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Predicting Tuberculosis Vulnerability Based on Environmental Factors Using Multi-Criteria Analysis in Bukittinggi

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ABSTRACT
Tuberculosis is still an infectious disease problem and the main cause of death in Indonesia, where there was an increase in cases from 301 per 100,000 population (2020) to 354,000 per 100,000 population (2021), with the death rate increasing by 55%. This research aims to determine the TB vulnerability cluster influenced by the main risk factors, namely TB prevalence, cure rate, immunization, population density, and population arrivals in Bukittinggi, using the Weight Product (WP) analysis method, and then describe them by mapping tuberculosis vulnerability. The findings indicate that four sub-districts exhibit the highest levels of tuberculosis vulnerability: Tarok Dipo (0.0379), Campago Guguk Bulek (0.0399), Campago Ipuh (0.0399), and Aur Tajungkang Tangah Sawah (0.0389). A multi-sectoral TB control committee comprising public works, environmental, and health agencies should be formed to organize and carry out focused actions. Establish a strong TB surveillance system that includes contact tracing, active case finding, and routine monitoring of important indicators. Create and implement specialized intervention packages for high-vulnerability subdistricts, including social support programs, housing rehabilitation, and air quality control.

INTRODUCTION

An imbalance between disease components (agents), human components (hosts), and the environment leads to the infectious disease tuberculosis. Environmental factors that do not support them, such as unhealthy behavior, poverty, poor sanitation, and even the negative stigma that still exists in society, are the cause of the imbalance of abiotic elements like Mycobacterium tuberculosis bacteria and air as an intermediary for the entry of these bacteria into the human body (biotics) that are released through droplets.[1,2]

Populations, societies, and physical and biological ecosystems are all in a state of dynamic equilibrium, according to the principle of disease ecology.[3] The introduction or spread of novel species can indicate severe maladaptation in the human-environment relationship, provided that significant changes in land use, migration, population pressure, or other stresses cause enough disruption. Ecosystems and cultural systems have an impact on maintaining the equilibrium needed for the reciprocal link between humans and the environment.[4,5] An imbalance in the ecosystem can make people more susceptible to the onset of tuberculosis and other infectious diseases. Decisions made without taking into account the needs of the population's most disadvantaged segments have the potential to widen gaps in health disparity.

Tuberculosis is one of the 10 highest causes of death worldwide and the main cause of death from infectious agents. Globally, it is estimated that 10.6 million people are suffering from tuberculosis, with a death rate of around 1.4 million people suffering from tuberculosis. In Indonesia, new cases of tuberculosis in 2021 went up by 18% compared to 2020.[6]

In 2020, there were 819,000 tuberculosis cases (301 per 100,000 population), and in 2021, it went up to 969,000 cases (354 per 100,000 population)). The death rate due to tuberculosis went up by 55%, reaching 93,000 cases in 2020 (34 per 100,000 population) and 144,000 cases in 2021 (52 per 100,000 population).[7]

In the province of West Sumatra, tuberculosis is a prevalent infectious disease. The West Sumatra Provincial Health Service reports that the number of TB cases in the province increased from 5,987 in 2020 (108 per 100,000 population) to 9,730 in 2021 (176 per 100,000 population). Bukittinggi City and Solok City had the most new instances of tuberculosis, with 241 cases (199 per 100,000 population) and 147 cases (200 per 100,000 population), respectively, while Dharmasraya Regency had the fewest, with 97 cases (42 per 100,000 population).[8]

Bukittinggi is a well-liked location for trade, education, and tourism, with a population of 124,050 and a population density of 5,131.63 people per km2. Its major public health problems include urban slum regions, rising population mobilization, and a poverty rate that is predicted to increase by 4.11% in 2023.[9]

The 2030 tuberculosis elimination strategy supported by the World Health Organization (WHO) provides strategic direction for achieving tuberculosis control targets by including them in sustainable development goals. These strategies include various medical and socio-economic interventions to address morbidity and mortality.[10,11] Tuberculosis control efforts are essentially development efforts whose results can be observed and measured to determine the success of the tuberculosis control program.[12,13] Despite a wealth of studies on TB risk factors, little is known about how environmental factors contribute to an individual's increased vulnerability to contracting TB.

