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UTILIZATION OF GEOGRAPHIC INFORMATION SYSTEMS IN MAPPING MALARIA VULNERABILITY

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Abstract: To address the persistently high malaria cases, the Indonesian government has set a target of malaria elimination by 2030. One strategy implemented by the central government is to encourage the commitment of local governments, especially in highly endemic areas, in malaria control. Research that can support the government's strategy to achieve the malaria elimination target needs to be continuously conducted and developed. One study that is highly relevant to the government's malaria elimination program is mapping or zoning malaria vulnerability levels. Jayapura City itself is the second-highest area for malaria cases in Papua. According to a report from the Jayapura City Health Office, there were 28,648 malaria cases in Jayapura City in 2019 with an API of 92.55 per 1,000 residents. In 2020, there were 28,075 cases with an API of 89.35 per 1,000 residents. In 2021, there were 30,235 cases with an API of 99.49 per 1,000 residents. This condition also makes Jayapura City highly vulnerable to malaria. Therefore, mapping malaria vulnerability in Jayapura City is crucial. One technology that can be used to map malaria vulnerability is a Geographic Information System (GIS). The GIS used in this study was combined with specific methods. The method used in this study was Spatial Multi-Criteria Analysis (SMCA). The parameters used in this study were geology, NDVI, and land cover. Each parameter has its own weight and score. The results showed that the overall Jayapura City area has a high vulnerability class in the Slightly Vulnerable class. The Slightly Vulnerable class is most common in Muara Tami District, while the Not Vulnerable class is most common in North Jayapura District. Data on the distribution of malaria from 2021 to 2024 shows that Muara Tami District has the highest number of malaria cases. On average, the pattern of malaria distribution shows that the southern to eastern areas have a higher prevalence of the disease compared to the northern areas of Jayapura City. The results of the malaria vulnerability mapping model, case data, and the average distribution pattern of malaria cases indicate that the modeled data aligns with the actual data and case distribution pattern. This model still needs to be developed, particularly by adding parameters appropriate to the study area.
Keywords: Malaria; Mapping; Vulnerability

1. INTRODUCTION

Malaria is a constant threat and often causes special incidents in some areas due to undetected cases. Malaria is an infectious disease of global concern. The World Health Organization (WHO) reported that malaria cases increased globally from 2019 to 2021. The number of malaria deaths globally in 2019-2020 increased by 12%, and in 2021, four countries accounted for more than half of global malaria deaths: Nigeria (31%), the Democratic Republic of the Congo (13%), Niger (4%), and Tanzania (4%). An estimated two-thirds of global malaria deaths occur in children under 5 years of age (World Health Organization, 2022).

In Indonesia, the number of malaria cases remains quite high. In 2022, the number of malaria cases reached 443,530 (Ministry of Health, 2022). Of these cases, almost the majority occurred in the provinces of Papua and West Papua, accounting for 94%. Although malaria only accounts for 2% of Indonesia's population, the intensity of the malaria threat is alarming, with residents potentially infected more than once a year.

To address the persistently high malaria cases, the Indonesian government has set a target of malaria elimination by 2030 (Ministry of Health, 2022). One strategy implemented by the central government is to encourage the commitment of local governments, especially in highly endemic areas, to malaria control. Research that can support the government's strategy to achieve the malaria elimination target needs to be continuously conducted and developed. One study highly relevant to the government's malaria elimination program is mapping or zoning malaria vulnerability levels (Muhandarwati et al., 2015).

The Papua Province region, which is an endemic malaria area, is crucial for mapping or zoning malaria vulnerability levels. This study will allow for more detailed identification of zones from low to highly vulnerable. The results of this research can be used by the government to determine malaria management priorities. Treatment can be prioritized in locations with high vulnerability. The ranking of vulnerability levels can be used as a basis for determining priority.

Jayapura City has the second highest number of malaria cases in Papua. According to a report from the Jayapura City Health Office, there were 28,648 malaria cases in Jayapura City in 2019 with an API of 92.55 per 1,000 residents. In 2020, there were 28,075 cases with an API of 89.35 per 1,000 residents, and in 2021, there were 30,235 cases with an API of 99.49 per 1,000 residents. This situation makes Jayapura City highly susceptible to malaria. Therefore, mapping malaria vulnerability in Jayapura City is crucial.

