



Dengue Vulnerability Mapping Using AHP and Weighted Overlay Method: A Case Study from Bandar Lampung City, Indonesia

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ABSTRACT

Dengue fever remains a serious health problem due to its high morbidity and mortality. Given its potential future impacts, vulnerability maps are needed to guide the design of evidence-based control strategies. This study aims to develop a dengue fever vulnerability map by combining the AHP and weighted overlay techniques. This study used an ecological design and was conducted in Bandar Lampung City, Lampung Province. All secondary data were aggregated into percentages and used as sub-districts as spatial boundaries. The AHP method involved 20 informants to determine the weight of each variable (population density, water storage facilities, house index, and 3M behavior). The weighting results served as a reference for developing a dengue fever vulnerability map using the weighted overlay technique. Risk categories are distinguished by green (low), yellow (medium), and red (high). The AHP yielded the following weighted values for each variable: 30% (house index), 28.3% (3M behavior), 23.2% (water storage facilities), and 18.5% (population density). Based on the weighted overlay technique, five high-risk sub-districts were obtained (East Tanjungkarang, North Telukbetung, South Telukbetung, Bumi Waras, and Panjang), five medium-risk sub-districts (Langkapura, Kedaton, Central Tanjungkarang, Enggal, and East Telukbetung), and ten low-risk sub-districts (Rajabasa, Tanjung Senang, Labuhan Ratu, Sukarame, Kemiling, West Tanjungkarang, Way Halim, Kedamaian, Sukabumi, and West Telukbetung). GIS applications by combining the AHP and weighted overlay methods can be applied to develop dengue fever vulnerability maps

Demam berdarah tetap menjadi masalah kesehatan serius karena angka kesakitan dan kematiannya yang tinggi. Mengingat potensi dampaknya di masa depan, peta kerentanan diperlukan untuk memandu perancangan strategi pengendalian berbasis bukti. Studi ini bertujuan untuk mengembangkan peta kerentanan demam berdarah dengan menggabungkan teknik AHP dan overlay berbobot. Studi ini menggunakan desain ekologis dan dilakukan di Kota Bandar Lampung, Provinsi Lampung. Semua data sekunder diagregasikan menjadi persentase dan digunakan sebagai batas spasial kecamatan. Metode AHP melibatkan 20 informan untuk menentukan bobot setiap variabel (kepadatan penduduk, tempat penyimpanan air/TPA, House indeks, dan perilaku menutup TPA, menguras TPA, dan mengolah sampah/3M). Hasil pembobotan tersebut berfungsi sebagai referensi untuk mengembangkan peta kerentanan demam berdarah menggunakan teknik overlay berbobot. Kategori risiko dibedakan dengan warna hijau (rendah), kuning (sedang), dan merah (tinggi). AHP menghasilkan nilai bobot untuk setiap variabel: 30% (indeks rumah), 28,3% (perilaku 3M), 23,2% (fasilitas penyimpanan air), dan 18,5% (kepadatan penduduk). Berdasarkan teknik overlay berbobot diperoleh lima kecamatan risiko tinggi (Tanjungkarang Timur, Telukbetung Utara, Telukbetung Selatan, Bumi Waras, dan Panjang), lima kecamatan risiko sedang (Langkapura, Kedaton, Tanjungkarang Tengah, Enggal, dan Telukbetung Timur), dan sepuluh kecamatan risiko rendah (Rajabasa, Tanjung Senang, Labuhan Ratu, Sukarame, Kemiling, Tanjungkarang Barat, Way Halim, Kedamaian, Sukabumi, dan Telukbetung Barat). Aplikasi GIS dengan menggabungkan metode AHP dan Weighted Overlay dapat diterapkan untuk mengembangkan peta kerentanan penyakit demam berdarah.

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1. Introduction

Dengue Hemorrhagic Fever (DHF) is a vector-borne disease that typically occurs during certain seasons of the year. The primary option for preventing the spread of dengue fever is to control and monitor the vector, focusing on specific localized areas and eliminating suitable breeding environments.

In Indonesia, dengue fever was first reported in Surabaya in 1968, with a total of 58 cases (24 resulting in death). Since then, the number of dengue fever cases in Indonesia has continued to increase (Husna et al., 2020). Currently, the reported incidence of dengue fever is above 10 per 100,000 population (Ministry of Health, 2023). A major response is needed to tackle dengue fever, which is increasingly burdening public health. Efforts to control this health problem must be grounded in evidence and facts (*evidence-based*) to avoid disparities in incidence rates across regions (Eryando et al., 2022; Yushananta & Ahyanti, 2025). Thus, determining risk areas is an essential first step in planning to overcome them (Ajim Ali & Ahmad, 2018; Dom et al., 2016; Eryando et al., 2022; Hoque et al., 2025; Lin & Wen, 2022; Pfeiffer et al., 2008; Yushananta & Ahyanti, 2025).