A multi-criteria decision-making problem's weights can be determined in a number of ways by various academics, the Weighted Product Method (WPM) is one of them. Researchers utilize it to assess TB vulnerability in order to fill in some of its voids.[14,15]

After that, TB vulnerability is examined and mapped using a GIS methodology. It is envisaged that by using these two approaches, TB vulnerability issues can be exploited to target environmental and regional TB control efforts.[16,17]

This study aims to analyze tuberculosis vulnerability in Bukittinggi, West Sumatra Province, based on TB prevalence, rate of recovery, immunization, population density, and population arrivals using the weighted product method and Geographic Information Systems.

MATERIAL AND METHOD

The study was conducted at Bukittinggi City, at latitudes 00'16'–00 16' South and longitudes 100'20'–100 25' East in the West Sumatra Province. The location's elevation is between 756 and 960 meters above sea level. Bukittinggi City is 25,239 Km^2 in size, or 0.06. There are three subdistricts and twenty-four subdistricts in the West Sumatra Province, with 122,311 people living there (Figure 1). Data for the study came from the Bukittinggi City Central Statistics Agency and the Health Service, and it was carried out between August and October of 2023.

Primary and secondary sources are both used in the data collection process. Expert interviews werecarried out to bolster the analysis. The prevalence of tuberculosis, on the other hand, was obtained from reports on the TB program of the Health Service. The Central Statistics Agency/*Badan Pusat Statistik (BPS)* provided demographic data up to 2022, ethics approval number 143/KEPK/VII/2023. Tuberculosis control policy plans can be developed and evaluated using area-based tuberculosis vulnerability. The availability of TB susceptibil-ity data can be used as a basis for preparing and evaluating tubercu-losis control policies.[18]

The determination of the level of vulnerability can be done using the weighted product method. The weighted product is a popular multi-criteria analysis decision and a multi-criteria decision-making method. It consists of several stages, including determining criteria, normalizing weights, determining alternatives, calculating vector S and Vector V, andranking. The weighted product method is also widely used as a reference in ranking systems and decision support. The following steps are involved in calculating the WP method.[19,20]

1. In order to connect attribute ratings using the weighted product (WP) approach, each attribute's rating must first be increased to the power of the attribute's weight.
2. The normalization process is identical to this one.
3. Data analysis:
   a. Calculating the weight value for the profit attribute, W, Wj has a positive rank, and for the cost attribute, a negative value rank.

$$W = \frac{W^j}{\sum Wj}$$

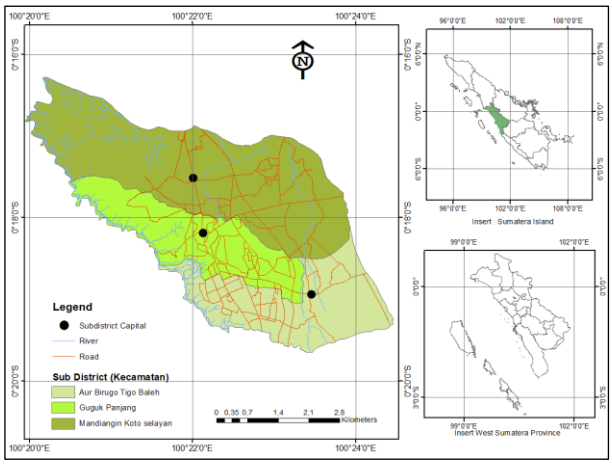
   b. Finding the value of the S weight:

$$Si = \Pi_{j=1}^{n} = X_{ij}^{wj}$$

   c. Determining the weight value V, where I and $V!$ are the possibilities that must be chosen. W is the result of multiplying the sum of the alternative ratings by each attribute:

$$v_i = \frac{\Pi_{j=1}^{n} X_{ij}^{wj}}{\Pi_{j=1}^{n} Xij * Wj}$$

Vi = The WP score for alternative i
W = Weight of criteria / subcriteria
Wj = Criteria importance weight j
∑Wj= The sum of all the importance weights, where wj is negative
j = Criteria
i = Alternative
n = Number of criteria
S = Alternative preference analogous to vector S