One technology that can be used to map malaria vulnerability is a Geographic Information System (GIS). The GIS used in this study was combined with specific methods. The methods used in this study were Spatial Multi-Criteria Analysis (SMCA) or Analytical Hierarchy Process (AHP). Each method requires geospatial data as input. Geospatial data varies from region to region, so data needs are tailored to the specific conditions of each region, particularly in Jayapura City. Therefore, the malaria vulnerability map generated from this research is crucial, particularly for prioritizing malaria management in Jayapura City.

Geographic Information Systems

By definition, a Geographic Information System (GIS) is a tool for collecting, storing, displaying, and correlating spatial data from geographic phenomena for analysis and communicating the results to data users for decision-making purposes (Zain and Wiwik, 2020). Based on this definition, GIS clearly has the characteristics of a database management system (DBMS), a spatial analysis tool, and a communication process for decision-making.

The uniqueness of GIS compared to other database management systems is its ability to present both spatial and non-spatial information simultaneously. The digital representation of geographic phenomena on a computer can be done in two formats: raster (grid-cell) and vector. Raster format presents objects as a series of cells or picture elements (pixels). In this format, for example, a line is presented as a series of cells/pixels. Vector format, on the other hand, presents objects as a series of coordinates. For example, a line in vector format will be presented in coordinate form from both ends. As a tool, a GIS consists of both hardware and software. In terms of hardware, the main components of a GIS are data input devices, a computer unit for data processing, and output devices and a communication network (Cleary et al., 2021).

Utilization of GIS in the Health Sector

The use of GIS in the health sector is driven by an orientation toward efficiency and effectiveness, both in the process and in the results achieved, as well as in developing holistic thinking based on clearly located spatial information, where each position can be measured with certainty. GIS, as a tool, can demonstrate public health problems, especially those based on regions or areas. Through spatial analysis capabilities, health planning and interventions become more specific and based on target areas (Sunaryo, 2010).

In Indonesia, GIS is currently widely recognized in the health sector as a surveillance tool. At an advanced level, GIS can even be used to predict or forecast disease events based on risk factors. GIS can generally be used as an early warning system for infectious diseases and for decision-making (Sunaryo, 2010).

Geographic Information Systems (GIS) manipulate geographic data into map visualizations. When used in the health sector, they can facilitate health workers' analysis of problems in their work areas. The use of GIS to map the distribution of malaria cases provides an overview of the distribution of malaria cases, which can then be used to analyze malaria distribution patterns in a specific area. To control and manage the spread of malaria, government programs and information related to malaria patients are needed. The need for information on malaria patients is crucial so that government programs launched are based on robust data (Hastuty and Denik, 2021).

Malaria Vulnerability Mapping

Geographic Information Systems (GIS) can be utilized to facilitate the acquisition of processed data stored as attributes for a location or object. This system connects spatial data (geographic location) with non-spatial data, allowing users to create maps and analyze the information in various ways (Hastuty and Denik, 2021).

Mapping or zoning malaria vulnerability levels is a study highly relevant to the government's malaria elimination program (Muhandarwati et al., 2015). This study allows for more detailed identification of zones ranging from low to high vulnerability. The results of this study can be used by the government to determine priorities for malaria management. Treatment can be prioritized in locations with high vulnerability. The ranking of vulnerability levels can be used as a basis for determining priority. Malaria vulnerability can be assessed and mapped using Geographic Information Systems (GIS) combined with specific methods. These methods include Spatial Multi-Criteria Analysis (SMCA) or Analytical Hierarchy Process (AHP). Each method requires geospatial data as input. The geospatial data required will vary depending on the theory, concept, approach, and assumptions underlying each method. A malaria-endemic area often encompasses different administrative areas. Each administrative area may employ different methods. Consequently, the data required and used may also differ (Rozi et al., 2024).

2. RESEARCH METHODS

The method used to map vulnerability is SMCA (Spatial Multicriteria Analysis). This method considers determining the most dominant variables and calculating their weights to produce appropriate results. The presence of malaria vectors is essential for understanding malaria transmission (Hanandita and Gindo, 2016). Important factors in mapping malaria vulnerability are based on habitat formation. Therefore, understanding the mosquito's environment as a breeding host is crucial. The presence of water sources, land cover, and vegetation density are factors that contribute to the breeding of Anopheles mosquitoes (Nugraheni et al., 2022).

