Environmental Health Engineering and Management Journal 2024, 11(2), 201-209
http://ehemj.com
doi 10.34172/EHEM.2024.20
Environmental Health Engineering and Management Journal
Original Article
Open Access Publish Free

Dengue hemorrhagic fever risk model using a spatial approach in Batam City, Indonesia 2022

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Abstract

Background: Uninhabited shophouses become breeding places for mosquitoes which cause high levels of dengue hemorrhagic fever (DHF), whereas the existence of squatters causes a reduction in green open space, one of which becomes a breeding place for *Aedes* sp.

Methods: This study aimed to develop a DHF risk model in shophouses and squatters in Batam city. This research applied an ecological study design using a spatial approach with the geographically weighted regression (GWR) method. The variables studied were the incidence of dengue fever, vector density, and rainfall.

Results: The results of the analysis show that for the vector density in the shophouses, the odds ratio (OR) was 4.71 while for the vector density in squatters, the OR was 6.76. For the rainfall in the shophouses, the OR was 0.83 while for the rainfall in the Squatters, the OR was 1.68. Model analysis shows that the higher shophouses and squatters can cause an increase in dengue cases.

Conclusion: Risk analysis shows that factors that can increase DHF vulnerability include high vector density with a risk of 4.71 times (shophouses) and 6.76 times (squatters), and high rainfall in squatters with a risk of 1680 times. The distribution of dengue cases shows that Sambau dan Batu Selicin are subdistricts that have a high distribution of vulnerabilities in both shophouses and squatters. The mathematical model of dengue risk shows that every construction of one shophouse or one squatter can cause an increase in dengue cases by one case.

Keywords: Dengue fever, Indonesia, *Aedes* sp., Spatial

Citation: Herdianti, Susanna D, Eriando T, Abdullah H, Cyndythia R. Dengue hemorrhagic fever risk model using a spatial approach in Batam City, Indonesia 2022. Environmental Health Engineering and Management Journal 2024; 11(2): 201-209 doi: 10.34172/EHEM.2024.20.

Article History:
Received: 2 October 2023
Accepted: 20 January 2024
ePublished: 21 April 2024

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Introduction

Dengue hemorrhagic fever (DHF) is commonly found in tropical and subtropical areas. Based on the global data, Asia ranks first in the number of sufferers each year (1). The World Health Organization (WHO) has reported an overall increase in the incidence across the globe, with the highest cases occurring in the Americas, Southeast Asia, and the West Pacific (2). In 2019, the Philippines recorded 420 000 cases and Malaysia reported 131 000 suspected cases. Several cases were also found in different countries in 2020 including India, Singapore, Malaysia, and Indonesia (3). Furthermore, the WHO data show that approximately more than 70% of the global population at risk of DHF live in Southeast Asia and the West Pacific Region, accounting for almost 75% of the current disease burden (4,5). The number of cases in the last two decades has increased > 8 times, from 505 430 in 2000, to > 2.4 million in 2010, and 5.2 million in 2019 (3,6). Meanwhile, in 2020, Indonesia was recognized as the country with the highest number of cases in Southeast Asia (7,8).

The trend in morbidity rates within Indonesia over the last 10 years has been fluctuating. In 2017, the DHF incidence rate (IR) per 100 000 population was 26.10 with a case fatality rate (CFR) of 0.72%, while in 2018, the values were 24.75% and 0.71%, respectively. Furthermore, in 2019, the IR of dengue cases increased to 51.48 with a CFR of 0.67% (7,9). This shows a significant increase compared to the previous two years, namely 2017 and 2018. In 2020, the IR declined to 40 per 100 000 population but the CFR increased by 0.7% compared to the previous year (10).

Based on the 2021 Indonesia Health Profile, the incidence of DHF has spread to almost all provinces in Indonesia. Five provinces with the highest IR cases in 2020 were Bali Province (273.1), East Nusa Tenggara (107.7), Yogyakarta Special Region (93.4), West Nusa Tenggara (92.1), and Riau Islands (78.2) (10,11). The morbidity rate in the Riau Islands in 2020 was 78.2 with a CFR of 0.5% (10,12). In 2017, the morbidity rate was 35.08 with a CFR of 0.31% (13). and in 2018, the values increased to 56.35% and 0.58%, respectively (14). In 2019, the dengue morbidity rate was raised to 85.17 with a CFR of 0.59% (7).