Spatial analysis can identify localized disease clusters that exceed what would be expected given the underlying population structure and demographics (Donzelli et al., 2026; Gil et al., 2010; Lin & Wen, 2022). Analyzing the spatial distribution or dependency of disease remains a key public health concern (Li et al., 2017; Tu et al., 2014). Therefore, to better understand the distribution of dengue fever in time and space, it is essential to develop spatial databases, apply spatial statistics, and correlate this information with environmental factors in an area.

The use of spatial analysis in geographic information systems (GIS) for health purposes has become one of the main techniques for identifying spatial associations and has been adopted by several researchers worldwide (Dom et al., 2016; Franch-Pardo et al., 2020; Gil et al., 2010; Li et al., 2017; Murad, 2018; Pakaya et al., 2021; Richardson

et al., 2013; Tu et al., 2014; Yushananta & Ahyanti, 2025). The integration of the analytical hierarchy process (AHP) method in GIS to solve spatial planning problems has received considerable attention among multidisciplinary planners. The ability of GIS to integrate with AHP has been demonstrated in several studies related to nature and environmental management (Abdekareem et al., 2022; Ajim Ali & Ahmad, 2018; Aykut, 2021; Baite et al., 2024; Deswal & Laura, 2018; Dom et al., 2016; Pakaya et al., 2021; Raja Shekar & Mathew, 2023; Sahin et al., 2020).

Multi-criteria decision-making techniques can be used to make the process more explicit, rational, and efficient. For this evaluation, AHP is used to determine the weight of each characteristic. The determination of weights in AHP relies on a pairwise ranking matrix developed from expert opinion (Niemira & Saaty, 2004; T.L. Saaty, 2008). A systematic decision-making process helps decision-makers summarize and evaluate information effectively, define appropriate questions, and determine optimal solutions. The AHP method is applied to obtain parameter weights because of its simple hierarchical structure, strong mathematical basis, widespread use, and ability to measure inconsistencies in judgments (Li et al., 2017; Niemira & Saaty, 2004; T.L. Saaty, 2008; Tu et al., 2014).

Previously, most studies used GIS to model dengue risk by predicting risk based on a limited number of variables, such as mosquito numbers (Dom et al., 2016). This technique has limitations in understanding the relationship between environmental and social factors and dengue incidence. Therefore, we propose using several variables (confirmed dengue cases, population density, water storage facilities, *house index*, and 3M behavior) to formulate dengue risk zones. This study aims to analyze the dynamics of dengue cases, assess the correlation between dengue risk and environmental factors and population behavior, and produce a dengue vulnerability map based on the research variables.

2. Methods

This study employed an ecological study method that utilizes aggregated data in percentage form. The approach employed was a spatial analysis combining *AHP* and *weighted overlay techniques*. Data were obtained from the 2023 Bandar Lampung City Health Profile. The spatial analysis covered all 20 sub-districts (Figure 1) and 20 informants. This study used four research variables: population density, water storage facilities, *house index*, and 3M behavior.

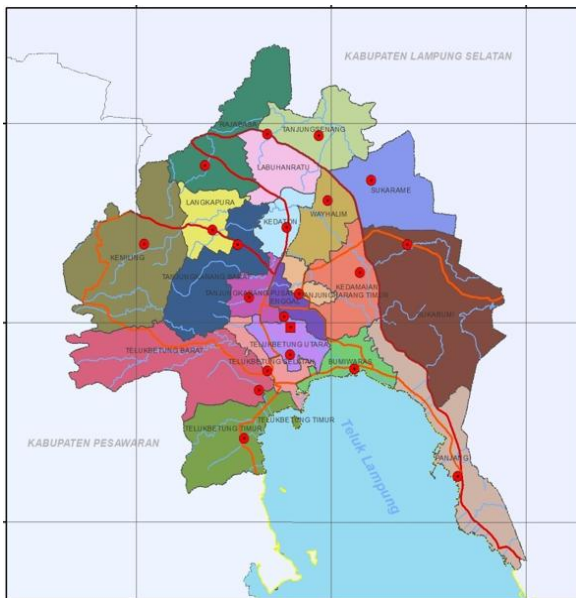


Figure 1. Research Location

The AHP method is applied to identify the weight of each criterion (risk factor). AHP is an efficient decision-making technique for evaluating and prioritizing alternatives, thereby enabling the selection of the optimal option among available choices (Niemira & Saaty, 2004; RW Saaty, 1987; TL Saaty, 2008).

The map layering process was based on the resulting weights. Twenty informants from various scientific backgrounds (including medicine, public health, epidemiology, nursing, and environmental science) contributed to determining the weights for each criterion. Each informant compared the criteria pairwise according to their perceived importance. Following T.L. Saaty (2008), the importance levels ranged from 1 (equally important) to 9 (very important).