The variables used in this study were the Vegetation Density Index (NDVI), geological data, and land cover. Each variable has a score for each criterion. Each criterion also has a weight. These scores and weights have been previously used in research by Sunaryo (2010), so the scores for each criterion and their weights are shown in Table 1, and the research stages are shown in Figure 1.

Table 1. Weighting of Malaria Vulnerability Variables

Variable	Category	Score	Weight
Geology	All Alluvium	1	0.25
	Andesite; Basalt; Breccia	3	
	Andesite; Basalt; Diorite; Gabbro; Conglomerate	2	
	Andesite; Basalt; Fine grained tephra; Coarse grained tephra; Alluvium, recent volcanic	1	
	Basalt	3	
	Basalt; Andesite	2	
	Basalt; Andesite; Breccia; Fine grained tephra	2	
	Basalt; Andesite; Fine grained tephra; Coarse grained tephra	1	
	Basalt; Tuffite; Andesite	2	
	Breccia; Basalt; Andesite; Fine grained tephra; Coarse grained tephra	3	
	Fine grained tephra; Coarse grained tephra; Alluvium, recent volcanic	1	
	All Limestone	3	
	Marble; Limestone	3	
	Marl; Limestone	3	
	Mudstone; Marl; Limestone; Tuffite; Sandstone; Shale	2	
	Sandstone; Conglomerate; Mudstone; Shale; Marl	3	
	Sandstone; Mudstone; Shale; Conglomerate; Limestone	3	
	Sandstone; Mudstone; Tuffite; Fine grained tephra; Siltstone 3	3	
	Shale; Mudstone; Sandstone; Conglomerate; Marl	3	
	Tuffite; Mudstone; Sandstone	3	
Land Cover	50 meter Buffer River	3	0.25
	Lake	1	
	Dryland Forest	3	
	Plantation Forest	3	
	Settlement	1	
	Dryland Farming	2	

	Mixed Dryland Farming	2	
	Ricefield	1	
	Shrubs	3	
	Open Land	1	
Vegetation density (NDVI)	Non-Vegetation and Low Density	1	
	Medium Density	2	0.5
	High Density	3	

This research stage begins with analyzing the NDVI from Landsat 8 imagery, followed by scoring according to the parameters in Table 1. After the NDVI parameters are obtained, the next step is analyzing the geological parameters. After the geological parameters are obtained, scoring is also performed according to the parameters. The final parameter is land cover, which is the result of image analysis. Land cover parameters are also analyzed first from satellite imagery, then scoring is performed according to the parameters. An outline of the research stages can be seen in Figure 1.