Batam city is the largest contributor of dengue cases in the Riau Islands (15,16). Approximately 728 cases with a CFR of 0.32% (17) were recorded in 2019. This figure increased to 767 with a CFR of 0.52% in 2020 (18), and 902 in 2022 (12).

Geographically, Batam city borders other countries, covering more than 400 islands, 329 of which have been named. An area is considered to be at high risk of dengue transmission when the house index (HI) is ≥ 10%, container index (CI) is ≥ 5%, and flick-free numbers are ≤ 95% (19). Batam city still exceeds these standards with HI > 10% and CI > 5%. Furthermore, the average larvae-free rate remains below the national standard, at 83.5% (17). The city has a tropical climate, while the minimum and maximum temperatures in 2020 ranged from 20.0 to 27.1 °C and 32.5 to 33.2 °C. The minimum and maximum average air pressure were 1001.1 and 1014.4 Milibars, respectively. Air humidity averaged between 75% and 91% and the maximum wind speed was 15-30 knots. The number of rainy days was 210 with a yearly rainfall of 2471 mm, and the height of the sub-district capital ranged from 2-10 meters above sea level (20).

Batam society is a heterogeneous society consisting of various tribes and groups. The dominant ethnic groups include Malay, Javanese, Batak, Minangkabau, and Chinese. Until 2020, the population of Batam reached 1 329 773 people and had a very high population growth rate. The population of productive age (15-64 years) is 70.31%. This situation means that Batam city is still in a demographic bonus condition (21). Industry in Batam is divided into heavy industry and light industry. Heavy industry is dominated by the shipbuilding industry, fabrication industry, steel industry, metal industry, etc. Meanwhile, the light industry includes the manufacturing industry, electronics industry, garment industry, plastics industry, etc. Apart from that, Batam is also known to have the largest shipyard production in Indonesia (22).

Based on a report from the Batam City Health Service, environmental factors play an important role in influencing the level of public health. These factors, including the presence of mosquito larvae, significantly impact the transmission of DHF, which is transmitted by the *Aedes aegypti*. Efforts to break the chain of transmission are carried out by controlling the vector (23). Environmental conditions including breeding places inside and outside the house, as well as room lighting levels, influence the incidence of DHF (24).

To eradicate and control the disease, various programs have been implemented specifically to break the chain of transmission, as outlined in the Batam Mayor's policy Regulation Number 33 of 2019 concerning controlling mosquito vectors for infectious diseases originating from animals. This regulation known as Perwako specifies that the prevention and control of disease-carrying mosquitos can be achieved through efforts including (a) "The 1 House 1 Jumantik Program", which aims to eradicate mosquito breeding sites by properly managing drains, burying or recycling stagnant water, (b) Periodic larvae inspection, (c) Surveillance, (d) Socialization and counseling mass mobilization, (e) Larvicidation, and (f) Selective Abatement (25,26).

Based on a report from the Batam City Health Service, the current challenge in the transmission of dengue fever is the increasing presence of shophouses and squatters (23). Shophouses are defined as buildings that combine residential and work functions (27). Meanwhile, squatters are settlements that are unfit for habitation due to their locations not suiting the designation or spatial layout, the building density is very high with a very limited area, vulnerability to social and environmental diseases, low general quality, endangering the sustainability of life and its residents (28).

As found in a research by Onasis et al, high shophouse construction resulted in many shophouses not being used, especially during the pandemic, so this could cause these uninhabited shophouses to become breeding places and resting places for mosquitoes (29). Apart from that, Washliyah and colleagues' research explains that one of the factors that causes a house to be at risk is the presence of mosquito breeding areas around the house. Brooding areas are water reservoirs such as puddles of water that are stored either inside the house or outside the house or in public places, usually not exceeding a distance of 500 meters from the house (30). Research by Lover et al identified spatial clusters statistically significant at the urban village scale, and showed that climate key predictors in increasing dengue cases include weekly minimum temperature, and median relative humidity, but negative associations with maximum rainfall, all at a time lag of 1-6 weeks, with significant effects up to 10 weeks (31). Rain has a big influence on mosquito life, namely causing high air humidity and supporting mosquito breeding habitat. Every 1 mm of rainfall will increase the density of mosquitoes by one head (15,32). The increase in rainfall is in line with the increase in temperature and air humidity, which can increase or increase human contact with vectors (33).