Source: Primary Data, 2023

Figure 1. Research Object Location in Bukittinggi City, West Sumatera

The steps in calculating the Weighted Product method are as follows:

1. Multiplying all attributes for all alternatives with the weight as a positive rank for the cost attribute.
2. The multiplication result is summed to produce a value for each alternative.
3. Divide the value of V for each alternative with the value of each alternative.
4. Found the best alternative sequence that will be a decision.

The following factors will determine which sub-districts have the highest, moderate, and low levels of vulnerability after the product weight study is completed:

1. Quartile 1 (Q1): less than 25% indicates high vulnerability.
2. Quartile 2 (Q2): 25%–50% indicates moderate vulnerability.
3. Quintile 3 (Q3): greater than 50% indicates low vulnerability.

The criteria listed in Table 1 were used to evaluate Bukittinggi City's vulnerability to tuberculosis, with each of the city's subdistricts acting as a backup. Weights and values in the sub-criteria and criterion were determined based on the researcher's analysis of the last three years' worth of data from the Central Statistics Agency/*Badan Pusat Statistik (BPS)* and the literature on the Ministry of Health's tuberculosis control program. Following WP calculation with Microsoft Excel, data analysis revealed TB clusters per sub-district that were then mapped using Geographic Information System methods. To determine the criterion values for each sub-district, a descriptive analysis employing spider diagrams was carried out based on the dimensions assessed.[21,22] Based on the dimensions evaluated, a descriptive analysis utilizing spider charts was done to identify the criterion values for each subdistrict.[23]

RESULTS

Table 2 presents the findings of the sub-district-specific criteria assessment based on the data collected. Subsequently, the observation data is examined using the criteria shown in Table 3. The criterion assessment's findings indicate that multiple subdistricts may be at risk of tuberculosis transmission.

Table 1. Criteria, Weight, Subcriteria, and Criteria Value Used in Data Analysis

Criteria and Weight	Explanation	Sub-Criteria	Criteria Value
TB prevalence (0,9)	The percentage of the population estimated to be infected with TB at a given time. It reflects the overall TB burden in a population (100.000)	1=High: >150 2=Moderate: 65-150 3=Low: <65	0,23
Cure rate (0,9)	The percentage of TB patients who successfully complete treatment and are declared cured (%)	1=Low:<30 2=Moderate:30-89,9 3=High: ≥90	0,23
Immunization (0,7)	The percentage of children in the target age group who have received at least one dose of the BCG vaccine (%)	1=Low: <64 2=Moderate: 64-84,9 3=High: ≥85	0,18
Population density (0,7)	The number of people per square kilometer (people/km2)	1=High: >265 2=Moderate: 98-264 3=Low: <98	0,18
Population arrivals (0,7)	The number of new people arriving or moving to a sub-district in a certain period (people)	1=High:>8328 2=Moderate: 2990-8327 3=Low: <2990	0,18