The pairwise comparison matrix containing the assessment results from each informant is arranged according to the reciprocity axiom. For example, if criterion A is considered seven times more important than criterion B, then the relative importance of criterion B to A is 1/7. Considering that there are 20 informants, the geometric Mean (Formula 1) is used to obtain the final value for each matrix cell. The matrix's consistency is assessed to ensure reliability. According to TL Saaty (2008), the comparison matrix is considered consistent if *the Consistency Ratio (CR)* is less than or equal to 10%.

Table 1. Scale Pairwise Comparison Matrix

Intensity	Definition	Explanation
1	One element is as important as another element (<i>equal importance</i>)	Both elements contribute equally to this characteristic
3	One element is slightly more important than the other element (<i>moderate more important</i>)	Experience suggests a slight bias in favor of one element
5	One element is clearly more important than the other elements (<i>essential, strong, more important</i>)	Experience shows strongly in favor of one element
7	One element is clearly more important than the other elements (<i>demonstrated importance</i>)	Experience shows a strong preference for and dominance of a particular element in
9	One element is absolutely more important than another element (<i>absolutely more importance</i>)	Experience shows one element is clearly more important
2, 4, 6, 8	When in doubt between two adjacent values (<i>grey area</i>)	This value is given when a compromise is required.

The CR calculation uses Formulas 2 and 3. The dengue risk map was developed using the weights obtained from the previous AHP analysis. First, the variables were converted into raster format. The raster map was then sequentially fed into an overlay calculation, which combined the weights and their corresponding classification values (high = 3, medium = 2, and low = 1). This process produced a composite map that combined all variables and their corresponding classifications. The resulting raster map was then converted to a *shapefile*. The dengue risk map was classified into three risk categories, each represented by a different color: high risk (red), medium risk (yellow), and low risk (green).

Geometric Mean =

$$\left(\prod_{i=1}^n x_i\right)^{1/3} = \sqrt[3]{x_1 \cdot x_2 \cdot \dots \cdot x_n} \dots \dots \dots \text{(Formula 1)}$$

$$\text{Consistency Ratio} = \frac{CI}{RI} \dots \dots \dots \text{(Formula 2)}$$

$$\text{Consistency Index} = \frac{(\text{Eigen value} - n)}{(n-1)} \dots \text{(Formula 3)}$$

3. Results

3.1. Distribution of risk factors

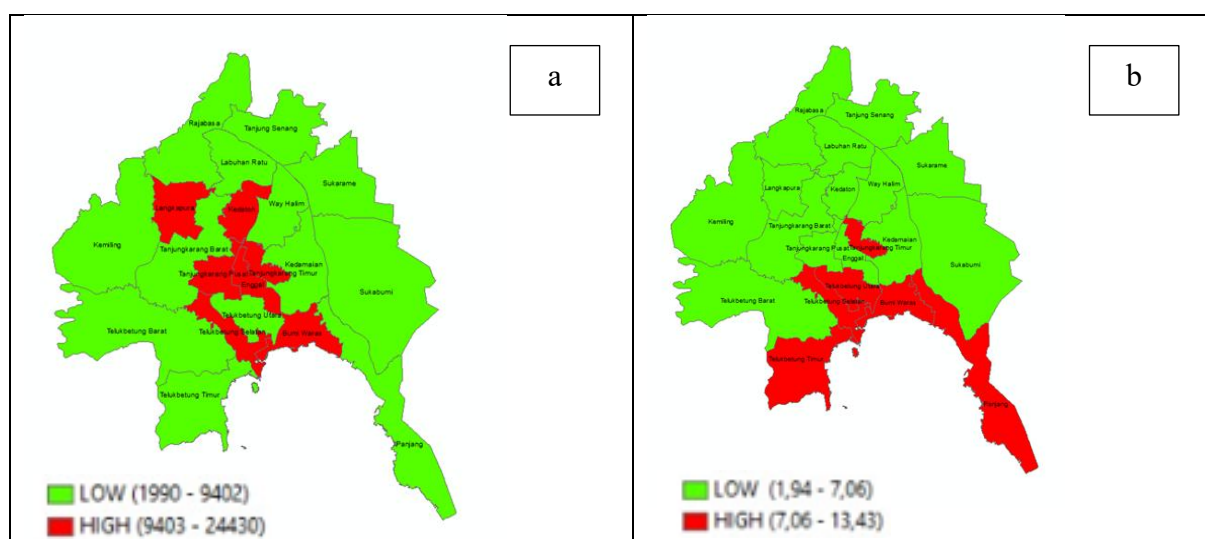
South Telukbetung, Bumi Waras, East Tanjungkarang, Central Tanjungkarang, Enggal, Langkapura, and Kedaton are seven districts with high population densities ($\geq 9,402$). Low population densities ($< 9,402$) are found in thirteen

districts, namely West Telukbetung, East Telukbetung, Panjang, Kedamaian, North Telukbetung, West Tanjungkarang, Kemiling, Rajabasa, Tanjung Senang, Labuhan Ratu, Sukarame, Sukabumi, and Way Halim (Figure 2a).