The novelties of this research include: (a) This research examines, identifies, and analyzes vector density and rainfall in shophouses and squatter environments, which has never been programmed by the health department so they support this research because it is one of the bases for determining the dengue control program in Batam; (b) This research will develop a model of vector density and rainfall in shophouse and squatter environments; (c) This research looks at the distribution of vector density and rainfall so that it is different from previous studies where the distribution of cases was spatialized; (d) The research compares two community housing environments, namely shophouses and squatters, as characteristics of Batam, which can also become role models later that can be applied in other cities with the same environmental characteristics in this research.

This study aimed to apply statistical spatial analysis to model DHF control based on a review of ecological niche variables, including vector density and rainfall in shophouses and squatters within Batam city. The model was developed to effectively differentiate between control strategies according to the risks and characteristics of each region. Furthermore, mapping was carried out to determine the distribution of DHF vulnerability at the sub-district/ward level in the two regions. The data obtained are expected to assist the Batam City Health Office in controlling DHF.

Materials and Methods

This is a quantitative analytical study with a spatial approach utilizing geographic information system (GIS) tools. The population was 767 cases, of which 88 samples were selected using simple random sampling technique. Data were obtained from the Batam City Health Office, Meteorology Climatology and Geophysics Council, Batam City Central Statistics Council, and Batam City Government. Additionally, a survey was conducted to determine the coordinates of DHF cases. Pre-adult vector density was measured with Flick free numbers, HI, and CI, at each sample location. Larval surveys were conducted on 2 houses from each location for a total sample of 88 households. The collection of Aedes aegypti larvae was obtained from a survey of water storage containers (bathtubs, behind refrigerators, dispensers, jars, drums, flower vases, water containers in bird cages, cans, plastic, used tires, etc), which have the potential to be used as reservoirs. Breeding of Aedes aegypti mosquitoes was done using a flashlight. The larvae that were found were scooped up using a dipper and pipette, then, put into the prepared plastic pots, labeled, and recorded on an entomology form. Flick density (density figure) is calculated based on the flick-free numbers, HI, and CI values categorized into low and high density. Climate data were obtained from the Hang Nadim Meteorological Station. It is also equipped with microclimate measurements at each sample location. Before being used for data collection, the instrument was tested first on 10% of the total sample, namely 12 respondents in areas whose characteristics were almost the same as the shophouses and squatter locations. The researchers took residents who lived in housing around shophouses and squatters. The validity of the instrument was tested using the Pearson Product Moment correlation technique, and the reliability of the instrument was tested using Cronbach's Alpha. All research instruments used in this research are valid (r-count of validity > 0.60) and reliable (r-count of reliability > 0.70).

The analytical method comprised both univariate and bivariate analyses. The univariate analysis included DHF incidence, vector density, and rainfall, while the bivariate aimed to determine the potential relationship between the independent and dependent variables. Spatial analysis was carried out using ArcGIS software for spatial using the ordinary least square (OLS) and geographically weighted regression (GWR) methods. The analysis technique used is GIS analysis with buffering, scoring, and overlay techniques, as well as correlation analysis. The analysis steps carried out in this research are as follows:

1. Carry out variable descriptions;
2. Identify the relationship pattern between the dependent and independent variables;
3. Standardize the data;
4. Carry out a regression model (OLS);
5. Analyze the GWR model;
6. Determine the best model using the determination coefficient (R^2) and AIC for the GWR model with Gaussian kernel weighting;
7. Draw conclusions based on the analysis.

A model with a smaller AIC value is considered better than a model with a larger AIC value, so comparing the AIC value in the OLS model with the AIC in the GWR model is one way to assess the benefits of moving from the OLS regression model to the GWR model. The GWR model is a development of the regression model where each parameter is calculated at each location point so that each geographic location point has a different regression parameter value at each geographic location point. The GWR results presented in this research use a fixed kernel function or fixed kernel type. The selection of the best model can be seen from the residual sum of square, classic AIC (AICc), and R-squared values.