Source: The Ministry of Health, 2020 & 2023*; BPS* Bukittinggi, 2023

Table 2. Data and Assessment Criteria

Alternatif		Criteria									
		C1		C2		C3		C4		C5	
		Data	Sub Criteria	Data	Sub Criteria	Data	Sub Criteria	Data	Sub Criteria	Data	Sub Criteria
K1	Aur Kuning	239	High	67	Moderate	53	Low	245	Moderate	8370	High
K2	Aur Tajungkang Tengah Sawah	242	High	18	Low	73	Moderate	279	High	11386	High
K3	Birugo	136	Moderate	33	Moderate	84	Moderate	287	High	6972	Moderate
K4	Bukit Apit Puhun	149	Moderate	0	Low	79	Moderate	186	Moderate	3257	Moderate
K5	Bukit Cangang Kayu Ramang	256	High	0	Low	61	Low	63	Low	4977	Moderate
K6	Campago Guguk Bulek	331	High	17	Low	64	Moderate	332	High	4840	Moderate
K7	Campago Ipuh	156	High	13	Low	65	Moderate	400	High	8180	Moderate
K8	Garegeh	255	High	0	Low	76	Moderate	125	Moderate	4740	Moderate
K9	Kayu Kubu	262	High	0	Low	79	Moderate	97	Moderate	4605	Moderate
K10	Koto Selayan	221	High	0	Low	70	Moderate	101	Moderate	2434	Low
K11	Kubu Gulai Bancah	144	Moderate	14	Low	90	High	265	Moderate	3765	Moderate
K12	Kubu Tanjung	162	High	0	Low	100	High	65	Low	2014	Low
K13	Ladang Cakiah	217	High	0	Low	58	Low	62	Low	3095	Moderate
K14	Manggis Ganting	350	High	14	Low	76	Moderate	220	Moderate	8200	Moderate
K15	Pakan Kurai	150	Moderate	100	High	79	Moderate	236	Moderate	8451	High
K16	Parit Antang	382	High	0	Low	96	High	40	Low	2218	Low
K17	Pekan Labuhan	28	Low	100	High	73	Moderate	121	Moderate	2955	Low
K18	Puhun Pintu Kabun	273	High	9	Low	92	High	181	Moderate	2192	Low
K19	Puhun Tembok	182	High	20	Low	90	High	152	Moderate	9111	High
K20	Pulai Anak Air	178	High	10	Low	76	Moderate	261	Moderate	7545	Moderate
K21	Sapiran	87	Moderate	0	Low	49	Low	237	Moderate	13108	High
K22	Tarok Dipo	207	High	21	Low	55	Low	683	High	12101	High
K23	Belakang Balok	35	Low	100	High	84	Moderate	107	Moderate	5740	Moderate
K24	Benteng Pasar Atas	69	Low	100	High	79	Moderate	50	Low	2588	Low

Source: Secondary Data Analysis from Health Office of Bukittinggi City, 2022[24,25]

As seen in Table 4, the weight product analysis results produced a vector S value. The vector S value is then separated into three quartiles using the analytical data as a guide. Quartile 1 falls between 0.0400 and 0.0430, Quartile 2 lies between 0.0400 and 0.0430, while Quartile 3 lies above 0.04300. The level of tuberculosis vulnerability in the subdistrict region increases with a lower vector S value. On the other hand, the higher the vector S value, the lower the level of tuberculosis vulnerability. The results of the analysis based on the spider charts as in figure 2 show the value of each sub-criteria in each sub-district. There are several sub-districts that have criteria with low vector S values, this certainly has the potential to increase tuberculosis vulnerability.

Figure 3 shows the results of the weighted product analysis of tuberculosis vulnerability based on five assessment criteria in three sub-districts in Bukittinggi. There are 4 sub-districts that have the highest level of tuberculosis vulnerability, namely Tarok Dipo (0.0379), Campago Guguk Bulek (0.0399), Campago Ipuh (0.0399), and Aur Tajungkang Tangah Sawah (0.0389). 17 sub-districts have a moderate level

of tuberculosis vulnerability, and 3 sub-districts have a low level of tuberculosis vulnerability, namely Benteng Pasar Atas (0.0466), Behind Balok (0.0453), and Pakan Kurai (0.0434).

