
Incidence of Tuberculosis ← Literacy Rate	34,654	13,535	0,010	
Indirect Effect	**Path Coefficients**	**S.E**	**Sobel Test**	**P**
Incidence of Tuberculosis ← Literacy Rate ← Population Density	-1,638	2.977	2.526	0.012
Incidence of Tuberculosis ← Access to Improve Sanitation ← Population Density	-1,638	3.017	-3.039	0.002
Fit Model: Chi-Square = 1,236, p=0.539; CMIN/DF= 0,618; GFI = 0,962; RMSEA = 0,000; AGFI = 0,808; TLI = 1,022; CFI = 1,000; IFI = 1,007; NFI = 0,989				

Based on the results of the final direct effect model, it can be inferred that all variables exhibit statistical significance at a significance level of $p<0.05$. The relationship between population density and access to improved sanitation exhibits a positive effect (1.818), indicating that as population density increases, so does access to improved sanitation. This relationship is supported by a highly significant R^2 value (0.970), indicating a strong explanatory power of the model. In addition, it is observed that there exists a positive correlation between population density and literacy rate, with a coefficient of 0.217. This implies that as population density increases, the literacy rate also tends to increase. Moreover, this relationship is highly significant, as indicated by the strong R^2 value of 0.939. Access to improved sanitation has a negative impact (-0.504) on the incidence of tuberculosis, indicating that a higher level of access to improved sanitation is associated with a lower incidence of tuberculosis. Conversely, the literacy rate has a positive impact (34.654) on the incidence of tuberculosis, suggesting that a higher literacy rate is associated with a higher incidence of tuberculosis. The coefficient of determination (R^2) falls within the moderate range (0.465).

The final model examines the indirect impact of population density on tuberculosis incidence, mediated by literacy rate. The analysis reveals a negative effect (-1.638), indicating that higher population density, when mediated by literacy rate, is associated with lower tuberculosis incidence. Additionally, the model demonstrates a negative effect (-1.638) of population density on tuberculosis incidence, mediated by access to improved sanitation. This implies that by enhancing sanitation facilities, the prevalence of tuberculosis is expected to decrease. The fit model, which incorporates all indicators, demonstrates a high level of effectiveness.

DISCUSSION

Population density has an effect to access to improve sanitation

Population density can impact access to improved sanitation. The lack of access to safely managed sanitation is a significant issue worldwide. Approximately 46% of the global population does not have access to safely managed sanitation, and around 6% of the world's population still practices open defecation[16]. In urban areas, limited access to sanitation facilities can be a challenge due to population density, homelessness, and inadequate infrastructure. It is estimated that 57% of urban dwellers lack access to toilets that provide a full sanitation service, and nearly 100 million urban residents still practice open defecation. Limited access to sanitation facilities for people experiencing homelessness and those living in emergency shelters can lead to unhygienic conditions and the spread of diseases[17]. Inadequate investment in urban sanitation infrastructure and lower access to public toilets can further exacerbate the issue[18].

Sanitation disparities are also prominent in rural areas, affecting a significant proportion of the population, where approximately two-thirds of people without basic sanitation services reside. Meeting the sanitation needs of rural households presents a significant challenge due to the large number of households spread over vast areas[17]. Access to proper sanitation and toilet facilities is crucial for a healthy environment and community health. However, almost two out of five households in Indonesia are without access to improved sanitation[19].

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Rural areas in Indonesia have lower access to improved sanitation facilities compared to urban areas. Households living in rural areas were laggards compared with their urban counterparts in access to improved sanitation facilities[19]. The proportion of households using improved sanitation services (including safely managed sanitation) has increased by 2.14% within a year, from 77.34% in 2019 to 79.53% in 2020[20].

Efforts to improve access to safe water and sanitation are ongoing in Indonesia. The PAMSIMAS program has helped Indonesia's low-income rural and peri-urban population, spread across almost 23,000 villages, by providing grants directly to communities for local water and sanitation infrastructure and technical assistance to enhance the role of the community through capacity building, planning, procurement, and management, including community monitoring with a web-based and mobile monitoring system[21].

Population density has an effect to literacy rate

Population density and literacy rate are two important factors that can affect a country's development. In Indonesia, the literacy rate was around 96% in 2020, and the illiteracy rate among citizens aged 15 years and above was 3.96% in 2021. However, Indonesia ranks 62 out of 70 for literacy rate[22]. The importance of literacy in Indonesia is crucial for the coming demographic bonus[23].

As the world's fourth most populous country, Indonesia's population growth rate is expected to stay high[24]. In densely populated areas, there may be a greater demand for educational resources and infrastructure, which can pose challenges in providing quality education to all individuals. Limited resources, overcrowded classrooms, and inadequate facilities may hinder educational opportunities[25].