Results

Univariate analysis was carried out to determine the frequency distribution of each variable studied.

Table 1 shows that shophouses had similar levels of high and low vulnerability to DHF with 21 cases (50%). Meanwhile, squatters exhibited high vulnerability, amounting to 22 cases (47.8%). In total, 43 cases (48.9%) of DHF were in the high vulnerability category. About 37 (88.1%) shophouses had high vector density, while squatters also exhibited a high vulnerability with 40 cases (87.0%). The frequency distribution showed that 77 cases (88.7%) were classified in the high category for vector density. Both shophouses and squatters had a high risk of transmitting dengue fever due to rainfall with 29 (69.0%) and 28 cases (60.9%) respectively. The overall distribution showed that 57 cases (64.8%) were in the high-risk category.

The bivariate analysis results are shown in Tables 2 and 3. Based on the risk analysis for shophouses in Table 2, people living in areas with high vector density had a 4.71 times greater risk of being susceptible to dengue fever than those living in low-density areas. For squatters, it was found that people living in areas with high vector density had a 6.76 times greater risk of being susceptible to dengue fever than those living in low-density areas. This is a significant result with a *P* value of 0.034 for shophouses and 0.009 for squatters. Squatters have a greater risk than shophouses.

Table 1. Frequency distribution of DHF, vector density, and rainfall

Variable	Frequency				Total	
	Shophouses	%	Squatters	%	N	%
Gender						
Male	24	57.1	28	60.9	52	59.1
Female	18	42.9	18	39.1	36	40.9
Age (y)						
<30	37	88.1	41	89.1	78	88.6
≥30	5	11.9	5	10.9	10	11.4
DHF						
High	21	50.0	22	47.8	43	48.9
Low	21	50.0	24	52.2	45	51.1
Vector density						
High	37	88.1	40	87.0	77	88.7
Low	5	11.9	6	13.0	11	11.3
Rainfall						
High risk	29	69.0	28	60.9	57	64.8
Low risk	13	31.0	18	39.1	31	35.2

Table 2. Risk factors of vector density for DHF

Vector density	DHF				Total		*P* value	OR (CI: 95%)
	High		Low					
	n	%	n	%	N	%		
Shophouses							0.034	4.71 (3.48-46.23)
High	20	54.1	17	45.9	37	100.0		
Low	1	20.0	4	80.0	5	100.0		
Squatters							0.009	6.76 (5.72-23.33)
High	23	57.5	17	42.5	40	100.0		
Low	1	16.7	5	83.3	6	100.0		

Table 3. Risk factors of rainfall for DHF

Rainfall	DHF				Total		*P* value	OR (CI: 95%)
	High		Low					
	n	%	n	%	N	%		
Shophouses							1.000	0.83 (0.25-2.77)
High risk	10	47.6	11	52.4	21	100.0		
Low risk	11	52.4	10	47.6	21	100.0		
Squatter							0.054	1.68 (1.52-5.39)
High risk	14	58.3	10	41.7	24	100.0		
Low risk	10	45.5	12	54.5	22	100.0		

Table 3 shows that among 42 areas in shophouses, 10 (47.6%) and 11 (52.4%) had high- and low-risk rainfall respectively with high DHF vulnerability. The risk analysis for DHF susceptibility concerning rainfall indicated an odds ratio (OR) of 0.83. The significance test with a confidence interval of 95% resulted in the LL and UL values of 0.25 and 2.77, respectively with a P value of 1.000. This means that rainfall is not a risk factor in shophouses. Of the squatters, 14 (58.3%) had high-risk rainfall, while 10 (45.5%) had low risk with high DHF vulnerability. The risk analysis of DHF based on rainfall showed an OR of 1.68. The significance test obtained LL and UL values of 1.52 and 5.39, respectively with a *P* value of 0.054. This means that squatters with high-risk rainfall have a 1.67 times greater risk of contracting dengue fever than those who live in areas with low vector density.