DISCUSSION

Tuberculosis (TB) has long been considered a social disease. Even before the discovery of the tubercle bacillus by Robert Koch in 1882, there was a correlation between the incidence of TB and poverty because the majority of people who contracted or died from TB were those who worked in the middle class and poor families. In the 1950s, Dubos, a microbiologist, stated that TB is a social disease in which the social and economic dimensions are as important as the mechanisms used by tubercle bacilli to cause damage to the human body.[26] Many additional studies support the idea that the burden of TB is related to socio-economic problems and that people have the highest risk of contracting TB.[11,27,28]

Table 3. Grading Sub Criteria

Alternatif		C1	C2	C3	C4	C5
A1	Aur Kuning	1	2	1	1	2
A2	Aur Tajungkang Tengah Sawah	1	1	2	1	1
A3	Birugo	2	2	2	2	1
A4	Bukit Apit Puhun	2	1	2	2	2
A5	Bukit Cangang Kayu Ramang	1	1	1	2	3
A6	Campago Guguk Bulek	1	1	2	2	1
A7	Campago Ipuh	1	1	2	2	1
A8	Garegeh	1	1	2	2	2
A9	Kayu Kubu	1	1	2	2	2
A10	Koto Selayan	1	1	2	3	2
A11	Kubu Gulai Bancah	2	1	3	2	2
A12	Kubu Tanjung	1	1	3	3	3
A13	Ladang Cakiah	1	1	1	2	3
A14	Manggis Ganting	1	1	2	2	2
A15	Pakan Kurai	2	3	2	1	2
A16	Parit Antang	1	1	3	3	3
A17	Pekan Labuah	3	3	2	3	2
A18	Puhun Pintu Kabun	1	1	3	3	2
A19	Puhun Tembok	1	1	3	1	2
A20	Pulai Anak Air	1	1	2	2	2
A21	Sapiran	2	1	1	1	2
A22	Tarok Dipo	1	1	1	1	1
A23	Belakang Balok	3	3	2	2	2
A24	Benteng Pasar Atas	3	3	2	3	3

Source: Secondary Data Analysis from Health Office of Bukittinggi City and *BPS*, 2022[24,25]

Based on the investigation results, the variables show Bukittinggi City's highest susceptibility to tuberculosis. A high TB prevalence indicates a high TB-positive population in Bukittinggi City. This might increase the likelihood that the sickness will spread to other people, especially those with compromised immune systems. A strong indicator of the severity of tuberculosis transmission is the high prevalence rate of the disease.

The high prevalence of TB can increase the likelihood of the disease spreading to others, especially those with weakened immune systems. Research in India suggests that contaminated household environments increase the risk of tuberculosis, including other close contacts with TB.[29,30] Stronger support from stakeholders, self-awareness of personal hygiene, and literacy all have an impact on the spread of the disease and its transmission.[31]

Low cure rates suggest that many tuberculosis patients stop their therapy before it is too late. Treatment failure and drug resistance may become more likely as a result.[32] Cure of TB is statistically associated with time coverage by primary health care. Herawanto et al., also discovered that the recovery rate of TB patients in South Palu District was significantly impacted by drug-taking supervision, side effects, and drug-taking compliance.[33] This result supports the significance of primary care TB treatment.[34]

Bacille Calmette-Guerin (BCG) is currently the only licensed vaccine that protects against childhood TB but is ineffective against adult pulmonary TB. The low coverage of BCG immunization in children will influence the transmission of TB in the community.[35] Research shows that BCG protects against M. tuberculosis infection, including preventing the progression of LTBI to active TB.[36]