However, high population density can also lead to greater accessibility to educational institutions due to their proximity to residential areas. This accessibility may facilitate easier access to schooling and positively influence literacy rates. Additionally, socioeconomic conditions and cultural factors play significant roles in shaping literacy rates, and these factors can vary independently of population density. Further research is needed to determine the relationship between population density and literacy rate in Indonesia.

Access to improved sanitation has an effect to incidence of tuberculosis

Tuberculosis (TB) is a contagious disease that can spread quickly in environments with poor sanitation[26]. According to a WHO analysis of trends in TB incidence and their possible determinants in 134 countries, there is a significant association across countries between declining incidence and higher measures of access to improved sanitation[27]. Access to improved sanitation has been found to have a significant effect on the incidence and prevalence rates of tuberculosis (TB) in Asia and the Pacific region[28].

A systematic review and meta-analysis found that improved sanitation facilities play a crucial role in reducing the occurrence of tuberculosis[29]. This is supported by a longitudinal ecological study which identified various social determinants of health that influence tuberculosis incidence rates, highlighting the importance of addressing these determinants, including access to improved sanitation[30]. Furthermore, the World Health Organization recognizes that social and economic development, including improvements in hygiene and sanitation, contribute to the decline in tuberculosis cases and deaths[31]. Studies focusing on urban slums and low-income communities have shown that crowded living conditions and limited access to healthcare, combined with inadequate sanitation, contribute to the burden of tuberculosis[32,33]. Additionally, a study in the Asia-Pacific region revealed a strong association between access to improved water and sanitation and tuberculosis rates[28]. These findings emphasize the critical role of improved sanitation in reducing tuberculosis incidence, although it's important to note that a comprehensive approach to tuberculosis prevention and control should encompass multiple strategies.

Literacy rate has an effect to incidence of tuberculosis

The literacy rate has a significant impact on the incidence of tuberculosis (TB) due to several key factors. Firstly, education and literacy play a vital role in spreading knowledge and awareness about TB among individuals and communities[34]. Educated

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individuals are more likely to have access to accurate information about TB, its symptoms, transmission, and preventive measures. This knowledge empowers them to take appropriate actions to protect themselves, seek timely diagnosis and treatment, and adopt preventive behaviors that can contribute to reducing TB transmission and controlling the disease. Moreover, literacy is often associated with better access to healthcare services[35]. Individuals who are literate are more likely to understand the importance of regular health check-ups, including TB screenings, and are better equipped to navigate the healthcare system to seek appropriate medical care when needed.

However, this study found that the higher the literacy rate, the higher the incidence of tuberculosis. The possible reason caused by misleading information. If it leads to misconceptions or misinformation about tuberculosis, can contribute to the following detrimental scenarios:

Firstly, misleading information can result in delayed or missed diagnoses. If individuals are provided with inaccurate information about tuberculosis symptoms, transmission, or prevention, they may delay seeking medical attention or be misdiagnosed. Consequently, this delay may prolong the period of infectiousness, increase the risk of transmission, and ultimately contribute to a higher incidence of the disease[36].

Secondly, misleading information can perpetuate stigma and discrimination against individuals with tuberculosis[37]. If inaccurate information creates misconceptions about the disease, it can lead to stigmatization and discrimination. This negative social perception may discourage individuals from seeking healthcare services, resulting in delayed detection and treatment. Consequently, the incidence of tuberculosis could rise as a consequence of such misinformation.

Lastly, misleading information can lead to inadequate preventive measures[38]. If inaccurate information spreads, individuals may develop misunderstandings about effective preventive measures, such as infection control practices or the importance of completing treatment regimens. As a result, the risk of transmission may increase, leading to a higher incidence of tuberculosis. To combat the potential impact of misleading information, it is essential to promote accurate and up-to-date information from reputable sources.

Population density with good literacy rate has an effect to incidence of tuberculosis

A study conducted in Brazil found that the highest density of TB cases was strongly associated with higher population density but not with lower income or level of literacy[39]. Another study in Maharashtra, India, established a strong positive correlation between the number of reported cases of TB per thousand people and the population density. Additionally, there is a strong negative correlation between average elevation above mean sea level (MSL) and reported cases of TB per thousand people[40].

A study in Peru found that most outpatients attending a referral hospital in Northeastern Lima had high health literacy and only fair knowledge of TB. Health literacy and TB knowledge were not significantly associated[41]. Another study in China found that the prevalence of smear-positive TB fell by 65% from 1990 to 2010. Low health literacy has been identified as one of the key elements of the social infrastructure of TB management and control[42].

Furthermore, population density combined with good literacy rates can influence health-seeking behavior[43]. When individuals are well-informed about tuberculosis, they are more likely to recognize the symptoms, seek medical attention promptly, and adhere to the recommended treatment. Additionally, higher population density often leads to the establishment of better healthcare infrastructure in densely populated areas, including diagnostic centers, hospitals, and clinics. With good literacy rates, people can effectively navigate the healthcare system, understand medical instructions, and follow the prescribed treatment regimen. The combination of proactive health-seeking behavior and improved access to healthcare services can contribute to early detection and treatment of tuberculosis cases, ultimately preventing further transmission within the population[44].