Figure 1 shows the spatial distribution of vector density risk for DHF disease. The darker the color of the dots on the map, the higher the risk of DHF. Among the 44 sub-districts considered the mainland areas in Batam city, the Nongsa District had the highest vector density. Two sub-districts namely Sambau and Batu Besar sub-districts with high vector density were marked dark orange. This means that each increase in vector density can contribute an additional 0.008 or approximately one case of DHF.

Figure 2 shows that the Sambau sub-district had the highest rainfall risk for dengue fever vulnerability among the 44 sub-districts. On the map, the darker the color of the dot, the higher the risk of dengue fever. The coefficient was positive, and the significance test showed that the risk of this spread was significant. This means that each increase in rainfall can lead to approximately one additional DHF case.

Model analysis was performed using GWR. The GWR results are presented in Table 4. The weighting method in this study uses a fixed kernel-type function. The selection of the best model can be seen from the residual sum of squares (RSS), classic AIC (AICc), and R-squared values. The smaller the RSS and classic AIC values, the better the model form. Apart from that, AIC also considers the simplicity of the model formed. The greater the R-squared value, the better the model formed. In this GWR model, the AICc value is 90.86. The R-squared or R^2 value is 0.44 while the adjusted R^2 value is 0.36. The R-squared value for shophouses and squatters is the same, namely 0.44, which means that the independent variables in the model can explain Y (dengue susceptibility) as a response variable by 44% and the rest is explained by other variables outside the model. The adjusted R^2 value of 0.36 means that the variables used in this study can explain 36% of the incidence of dengue fever in Batam city.

From the GWR results (Table 4), a model can be formed for dengue fever vulnerability in Batam city as follows:

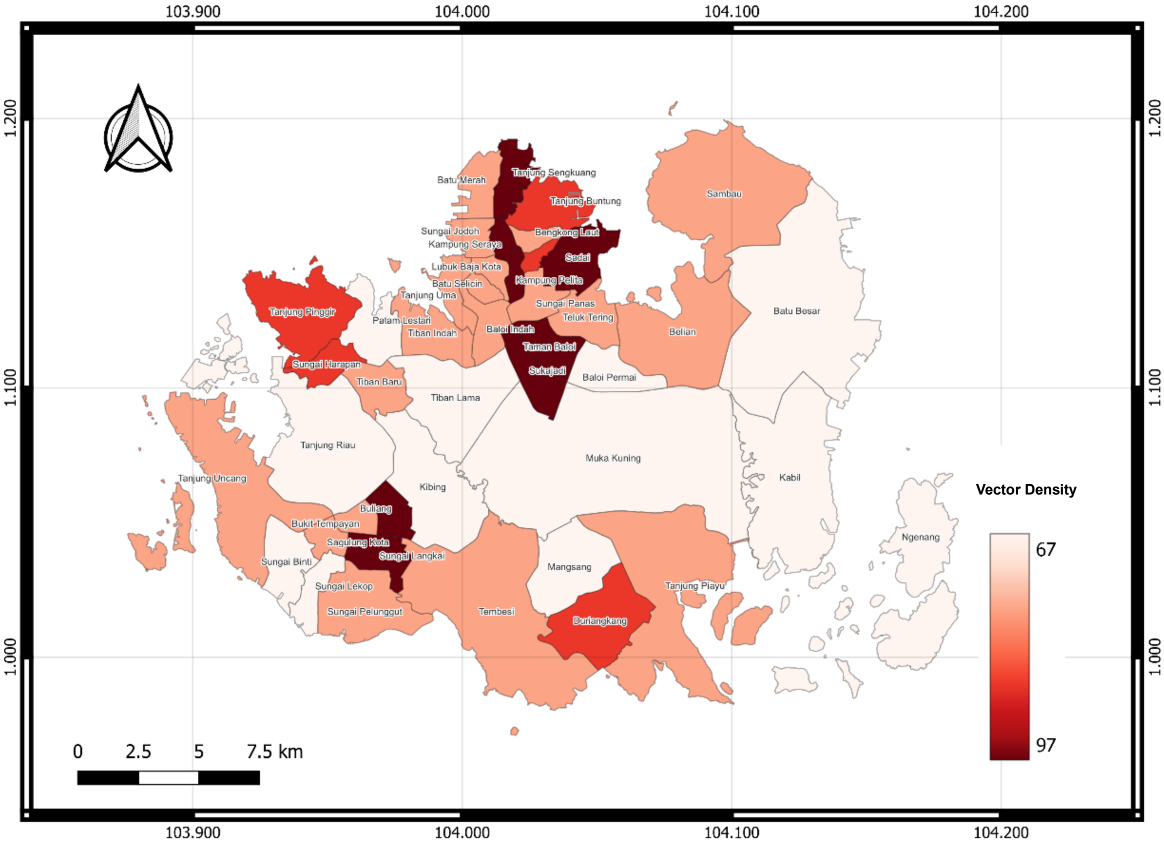

Figure 1. Mapping the risk of vector density on Dengue fever vulnerability

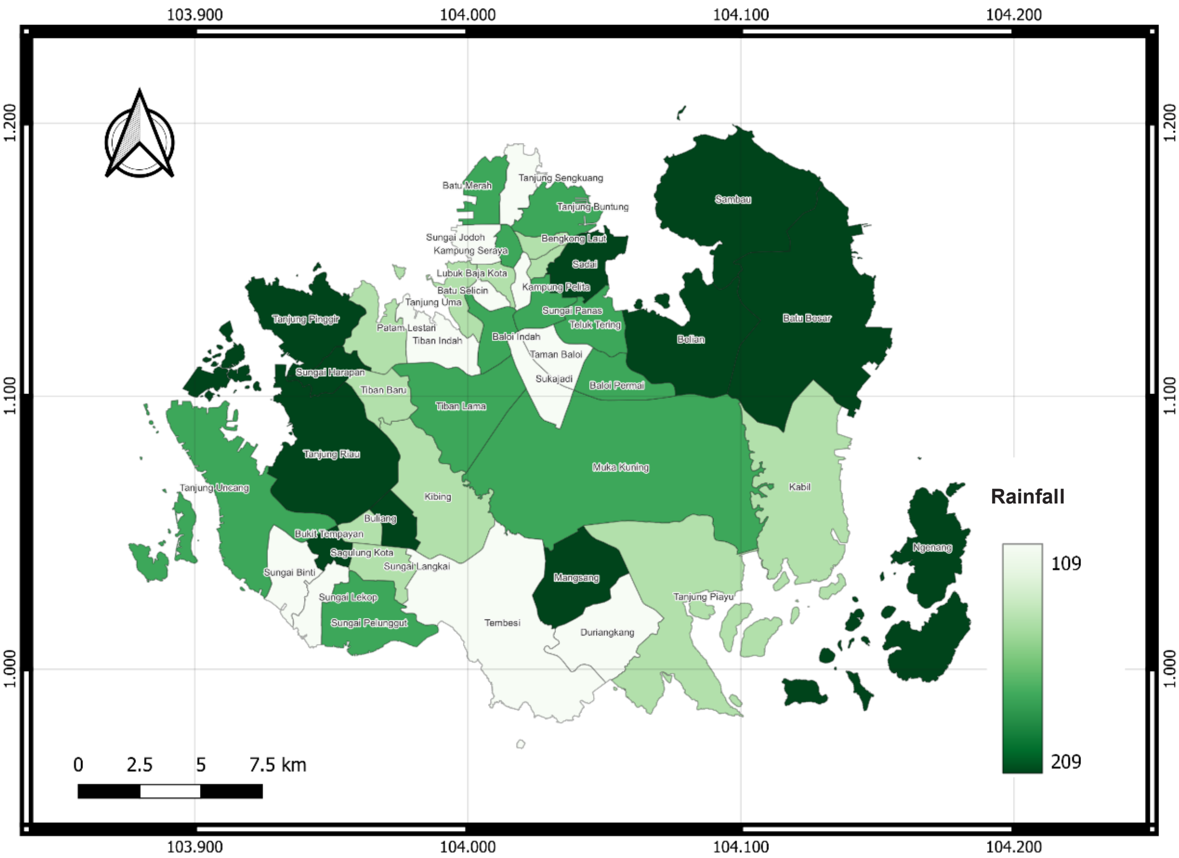

Figure 2. Mapping the risk of rainfall on Dengue fever vulnerability

Table 4. The results of geographically weighted regression (GWR)