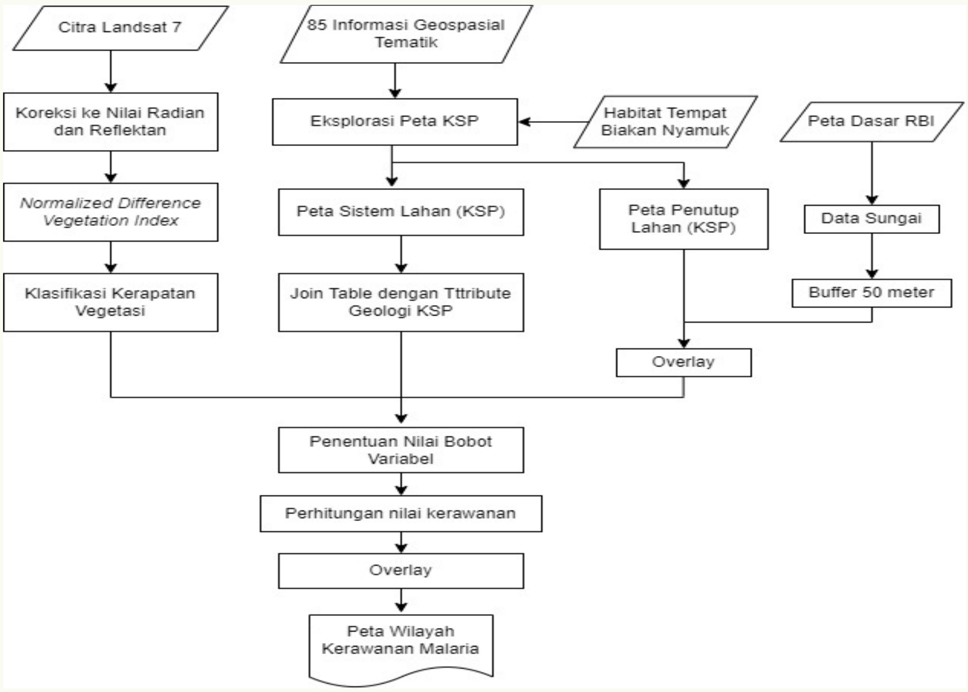

Figure 1. Research Stages

3. RESULTS AND DISCUSSIONS

Mapping Malaria-Prone Areas

This study used the SMCA (Spatial Multicriteria Analysis) method to map malaria-prone areas. This method considers determining the most dominant variables and calculating their weights to produce appropriate results. The presence of malaria vectors is essential for understanding malaria transmission (Watofa et al., 2017). This method uses three parameters: geology, vegetation density index (NDVI), and land cover. Each parameter has its own score and weight. After scoring each parameter, it is multiplied by its weight. The results are then summed to obtain a final score. This final score becomes the malaria vulnerability level. This vulnerability level is then stratified into interval classes, with three classes used in this study: not vulnerable, somewhat vulnerable, and vulnerable.

The analysis of this study found that almost all areas in Jayapura City have a vulnerability level ranging from somewhat vulnerable to vulnerable. The most vulnerable areas are Muara Tami and Abepura Districts. Non-vulnerable areas are found in many of the districts of North Jayapura and South Jayapura, as well as parts of Heram District. The distribution of malaria vulnerability levels can be seen in Figure 2.

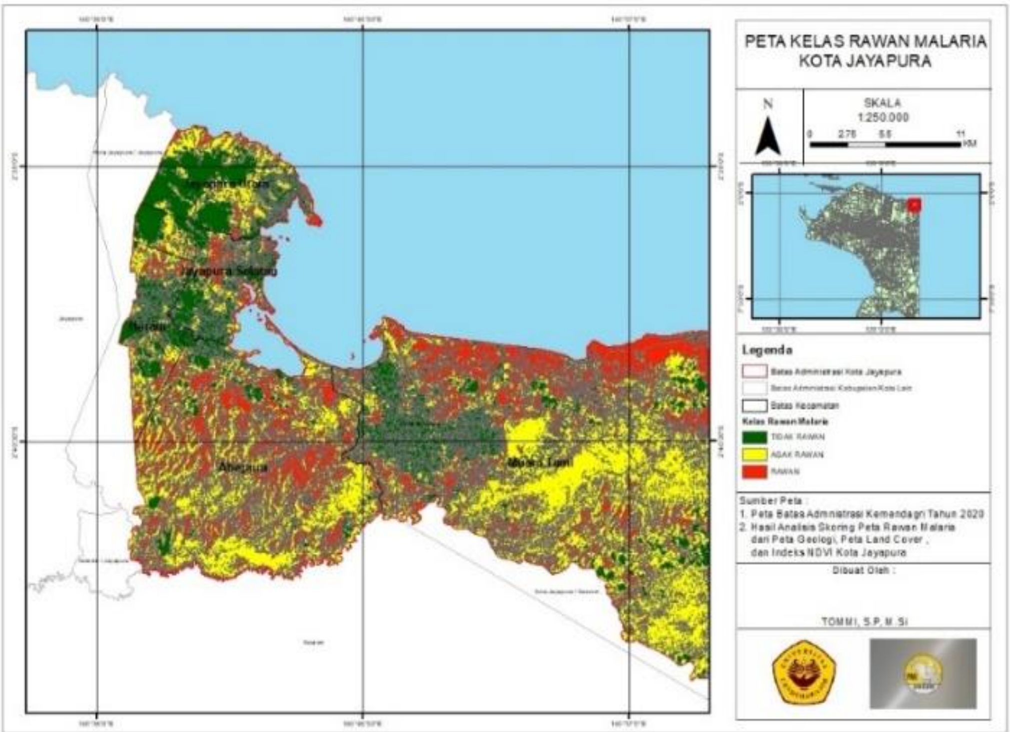

Figure 2. Malaria Risk Map for Jayapura City
Source: Analysis Results, 2025

The analysis results in Table 2 show that the most extensive vulnerability class is in Muara Tami District with an area of approximately 12,000 ha. However, the most vulnerable class percentage is in Abepura District, where the percentage area reaches 39.21%. Overall, the vulnerability class is the class with the largest area. Almost every district has a somewhat vulnerable class, with almost every sub-district area exceeding 1,000 ha. The most extensive non-vulnerable class is in South Jayapura District, with an area of more than 3,500 ha. The largest percentage area is also in South Jayapura, with a percentage of 57.69%.