Water storage facilities in Bandar Lampung City (Figure 2b) marked in red are sub-districts that have open water storage facilities with high categories ($> 7.06\%$) in Six Sub-districts (East Tanjungkarang, North Telukbetung, South Telukbetung, Bumi Waras, East Telukbetung, and Panjang) and low ($< 7.06\%$) in Fourteen Sub-districts (Rajabasa, Tanjung Senang, Labuhan Ratu, Langkapura, Kedaton, Way Halim, Sukarame, Kemiling, West Tanjungkarang, Central Tanjungkarang, Kedamaian, Enggal, Sukabumi, and West Telukbetung).

In Figure 2c, those with a high *house index* are marked in red; almost all sub-districts have a *house index* $> 5\%$, with the highest at 13% in Tanjungkarang Timur Sub-district. In contrast, the low *house index* is marked in green and is found only in one sub-district, namely Labuhan Ratu, at 2% .

In Figure 2d, the 3M behavior that does not carry out 3M behavior with a high category ($> 8.85\%$) is in five sub-districts (East Tanjungkarang, North Telukbetung, South Telukbetung, Bumiwaras and Panjang), and low ($< 8.85\%$) is in fifteen sub-districts (Rajabasa, Tanjung Senang, Labuhan Ratu, Langkapura, Kedaton, Way Halim, Sukarame, Kemiling, West Tanjungkarang, Central Tanjungkarang, Kedamaian, Enggal, Sukabumi, West Telukbetung, and East Telukbetung).



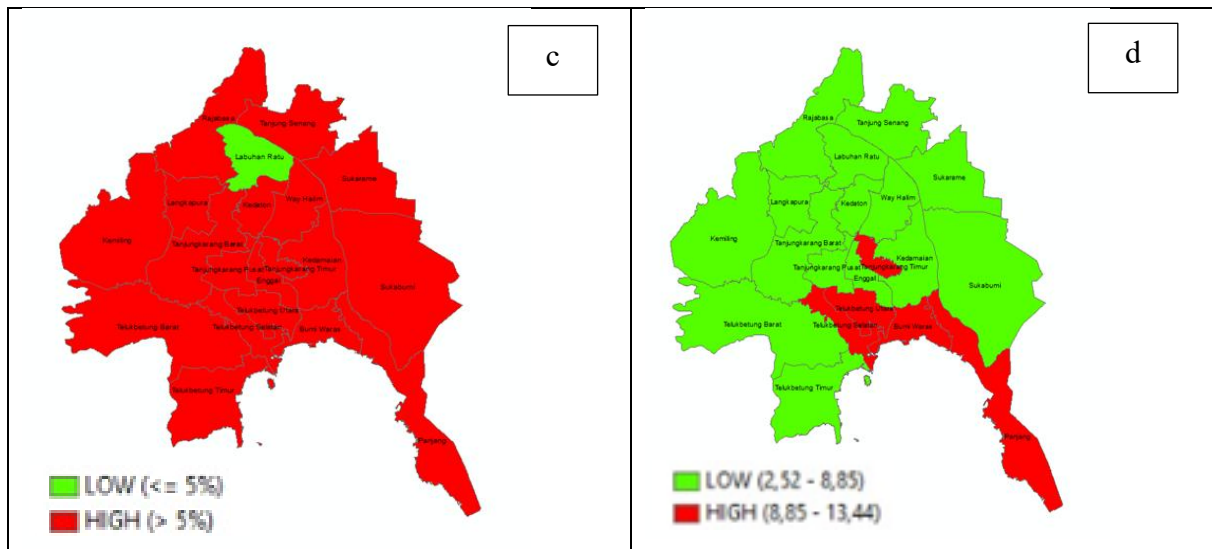


Figure 2. Spatial distribution of DHF risk factors (a. Population Density; b. Water Storage Facilities; c. House Index; and d. 3M Behavior)

3.2. AHP

AHP was used to determine the weight of each criterion (risk factor). In this study, 20 informants were involved in determining the weight of each

criterion. Table 2 shows the geometric Mean of the 20 informants who responded. Table 3 shows that the house index had the highest weighting (30.0%), followed by the population density criterion (18.5%), with a CR value of 8%.

Table 2. Weighted Geometric Mean of Participants

	1	2	3	4	Information
1		0.89	0.7	0.58	1= Population Density
2	1.12		2.38	0.73	2= House Index
3	1.43	0.42		1.26	3= Water Storage Facilities
4	1.73	1.36	0.8		4= 3M Behavior

Table 3: Weight Values from AHP calculation results

No	Criteria	Weight	Consistency Ratio (CR)
1	Population density	18.5%	8%
2	House Index	30.0%	
3	Water Storage Facilities	23.2%	
4	3M Behavior	28.3%	

3.3. Dengue Fever Vulnerability Map

The dengue fever vulnerability map is classified into three levels: low, medium, and high using the Weighted Overlay technique with weights from the AHP calculation. Figure 3 shows five high-risk sub-districts (East Tanjungkarang, North Telukbetung, South Telukbetung, Bumi Waras, and Panjang), five

medium-risk sub-districts (Langkapura, Kedaton, Central Tanjungkarang, Enggal, and East Telukbetung), and ten low-risk sub-districts (Rajabasa, Tanjung Senang, Labuhan Ratu, Sukarame, Kemiling, West Tanjungkarang, Way Halim, Kedamaian, Sukabumi, and West Telukbetung).