Variable	Coefficient	SE	Significance
Intercept	1.476	6.095	
Vector density (X1)	-3.856	1.400	Significant
Rainfall (X2)	-2.253	3.608	Significant
Shophouses (X3)	1.013	4.622	Significant
Squatter (X4)	0.979	3.415	Significant
Bandwidth	32		
Residual squares	16.94		
AIC	83.13		
AICc	90.86		
R^2	0.44		
Adjusted R-squared	0.36		

$$\hat{y} = 1.476 - 3.856X1 - 2.253X2 + 1.013X3 + 0.979X4$$

Where X1 is vector density, X2 is rainfall, X3 is shophouses, and X4 is squatter.

The model explains that every increase in the vector density and rainfall value as measured can reduce the vulnerability of dengue cases by 3.856 and 2.253, assuming the other predictor variables are constant. Every increase in the number of shophouses and squatters can increase dengue cases by 1.013 and 0.979, assuming other predictor variables are constant. In this case, the shophouse model has more risk than the squatter model.

Discussion

Based on the results of the present study, squatters are more at risk than shophouses in increasing the incidence of dengue fever, as big as 6.76 times the risk for high vector density and 1.67 times the risk for rainfall. Based on the model produced in this study, the risk model for the two variables studied (vector density and rainfall) for squatters is higher than for shophouses in increasing dengue cases.

According to previous studies, the higher the density of Ae. Aegypti mosquitoes, the greater the community risk of contracting DHF (34,35). The vector density was affected by the presence of containers in the form of bathtubs, jars, flower vases, and used cans, which served as mosquito breeding sites (36,37). Various parameters can be used to measure the vector density including larva-free number, as well as the HI and CI (38). Amelinda et al stated that the higher the vector density, the higher the risk of DHF transmission (39). Therefore, in areas with a high Ae. Aegypti density, the risk of DHF transmission is increased, posing a threat to the surrounding community.

This result was consistent with the results of the study by Istiqamah et al, as reported that the emergence of DHF disease was caused by agent, human, environmental, and vector factors (8). To reduce the risk of vector density, it is necessary to raise community self-awareness and encourage activities targeted at eradicating mosquito breeding sites, such as draining water reservoirs at least once a week.

DHF transmission is closely related to climatic conditions. Climate influences mosquito breeding, starting from mating, egg laying, and eating patterns of females, as well as the ability to transmit the dengue virus (40-42). Rainfall affects the pattern of infectious diseases and potentially increases the risk of DHF transmission (43,44). High rainfall in the tropics causes a buildup of water in the air, raising the humidity levels and leading to the formation of rain clouds (45). In addition, it creates stagnant water bodies, which serve as a breeding ground for mosquitoes (46,47).

Rainfall potentially affects the life of mosquitoes in two ways, by increasing the relative humidity of the air and creating additional breeding sites. Every 1 mm of rainfall increases the density of mosquitoes by one, but when the rainfall reaches 140 mm in a week, the larvae will drift away and die (48,49).

The results were consistent with the results of the study by Susilawaty et al, which reported a significant relationship between rainfall and the incidence of DHF in Makassar (50). It was assumed that rainfall contributed to the availability of suitable habitats for vectors to breed, ultimately impacting their populations. The presence of vector breeding habitats such as standing water, potentially increases the transmission of dengue fever in an area.

The risk modeling analysis showed that the Sambau and Batu Selicin subdistricts had high vector densities, indicated by dark orange color on the map. It was concluded that the higher the mosquito vector density, the greater the possibility of DHF transmission. There was a positive relationship between vector density and the number of dengue cases in these sub-districts, evidenced by a positive coefficient value of 0.008. The significance test showed that the risk of transmission was most significant in Sambau village. This means that each increase in rainfall can lead to 0.006 or approximately one additional DHF case.

These results indicate the need for urgent actions to prevent and control DHF in Sambau and Batu Besar Districts. Prevention measures, including vector control programs and public education on good practices, should be intensified. Further studies are needed to understand the environmental factors that contribute to the high vector density in these two sub-districts. This will aid in the formulation of a more appropriate control strategy. Besides, efforts to prevent and control DHF must be prioritized throughout Batam city, specifically in areas with high risk.