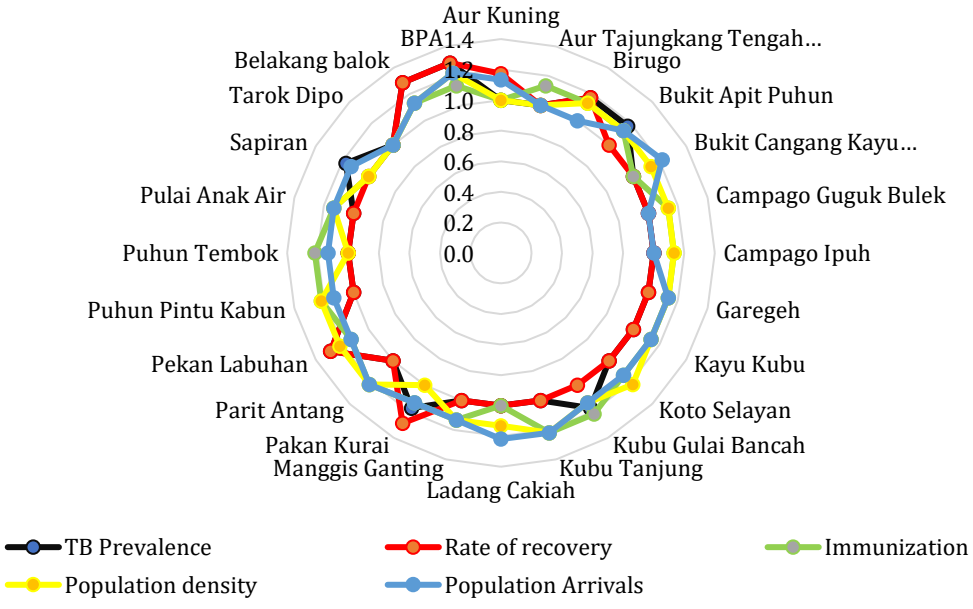
High population density has the potential to give rise to transmission among residents. Dynamic spatio-temporal information regarding TB clusters is beneficial in supporting TB control programs, especially in sub-districts with a high TB burden, high population density and a high percentage of poverty.[37] According to Saputra et al., TB is not solely brought on by risk factors that come from the medical field; other factors

like population density and poverty rate also influence it. Effective collaboration among sectors helps lower the prevalence of tuberculosis.[38,39]

Table 4. The TB Vulnerability Cluster and The S Vector Value as a Consequence of Data Analysis