Table 2. Area and Percentage of Malaria Vulnerability Classes

Subdistrict	Vulnerable Class	Wide	Percentage (%)
Abepura	Not Vulnerable	1608.316	6.85
	Somewhat Vulnerable	12671.32	53.94
	Vulnerable	9212.328	39.21
	Total Area	23491.97	
Heram	Not Vulnerable	1736.36	43.75
	Somewhat Vulnerable	1572.616	39.62
	Vulnerable	659.9847	16.63
	Total Area	3968.96	
Jayapura Selatan	Not Vulnerable	2974.736	56.97
	Somewhat Vulnerable	1551.389	29.71
	Vulnerable	695.7044	13.32
	Total Area	5221.83	
Jayapura Utara	Not Vulnerable	3669.36	57.69
	Somewhat Vulnerable	2189.386	34.42
	Vulnerable	501.5527	7.89
	Total Area	6360.30	
Muara Tami	Not Vulnerable	6666.796	16.01
	Somewhat Vulnerable	22378.66	53.73
	Vulnerable	12605.5	30.26
	Total Area	41650.96	

Muara Tami District has a high risk level due to its high NDVI value. A high NDVI value indicates a region with dense vegetation. A high NDVI value is strongly associated with a high risk of malaria (Ferrao et al., 2018). This indicates a higher potential for mosquito breeding in the area, as it can serve as a resting place for mosquitoes.

Geological factors describe the condition of the soil surface and parent rock in vulnerable areas. Mosquito habitats require water to reproduce, so formations with impermeable rocks are suitable locations for development. This relates to the ability of the land surface to hold water during the rainy season, thus providing a suitable habitat for larvae. Based on the geological land system map, Jayapura City has predominantly alluvial, sedimentary, and sandy rock formations. These impermeable rock formations allow the land surface to hold water during the rainy season, providing a suitable habitat for larvae (Widartono et al., 2023).

Land use, behavioral changes, and socioeconomic changes are all factors contributing to the increase in malaria incidence (Sunaryo, 2010). Land cover with vegetation is generally preferred as a resting place for mosquitoes. Land cover maps in the study area show that the Muara Tami District still contains extensive forest, secondary forest, and shrubland. Malaria case data indicate that most malaria cases occur in areas with high vegetation cover.

The physical environment of mosquitoes has the greatest impact on malaria incidence because the presence of certain mosquitoes (maculatus and balabacensis) is epidemiologically dominant in areas with high levels of vulnerability (Madayanti et al., 2022). Human factors (population density), however, do not directly correlate with the number of cases. Malaria cases only occur in certain individuals suspected of interacting with the mosquito's habitat. Humans only initiate the initial transmission process, but if left unchecked, this will impact the spread to other malaria-prone areas (Rumbiak and Barandi, 2022).

Distribution of Malaria

Based on data obtained from the Jayapura City Health Office in 2025, as shown in Table 3, from 2021 to 2024, the highest number of malaria cases was found in Muara Tami District. The highest number in this district was in 2021, reaching over 8,000 cases. This district consistently had a higher incidence rate than other districts, as evidenced in 2022. While other districts experienced fewer malaria cases, under 1,500, Muara Tami District also experienced a significant number of malaria cases, exceeding 2,000.

Table 3. Malaria Cases in Jayapura City 2021-2024

SUBDISTRICT	2021	2022	2023	2024
Abepura	3515	617	3277	3723
Heram	3349	329	3330	4828
Jayapura Selatan	4407	1300	3486	4403
Jayapura Utara	1190	472	2454	2855
Muara Tami	8242	2571	6219	4212

Source: Jayapura City Health Office, 2025

On average, from 2021 to 2024, almost all areas of Jayapura City had more than 2,700 cases, except for North Jayapura District. The area with the highest number of cases was Muara Tami District. The average distribution of malaria cases in Jayapura City from 2021 to 2024 can be seen in the distribution map in Figure 3. The map shows that malaria is increasingly prevalent in the southern to eastern parts of Jayapura City. Only the northern part of Jayapura City has fewer cases, below 2,700.