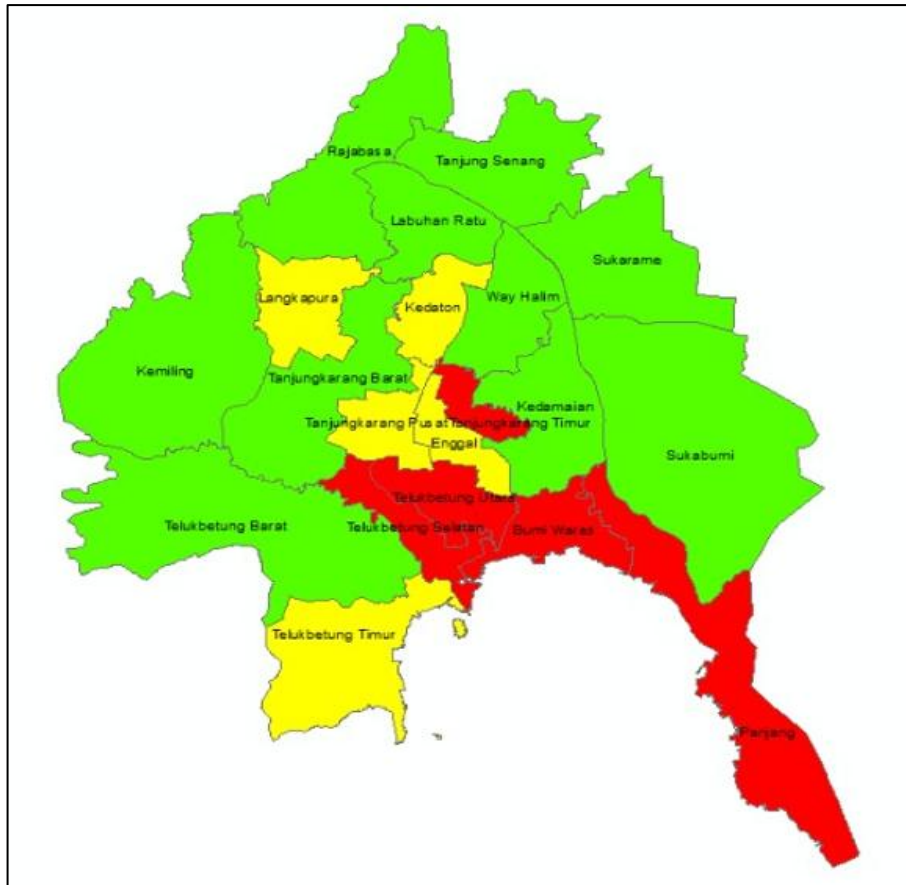


Figure 3. Dengue Fever Vulnerability Map of Bandar Lampung City

4. Discussion

4.1. Spatial distribution of dengue fever risk factors

Dengue fever cases occur more often in densely populated areas. Depends on population density, how the disease spreads from person to person. In terms of dengue fever transmission and mosquito flying distance, population density is an influencing factor. The denser the human population in a place, the greater the risk of spreading dengue fever (Girsang et al., 2024), because mosquitoes can fly up to around 50 meters. However, the study results of Nandini et al. (2017), found that there was no relationship between population density and the incidence of dengue fever in Jakarta from 2005 to 2015. The results showed that high cases of dengue fever did not necessarily occur in densely populated locations.

This study adds to the evidence that dengue fever can develop and spread even in less densely populated areas. These data reinforce the notion that the demographics of Bandar Lampung City do not influence dengue fever rates. Dengue fever

cases are not related to population density in this area (Nandini et al., 2017), because the population is generally evenly distributed and can easily move between sub-districts. The risk of dengue transmission is consistent in most places due to this similarity.

It is known that the *Aedes aegypti* mosquito prefers to breed in clean, permanent water storage that are not exposed to direct sunlight, as stated by Gafur and Saleh (2015). Closing the landfill is very important in this case to reduce mosquito arrival and breeding (Apriliana, 2017).

Another study conducted in 2018 by Octaviani in West Bangka Regency found that dengue fever transmission was 2.7 times more common in homes with open water storage. Homes with mosquito larvae in water storage, both indoors and outdoors (CI>20%), had a 5.6-fold higher risk of dengue fever. The presence of mosquito larvae in these areas increases the risk. Always ensure water storage are tightly covered to prevent mosquitoes from laying eggs in them (Octaviani et al., 2021).