The greater the intensity of the rainfall, the darker the color of the dot, indicating a higher risk of transmission. The positive coefficient (0.006) indicated that there was a positive correlation between increased rainfall and the risk of spreading dengue fever. Each increase in rainfall can lead to 0.006 or approximately one additional DHF case. The significance test showed that the risk of this spread was statistically significant in Sambau village.

The significant variables based on the model in this study are vector density and rainfall in the shophouses and squatters. So control efforts are needed by paying attention to these three variables. Shophouse areas require more comprehensive planning in building shophouses in Batam city. So it can control the dense population in the shophouse area. This includes the management of uninhabited shophouses because uninhabited shophouses can become resting and breeding places for dengue vectors. Meanwhile, for squatters, regulations need to be enforced to prevent the development of slum settlements, which are not intended for them. Squatters are mostly densely populated, which triggers high DD transmission. So there is a need to control squatters, especially in areas close to industry. There is a need for law enforcement related to controlling slum squatters, which are not intended for use by thinking about alternatives for re-locating people in squatters. There needs to be cooperation or coordination between the Batam City Health Service and the Meteorology, Climatology, and Geophysics Agency to obtain valid data on climate conditions every month so that they can develop mitigation programs considering climate.

One of the limitations of this research is that rainfall collection by secondary data taken in the Hang Nadim Meteorology, Climatology, and Geophysics Agency is not published per sub-district but rather by district. So to collect data per sub-district, we have to make a special request to the office. on the other side, these results do not guarantee that they can represent the micro rainfall conditions of the entire Batam city considering that Batam city has had extreme climate conditions in the last three years. Vector density data were collected using home observation methods and interviews with respondents using questionnaires. Several respondents already knew the information about the visit before the researchers arrived, so these respondents first cleaned all water reservoirs that could become breeding places for larvae/mosquitoes. So this can affect vector density measurements.

Conclusion

Risk analysis shows that factors that can increase DHF vulnerability include high vector density with a risk of 4706 times (shophouses) and 6765 times (squatters), and high rainfall in squatters with a risk of 1680 times. The distribution of dengue cases shows that Sambau dan Batu Selicin Subdistrict are subdistrict that has a high distribution of vulnerabilities in both shophouses and squatters. The mathematical model of dengue risk shows that each increase in the number of shophouses and squatters can increase one dengue case. In this case, the shophouse model has more risk than the squatter model.

Acknowledgments

The authors are grateful to the Doctoral Program in Public Health Sciences, University of Indonesia, Depok, Indonesia, and also, the School of Health Sciences, Batam city Government, Universiti Sains Malaysia, Malaysia for their support during the study and publication. This study was funded by the Ministry of Education, Culture, Research and Technology, Jakarta, Indonesia. The authors are also grateful for all the assistance provided by the Universitas Indonesia and Universitas Ibnu Sina who have collaborated in collecting data as well as to all parties involved in the completion of this study.

Authors' contributions

Conceptualization: Dewi Susanna, Herdianti.
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Funding acquisition: Dewi Susanna.
Investigation: Dewi Susanna, Herdianti.
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Software: Tris Eriando.
Supervision: Dewi Susanna
Validation: Dewi Susanna, Tris Eriando.
Visualization: Herdianti.
Writing–original draft: Dewi Susanna, Herdianti.
Writing–review & editing: Hasmah Abdullah.

Competing interests

The authors declare that there are no competing interests.

Ethical issues

Ethical issues (plagiarism, informed consent, infringement, falsification and/or falsification of data, multiple publication and/or submission, redundancy, etc) were met by the authors. This research achieved ethical approval from the Research and Community Engagement Ethical Committee Faculty of Public Health Universitas Indonesia (Ethical code: Ket-517/UN2.F10.D11/PPM.00.02/2022). Participants were asked to sign a written consent form before becoming respondents with ethical considerations including validity, voluntary participation and consent, confidentiality, risk of harm, research methods, and sampling.

Funding

This research received a dissertation grant (Grant No.: number NKB-1125/UN2.RST/HKP.05.00/2023) from the Ministry of Education, Culture, Research and Technology.

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