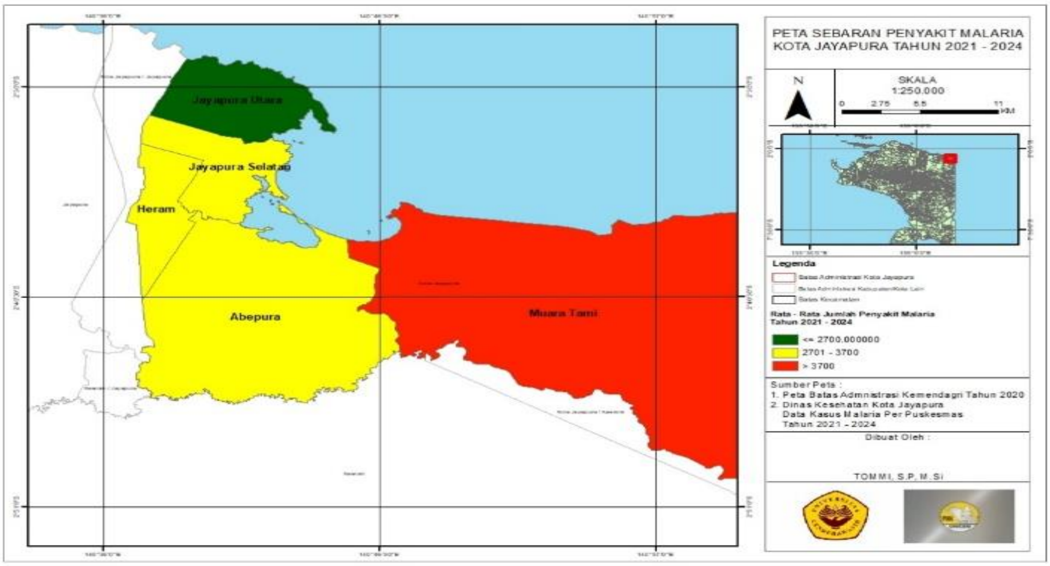

Figure 3. Map of Average Malaria Distribution from 2021 to 2024
Source: 2025 Analysis Results

Malaria distribution data and the average malaria distribution map indicate a congruence between the malaria distribution data and the malaria vulnerability map model. This is evident from the distribution data, the average malaria distribution map, and the vulnerability map, which indicate that Muara Tami District has a high level of vulnerability and is also the area with the highest number of cases. Furthermore, the distribution pattern and the vulnerability map also show a similar trend, with the disease spreading increasingly towards the south and east of Jayapura City, and the vulnerability map also indicates a higher level of vulnerability towards the south and east of Jayapura City.

The congruence between the malaria vulnerability mapping results in Jayapura City and the malaria distribution map indicates that this model is quite effective in predicting malaria-prone areas. This model needs to be further developed and additional parameters added to increase its accuracy. The results of the vulnerability map modeling and the disease distribution map show that the Muara Tami District area is the area most vulnerable to malaria, so it needs to be prioritized in handling malaria so that in the future it can reduce the number of malaria cases in Jayapura City.

4. CONLUSIONS AND SUGGESTIONS

CONLUSIONS

The results of the vulnerability mapping of Jayapura City show that most areas of Jayapura City have a moderate vulnerability class. Areas with a high vulnerability class are mostly found in Muara Tami District, while areas with a low vulnerability class are mostly found in North Jayapura District. The highest distribution of malaria in Jayapura City is found in Muara Tami District. The average distribution of disease from 2021 to 2024 shows that the average distribution of malaria in Jayapura City is highest in Muara Tami District. The average distribution pattern of malaria in Jayapura City shows that the distribution of malaria increases from the south to the east. The map of the level of vulnerability to malaria, data on the distribution of the number of diseases, and the distribution pattern of disease indicate alignment between the model and the distribution data.

SUGGESTIONS

The government needs to optimize spatial-based control strategies to increase the effectiveness of interventions in vulnerable areas. The Jayapura City Government is expected to establish Muara Tami District as a top priority for the malaria control program through cross-sectoral policies.

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