The WHO states that an area can be considered high-risk if its HI value is $\geq 5\%$, and low-risk if it is below that (Palupi et al., 2019). The indicator set as the national standard is the Larvae Free Rate (ABJ), with a 95% threshold. (Nurhidayah et al., 2022).

Research conducted by Indriyani, Rahardjo, and Setiani (2015) in Jepara Regency found that the p-value for the influence (HI) on the incidence of dengue fever was 0.006 ($p < 0.05$), indicating a significant relationship between the two variables based on the chi-square test. The odds ratio (OR) indicates that respondents whose homes have a high-risk HI value have a 7.480 times greater chance of experiencing dengue fever than respondents whose homes have a low-risk HI value, with a 95% confidence interval (CI) of 1.521-36.778.

As a multipronged strategy, eradicating dengue mosquito breeding sites uses chemical larvicides, biological predators, and physical methods (the "3M" activities) to kill the vector. Emptying water storage once a week is sufficient to repel mosquitoes. Reducing the *Aedes aegypti* mosquito population is our goal when implementing PSN-DBD throughout the community (Budiman, 2016).

According to the Indonesian Ministry of Health (2007), the 3M program for dengue fever prevention is a government initiative that began in 1992. In 2002, with the addition of larvicides, fish farming, and methods to reduce mosquito bites, this initiative became 3M Plus. Many steps to reduce its impact have failed. This mitigation strategy has been less successful because the mosquito nest eradication program has not led to changes in community attitudes (Riza Nurul Husna, Nur Endah Wahyuningsih, 2016).

This study uses the AHP to determine the relative importance of each risk factor associated with dengue fever. According to TL Saaty (2008), AHP is highly effective for constructing and analyzing complex decision-making scenarios involving multiple interrelated criteria. Its use in health and environmental research has been validated in studies by Yushananta and Ahyanti (2025) and Pakaya, Hano, and Oliy (2021). The application of AHP in this study follows the four sequential steps outlined previously.

A total of 20 informants from various professional backgrounds contributed to determining the weight of each variable (risk

factor). The AHP results (Table 3) show that the house index criteria have a weight of 30.0%, 3M behavior 28.3%, water storage facilities 23.2%, population density 18.5%, and a CR value of 8%, which means the assessment is considered consistent because $CR \leq 0.1$ ($\leq 10\%$). From these results, it can be concluded that the house index has the highest weight, meaning it is the most dominant risk factor for dengue fever incidents.

4.2. Dengue Fever Vulnerability Map

Spatial analysis (Figure 3) shows five high-risk sub-districts (East Tanjungkarang, North Telukbetung, South Telukbetung, Bumi Waras, and Panjang), five medium-risk sub-districts (Langkapura, Kedaton, Central Tanjungkarang, Enggal, and East Telukbetung), and ten low-risk sub-districts (Rajabasa, Tanjung Senang, Labuhan Ratu, Sukarame, Kemiling, West Tanjungkarang, Way Halim, Kedamaian, Sukabumi, and West Telukbetung).

To better understand the characteristics of each high-risk sub-district, the dengue fever vulnerability map (Figure 3) was compared with the distribution of individual risk factors (Figure 2). The results showed that Tanjungkarang Timur and Bumi Waras sub-districts had a high risk of dengue fever, as indicated by population density, water storage facilities, house index, and 3M behavior. Telukbetung Utara, Telukbetung Selatan, and Panjang sub-districts had a high risk in terms of water storage facilities, house index, and 3M behavior. These findings indicate that the construction of the dengue fever vulnerability map accurately reflects the actual risk distribution and is considered valid.

5. Conclusions

The availability of vulnerability maps is crucial for developing an effective, strategic, and data-based dengue control program. This study combines AHP with GIS to depict a dengue fever vulnerability map based on four risk factors. The results show that eleven of the twenty sub-districts in Bandar Lampung City are at high risk (East Tanjungkarang, North Telukbetung, South Telukbetung, Bumi Waras, and Panjang). Meanwhile, the medium category includes Langkapura, Kedaton, Central Tanjungkarang,

Enggal, and East Telukbetung. The rest are at low risk, namely Rajabasa, Tanjung Senang, Labuhan Ratu, Sukarame, Kemiling, West Tanjungkarang, Way Halim, Kedamaian, Sukabumi, and West Telukbetung. Based on the AHP technique, the main priorities for overcoming dengue fever are reducing the house index and strengthening the community's role in 3M behavior.