Population density with good access to improve sanitation has an effect to incidence of tuberculosis

Population density with good access to improved sanitation can have an effect on the incidence of tuberculosis[45]. Improvements in hygiene, housing,

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and nutrition have historically contributed to the decline in TB cases and deaths in certain parts of the world. However, globally and in many countries, TB remains a significant cause of ill health and mortality[31].

Access to improved sanitation plays a crucial role in reducing the transmission of TB. Improved sanitation facilities, such as proper sewage systems and hygienic disposal of human waste, contribute to preventing the spread of TB bacteria by minimizing the contamination of the environment[45,46]. When individuals have good access to improved sanitation, they are less likely to come into contact with contaminated materials or environments that may harbor TB bacteria. This can help reduce the risk of TB transmission, particularly in crowded and densely populated areas where the bacteria can spread more easily[47].

The Role of Defense Management

In the context of Defense Management and correlation to Health and Security in Indonesia, the study can be relevant and have implications for various aspects:

1. National Security: Tuberculosis (TB) is a significant public health concern that can have implications for national security[48]. A high prevalence of TB can weaken the overall health of the population, impacting the readiness and resilience of the military and defense forces[49]. By quantifying the effects of literacy, population density, and access to improve sanitation in combating TB, the study can provide insights into effective strategies to enhance national security by addressing health threats.
2. Defense Personnel Health: The health and well-being of defense personnel are crucial for maintaining a strong defense force[50]. TB is an infectious disease that can affect military personnel in crowded environments, such as barracks and training facilities[51]. The importance of literacy, population density, and access to sanitation can inform preventive measures to reduce the risk of TB transmission among defense personnel, thus safeguarding their health and operational readiness.
3. Military Operations and Stability: TB outbreaks can pose challenges to military operations, particularly in regions with high population density and limited access to sanitation facilities[52]. By improving sanitation infrastructure and promoting literacy, the risk of TB transmission can be reduced, ensuring the success and effectiveness of military operations.
4. Cross-Sector Collaboration: Addressing TB requires a comprehensive approach that involves collaboration between various sectors, including defense, health, and education[53]. The study's emphasis on literacy as a factor influencing TB can highlight the importance of educational initiatives within the defense sector to promote health literacy and raise awareness about TB prevention. It can encourage collaboration between defense and education authorities to implement programs that enhance literacy and health education, ultimately contributing to better defense health and security.

This study has encountered certain limitations that must be acknowledged. Firstly, the use of a generalized indicator for literacy rate (34.654) might not provide a precise assessment of its impact on tuberculosis incidence. The indicator's broad nature fails to capture specific aspects of literacy that are directly relevant to tuberculosis prevention and management. Consequently, the findings might not fully reflect the nuanced relationship between literacy and tuberculosis incidence.

Secondly, the study reveals a moderate R square value concerning the direct effect on tuberculosis incidence. This result indicates that there are other influential factors beyond sanitation alone, which contribute to the occurrence of tuberculosis. To gain a more comprehensive understanding of the situation, future research should focus on investigating the efficacy of management systems and include additional variables that might play significant roles in tuberculosis incidence. By delving into these factors, researchers can uncover a more nuanced picture of the issue and develop targeted interventions to combat tuberculosis effectively. Despite these limitations, this study provides valuable insights into the interplay between literacy and tuberculosis incidence while paving the way for further investigations in this field.

CONCLUSION

The analysis of the data indicates several important findings regarding the relationship between

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population density, literacy rate, access to improved sanitation, and the incidence of tuberculosis in Indonesia. The final direct effect model shows significant positive relationships between population density and access to improved sanitation (1.818), and between population density and literacy rate (0.217). Access to improved sanitation reduces tuberculosis incidence (-0.504), while literacy rate increases it (34.654). The indirect effects indicate that higher population density, mediated by literacy rate, is linked to lower tuberculosis incidence, and improving sanitation facilities can decrease tuberculosis prevalence. The model exhibits high effectiveness. It is recommended to prioritize investments in sanitation infrastructure, particularly in densely populated areas, and promote widespread access to improved sanitation facilities. Concurrently, targeted health education campaigns should be implemented to improve tuberculosis awareness and dispel misconceptions. Collaboration between the defense, health, and education sectors is crucial to enhance health literacy and implementing effective strategies for tuberculosis prevention and control.

ETHICAL APPROVAL

There is no ethical approval.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

RF; writing the manuscript and analysing the data, HZA; conceptualising the study, NL; Interpretation the data, MS: reviewing the correlation between health and defense management.

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