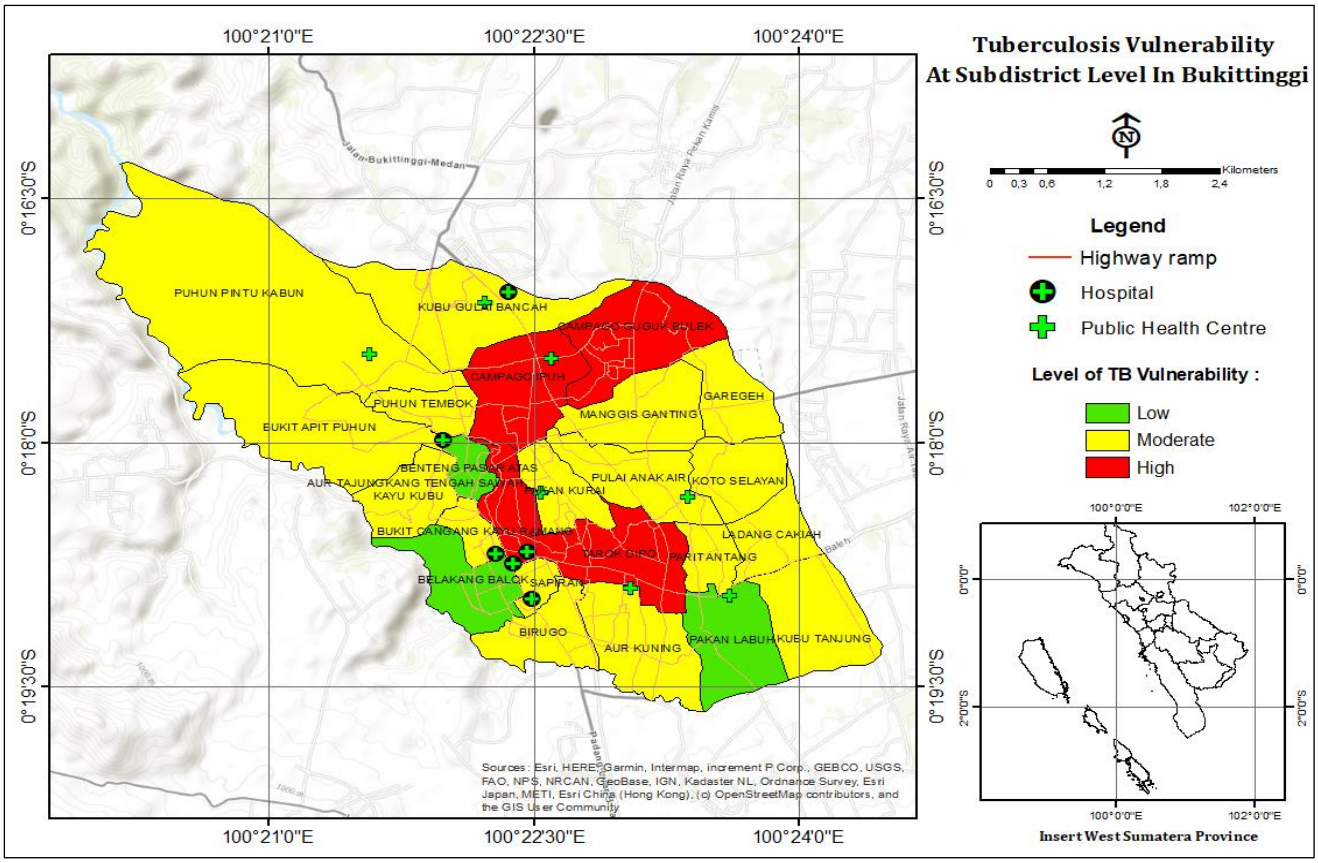
Alternatif, Criterion and Value	C1	C2	C3	C4	C5	∑ Vector S	Vektor S	Cluster/Level of Vulnerability
	0,23	0,23	0,18	0,18	0,18			
A1	1,0	1,2	1,0	1,0	1,13	5,306	0,0402	Moderate
A2	1,0	1,0	1,1	1,0	1,00	5,133	0,0389	High
A3	1,2	1,2	1,1	1,1	1,00	5,611	0,0426	Moderate
A4	1,2	1,0	1,1	1,1	1,13	5,571	0,0423	Moderate
A5	1,0	1,0	1,0	1,1	1,22	5,352	0,0406	Moderate
A6	1,0	1,0	1,1	1,1	1,00	5,266	0,0399	High
A7	1,0	1,0	1,1	1,1	1,00	5,266	0,0399	High
A8	1,0	1,0	1,1	1,1	1,13	5,399	0,0410	Moderate
A9	1,0	1,0	1,1	1,1	1,13	5,399	0,0410	Moderate
A10	1,0	1,0	1,1	1,2	1,13	5,484	0,0416	Moderate
A11	1,2	1,0	1,2	1,1	1,13	5,657	0,0429	Moderate
A12	1,0	1,0	1,2	1,2	1,22	5,656	0,0429	Moderate
A13	1,0	1,0	1,0	1,1	1,22	5,352	0,0406	Moderate
A14	1,0	1,0	1,1	1,1	1,13	5,399	0,0410	Moderate
A15	1,2	1,3	1,1	1,0	1,13	5,726	0,0434	Moderate
A16	1,0	1,0	1,2	1,2	1,22	5,656	0,0429	Moderate
A17	1,3	1,3	1,1	1,2	1,13	6,059	0,0460	Low
A18	1,0	1,0	1,2	1,2	1,13	5,570	0,0423	Moderate
A19	1,0	1,0	1,2	1,0	1,13	5,352	0,0406	Moderate
A20	1,0	1,0	1,1	1,1	1,13	5,399	0,0410	Moderate
A21	1,2	1,0	1,0	1,0	1,13	5,306	0,0402	Moderate
A22	1,0	1,0	1,0	1,0	1,00	5,000	0,0379	High
A23	1,3	1,3	1,1	1,1	1,13	5,974	0,0453	Low
A24	1,3	1,3	1,1	1,2	1,22	6,145	0,0466	Low