References

- Abdekareem, M., Al-Arifi, N., Abdalla, F., Mansour, A., & El-Baz, F. (2022). Fusion of Remote Sensing Data Using GIS-Based AHP-Weighted Overlay Techniques for Groundwater Sustainability in Arid Regions. *Sustainability*, 14 (13), 7871. <https://doi.org/10.3390/su14137871>
- Ajim Ali, S., & Ahmad, A. (2018). Using analytic hierarchy process with GIS for Dengue risk mapping in Kolkata Municipal Corporation, West Bengal, India. *Spatial Information Research*, 26 (4), 449–469. <https://doi.org/10.1007/s41324-018-0187-x>
- Apriliansa, R. (2017). *The Relationship between Environmental Conditions and the Incidence of Dengue Hemorrhagic Fever (DHF) in Families in Gagakan, Sambong District, Blora Regency in 2017*. 1 .
- Ayikut, T. (2021). Determination of groundwater potential zones using Geographical Information Systems (GIS) and Analytic Hierarchy Process (AHP) between Edirne-Kalkansogut (northwestern Turkey). *Groundwater for Sustainable Development*, 12, 100545. <https://doi.org/10.1016/j.gsd.2021.100545>
- Baite, L., Bhattacharjee, N., Debbarma, J., & Saikia, A. (2024). Agricultural land suitability analysis in Manipur, India using GIS and AHP. *AUC Geographica*, 59 (1), 93–107. <https://doi.org/10.14712/23361980.2024.6>
- Budiman. (2016). "The Relationship between the Implementation of 3M Activities and the Density of *Aedes aegypti* Larvae in Kawua Village, Poso Regency." *Tadulako Health Journal*, 2 (2), 1–72.
- Deswal, M., & Laura, J. S. (2018). GIS based modeling using Analytic Hierarchy Process (AHP) for optimization of landfill site selection of Rohtak city, Haryana (India). *Journal of Applied and Natural Science*, 10 (2), 633–642. <https://doi.org/10.31018/jans.v10i2.1753>
- Dom, NC, Ahmad, AH, Latif, ZA, & Ismail, R. (2016). Application of geographical information system-based analytical hierarchy process as a tool for dengue risk assessment. *Asian Pacific Journal of Tropical Diseases*, 6 (12), 928–935. [https://doi.org/10.1016/S2222-1808\(16\)61158-1](https://doi.org/10.1016/S2222-1808(16)61158-1)
- Donzelli, G., De Nes, M., Vivani, P., Sera, F., & Linzalone, N. (2026). Visualizing neighborhood health disparities: spatial epidemiology to map social vulnerability and mortality in an Italian city. *Cities & Health*, 1–19. <https://doi.org/10.1080/23748834.2025.2603782>
- Eryando, T., Sipahutar, T., Budhiharsana, MP, Siregar, KN, Nur Aidi, M., Minarto, Utari, DM, Rahmaniati, M., & Hendarwan, H. (2022). Spatial analysis of stunting determinants in 514 Indonesian districts/cities: Implications for intervention and setting of priorities. *Geospatial Health*, 17 (1). <https://doi.org/10.4081/gh.2022.1055>
- Franch-Pardo, I., Napoletano, B.M., Rosete-Verges, F., & Billa, L. (2020). Spatial analysis and GIS in the study of COVID-19. A review. *Science of the Total Environment*, 739, 140033. <https://doi.org/10.1016/j.scitotenv.2020.140033>
- Gafur, A., & Saleh, M. (2015). The Relationship between Water Storage and the Presence of *Aedes aegypti* Larvae in Type E Official Housing, Motu Village, Baras District, North Mamuju Regency. *Hygiene*, 1 (2), 92–99.
- Gil, J.F., Nasser, J.R., Cajal, S.P., Juarez, M., Acosta, N., Cimino, R.O., Diosque, P., & Krolewiecki, A.J. (2010). Urban Transmission of American Cutaneous Leishmaniasis in Argentina: Spatial Analysis Study. *The American Society of Tropical Medicine and Hygiene*, 82 (3), 433–440. <https://doi.org/10.4269/ajtmh.2010.09-0113>
- Girsang, VI, Harefa, HS, Siregar, LM, & Sirait Asima. (2024). Population Density and Dengue Hemorrhagic Fever Incidence in Medan City. *Cikini Nursing Journal*, 5 (2), 224–239.
- Hoque, M.A.-A., Sardar, M.L., Mukul, S.A., & Pradhan, B. (2025). Mapping dengue susceptibility in Dhaka city: a geospatial multi-criteria approach integrating environmental and demographic factors. *Spatial Information Research*, 33 (4), 33. <https://doi.org/10.1007/s41324-025-00635-y>
- Husna, I., Putri, DF, Triwahyuni, T., & Kencana, GB (2020). *Analysis of Factors Affecting the Incidence of Dengue Hemorrhagic Fever in the Working Area of Way Kandis Health Center, Bandar Lampung in 2020*. 9 (27), 9–16.
- Indriyani, Z., Rahardjo, M., & Setiani, O. (2015). The Relationship Between Environmental Factors and the Distribution of Dengue Fever Incidence. *Journal of Public Health*, 3 (April), 842–851.
- Ministry of Health. (2023). *Indonesian Health Profile*.

- Li, X., Liu, T., Lin, L., Song, T., Du, Application of the analytic hierarchy approach to the risk assessment of Zika virus disease transmission in Guangdong Province, China. *BMC Infectious Diseases* , 17 (1), 65.
<https://doi.org/10.1186/s12879-016-2170-2>
- Lin, C.-H., & Wen, T.-H. (2022). How Spatial Epidemiology Helps Understand Infectious Human Disease Transmission. *Tropical Medicine and Infectious Diseases* , 7 (8), 164.
<https://doi.org/10.3390/tropicalmed7080164>
- Murad, A. (2018). Using GIS for Determining Variations in Health Access in Jeddah City, Saudi Arabia. *ISPRS International Journal of Geo-Information* , 7 (7), 254.
<https://doi.org/10.3390/ijgi7070254>
- Nandini, DM, Susilowati, MHD, & Widyawanti. (2017). Comparison of Dengue Hemorrhagic Fever (DHF) Areas in Jakarta 2005-2015. *Industrial Research Workshop and National Seminar* , 435-443.
- Niemira, M. P., & Saaty, T. L. (2004). An Analytic Network Process model for financial-crisis forecasting. *International Journal of Forecasting* , 20 (4), 573-587.
<https://doi.org/10.1016/j.ijforecast.2003.09.013>
- Nurhidayah, K., Afifiani, AKL, Ramadhana, HAZ, Khotimah, SN, & Susilaningsih, S. (2022). Density Figure Identification and Dengue Fever Vector Control in Karanganyar Gunung Village. *Jurnal Bina Desa* , 4 (1), 8-14.
<https://doi.org/10.15294/jbd.v4i1.22124>
- Octaviani, O., Kusuma, MP, & Wahyono, TYM (2021). The Influence of Water Storages on Dengue Fever Incidence in West Bangka Regency in 2018. *Journal of Disease Vectors* , 15 (1), 63-72.
<https://doi.org/10.22435/vektor.v15i1.3263>
- Pakaya, R., Hano, Y. H., & Ollii, M. R. (2021). Hazard Level of Dengue Haemorrhagic Fever in Gorontalo Regency: Prediction of Spatial Distribution with AHP-GIS Integration. *Al-Sihah: The Public Health Science Journal* , 13 (2), 126.
<https://doi.org/10.24252/al-sihah.v13i2.21788>
- Palupi, D., Indarti, N., & Yuliawati, S. (2019). Larval Density in the Highly Endemic Subdistrict of Tembalang, Semarang City: A Descriptive Cross-Sectional Preliminary Study. *Journal of Public Health* , 7 (2), 1-6.
- Pfeiffer, DU, Robinson, TP, Stevens, KB, Rogers, DJ, & Clements, ACA (2008). Spatial Analysis in Epidemiology. In *Oxford University Press* . Oxford University Press.
- Raja Shekar, P., & Mathew, A. (2023). Assessing groundwater potential zones and artificial recharge sites in the monsoon-fed Murredu river basin, India: An integrated approach using GIS, AHP, and Fuzzy-AHP. *Groundwater for Sustainable Development* , 23 , 100994.
<https://doi.org/10.1016/j.gsd.2023.100994>
- Richardson, D.B., Volkow, N.D., Kwan, M.-P., Kaplan, R.M., Goodchild, M.F., & Croyle, R.T. (2013). Spatial Turns in Health Research. *Science* , 339 (6126), 1390-1392.
<https://doi.org/10.1126/science.1232257>
- Riza Nurul Husna, Nur Endah Wahyuningsih, D. (2016). The Relationship between 3M Plus Behavior and the Incidence of Dengue Hemorrhagic Fever (DHF) in Semarang City (Study in the Upper Semarang City Area). *Journal of Public Health* , 4 (2), 77-81.
- Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used. *Mathematical Modelling* , 9 (3-5), 161-176.
[https://doi.org/10.1016/0270-0255\(87\)90473-8](https://doi.org/10.1016/0270-0255(87)90473-8)
- Saaty, T.L. (2008). Decision making with the analytic hierarchy process. *Int. J. Services Sciences* , 1 (1), 83-98.
<https://doi.org/10.1504/IJSSCI.2008.017590>
- Sahin, F., Kara, M.K., Koc, A., & Sahin, G. (2020). Multi-criteria decision-making using GIS-AHP for air pollution problem in Igdır Province/Turkey. *Environmental Science and Pollution Research* , 27 (29), 36215-36230.
<https://doi.org/10.1007/s11356-020-09710-3>
- Tu, C., Fang, Y., Huang, Z., & Tan, R. (2014). Application of the Analytic Hierarchy Process to a Risk Assessment of Emerging Infectious Diseases in Shaoxing City in Southern China. *Japanese Journal of Infectious Diseases* , 67 (6), 417-422.
<https://doi.org/10.7883/yoken.67.417>
- Yushananta, P., & Ahyanti, M. (2025). Determining Stunting Risk Areas Using a Combined AHP-GIS Approach: A Case Study of Pesawaran Regency, Lampung, Indonesia. *Ruwa Jurai: Journal of Environmental Health* , 19 (1), 23-33.