Source: Secondary Data Analysis from Health Office of Bukittinggi City and *BPS*, 2022[24,25]



Source: Primary Data, 2023

Figure 2. Results of Weight Product (WP) Analysis of Tuberculosis Vulnerability Based on 5 Assessment Criteria



Source: Primary Data, 2023

Figure 3. Tuberculosis Vulnerability Map in Bukittinggi

Bukittinggi is known as a trading area for goods and services and a tourist destination, so every year, many residents come and stay. Population arrivals generally refer to events where several individuals or groups of people arrive in a particular region or country. This can happen for various reasons, such as migration, immigration and tourism. Migrants may move voluntarily in search of better social and economic opportunities or be forced to move due to factors.

Migrants are at increased risk for TB transmission due to a variety of personal, environmental and socio-economic determinants experienced during the four phases of migration (pre-departure, transit, arrival and early settlement, and return travel.[40] Migrants have intrinsic vulnerabilities that can lead to inequalities in access to health. Some of the main barriers to migrants' access to health arecultural differences, socioeconomic status, language difficulties, lack of documentation, lack of medical history, social isolation, lack of information about access to health care in the local public health care system.[41]

Figure 3 shows that Bukittinggi City already has adequate health service facilities, namely community health centers and hospitals, but it is not yet optimal in prevention and treatment efforts. The existence of these health service facilities will certainly facilitate adequate access to health services in screening examinations, prevention of transmission, early diagnosis and treatment as well as support and monitoring.[42]

It may be inferred from these signs that Bukittinggi City is very susceptible to tuberculosis. The government and other stakeholders must consider this seriously to improve TB prevention and control efforts.[43] So, better TB prevention and control efforts are needed to reduce the risk of TB transmission in the community. The following actions can be taken to enhance TB case detection efforts: raising TB screening rates, particularly in high-risk populations, and boosting access to TB diagnostic services to improve TB prevention

and control in Bukittinggi City. Ensure that all TB patients receive appropriate and comprehensive treatment and offer assistance to finish their treatment. Increase awareness of the value of the BCG vaccination and facilitate easy access to immunization facilities.

CONCLUSION AND RECOMMENDATION

The results showed 2 clusters of tuberculosis vulnerability levels based on city regency areas in Bukittinggi City. Tarok Dipo is the sub-district that has the highest level of vulnerability, it is necessary to establish a multi-sectoral TB control committee involving health, environment, and public works departments to coordinate and implement targeted interventions. Implement a robust TB surveillance system with active case finding, contact tracing, and regular monitoring of key indicators, and develop and implement tailored intervention packages for high-vulnerability sub-districts, including housing improvement, air quality control, and social support programs.

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AUTHOR CONTRIBUTIONS

Designed research, collected data, carried out quantitative data analysis using Weighted Product (WP) and GIS methods, and wrote the introduction, methods, and results sections by EBS; Served as a research promoter, analysis tools, revise manuscripts, and provide guidance on revisions from journal reviewers by ID; Served as research co-promoter, assisted weighted product and GIS data analysis, and contributed to writing discussion sections by IU; NS contributed wrote the manuscript; LH contributed wrote the manuscript; EH contributed materials and research management. EB = Eka Budi Satria; ID = Indang Dewata; IU = Iswandi Umar; NS = Nurhasan Syah; LH = Linda Handayuni; EH = Evi Hasnita.

CONFLICTS OF INTEREST

There are no conflicts of interest associated with this research.

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