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The Effects of Environmental Determinants and Vector Control Methods on *Aedes aegypti* Larval Presence at Bakauheni Seaport and Radin Inten II Airport

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A B S T R A C T

Seaports and airports are strategic points characterized by high mobility of people and goods, making them potential hubs for the dissemination of dengue vectors. The presence of *Aedes aegypti* larvae is strongly influenced by environmental factors and the effectiveness of vector control methods. This study employed an analytic observational quantitative design with a cross-sectional approach. The study was conducted at Bakauheni Seaport and Radin Inten II Airport in 2025. All identified at-risk sites were included as the study sample. The independent variables were temperature, humidity, physical control, and chemical control, whereas the dependent variable was the presence of *Aedes aegypti* larvae. Data were analyzed using multivariate logistic regression. The findings revealed that humidity and chemical control were the primary determinants of *Aedes aegypti* larval presence at Bakauheni Seaport. In contrast, at Radin Inten II Airport, physical control played a more prominent role than the other factors examined. Therefore, strengthening physical vector control integrated with chemical control is recommended as the principal strategy for dengue prevention at points of entry.

Pelabuhan dan bandara merupakan titik strategis dengan mobilitas manusia dan barang yang tinggi sehingga berpotensi menjadi simpul penyebaran vektor nyamuk Demam Berdarah Dengue (DBD). Keberadaan jentik *Aedes aegypti* sangat dipengaruhi oleh faktor lingkungan serta efektivitas metode pengendalian vektor yang diterapkan. Penelitian ini merupakan studi kuantitatif observasional analitik dengan desain *cross sectional*. Lokasi penelitian meliputi Pelabuhan Bakauheni dan Bandara Radin Inten II pada tahun 2025. Seluruh populasi tempat berisiko dijadikan sampel. Variabel independen meliputi suhu, kelembapan, pengendalian fisik, dan pengendalian kimiawi, sedangkan variabel dependen adalah keberadaan jentik *Aedes aegypti*. Analisis data dilakukan secara multivariat dengan uji regresi logistik. Hasil analisis menunjukkan bahwa kelembapan dan pengendalian kimiawi merupakan determinan utama keberadaan jentik di Pelabuhan Bakauheni. Sedangkan di Bandara Radin Inten II, faktor pengendalian fisik lebih berperan dibandingkan faktor lainnya. Oleh karena itu penguatan pengendalian fisik yang terintegrasi dengan pengendalian kimiawi direkomendasikan sebagai strategi utama pencegahan DBD di pintu masuk wilayah.

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1. Introduction

Dengue Hemorrhagic Fever (DHF) remains a significant global public health problem, with its incidence increasing due to climate change, urbanization, and high levels of human mobility (Gubler, 2012; Khairunisa et al., 2018; Rusli & Yushananta, 2020; Thi Tuyet-Hanh et al., 2018; Tosepu, Tantrakarnapa, Nakhapakorn, et al., 2018; Wowor, 2017; Yushananta et al., 2020; Yushananta & Ahyanti, 2014). The larval presence of *Aedes aegypti*, the primary vector of DHF, is strongly affected by environmental determinants, particularly temperature, humidity, and the availability of breeding sites, all of which directly influence vector density within a given area (Khairunisa et al., 2018; Thi Tuyet-Hanh et al., 2018; Tosepu, Tantrakarnapa, Nakhapakorn, et al., 2018; Tosepu, Tantrakarnapa, Worakhunpiset, et al., 2018; Yushananta, 2021). Elevated vector density reflects an increased risk of arboviral transmission, especially in tropical regions where environmental conditions are optimal for the mosquito life cycle (Gómez-Vargas et al., 2024; Katzelnick et al., 2024; Pakaya et al., 2023). These circumstances underscore that effective vector control should not rely solely on chemical interventions but must also incorporate environmental management and sustainable physical control measures (Bowman et al., 2016; Hariyanti, 2024; Marlinae et al., 2019).

The selection of Bakauheni Seaport and Radin Inten II Airport was based on their characteristics as the primary points of entry in Lampung Province, both of which experience exceptionally high levels of mobility. The Bakauheni–Merak route is the busiest ferry crossing in Indonesia, accommodating substantial volumes of passengers, vehicles, and cargo, thereby serving as a potential hub for the dissemination of vectors and environmentally related diseases (PT ASDP Indonesia Ferry (Persero), 2024). Meanwhile, Radin Inten II Airport recorded a 36% increase in air traffic in 2024, with 473,834 passengers and 2,904 aircraft movements during the first semester alone (Kemenhub RI, 2021; PT Angkasa Pura II [Persero], 2024). The contrasting operational and environmental characteristics of these two settings provide an opportunity to better understand how environmental determinants and the effectiveness of vector control measures vary across different points of entry. Consequently, the findings of this study are expected to provide a scientific basis for developing risk-based entomological surveillance and vector control strategies at points of entry in accordance with the framework of the *International Health Regulations* (World Health Organization, 2016).

2. Methods

This study employed a quantitative observational analytic design using a cross-sectional approach to examine the association between environmental determinants and vector control methods and the presence of *Aedes aegypti* larvae. The study was conducted at the Bakauheni Seaport and the Radin Inten II Airport in Lampung Province in September 2025.

The study population comprised all buildings with the potential to serve as mosquito breeding sites, as well as environmental management personnel at both locations. A total sampling technique was employed; therefore, all 201 buildings that met the observation criteria were included in the study. Larval presence was defined as the dependent variable and was determined through direct inspection of all water-holding containers within each building using a larval survey method.

The dependent variable was categorized as "larval presence" when *Aedes aegypti* larvae were detected (score = 1) and "no larval presence" when no larvae were found (score = 0). Data collection was conducted through direct observation and structured interviews. Environmental temperature was measured with a thermometer and classified as optimal (25–30°C) or non-optimal (<25°C or >30°C). Humidity was measured with a hygrometer and categorized as optimum when it ranged from 81.5% to 89.5% and as non-optimum when it fell outside this range.

Physical vector control was assessed based on the implementation of source-reduction activities, including draining and covering water storage containers, eliminating standing water, and managing discarded items that could serve as breeding sites for mosquitoes. Chemical vector control was evaluated of applying larvicides or insecticides in accordance with established procedures at the study sites. Both vector control variables were classified dichotomously as implemented (score = 1) when the measures were routinely carried out in compliance with the management guidelines, and not implemented (score = 0) when no evidence of implementation was identified during field observations or reported through structured interviews.

Data analysis was conducted in a stepwise manner, encompassing univariate, bivariate, and multivariate analyses. Univariate analysis was used to describe the frequency distribution and proportions of each study variable, including *Aedes aegypti* larval presence, temperature, humidity, physical vector control, and chemical vector control. Subsequently, a bivariate analysis using the Chi-square test was performed to assess the association between each independent variable and *the presence of Aedes aegypti* larvae.

Variables that met the selection criteria in the bivariate analysis were then included in the multivariate analysis, using binary logistic regression, to identify the dominant determinants of larval presence after controlling for other variables in the model. The results were presented as *p*-values, odds ratios (OR), and 95% confidence intervals (95% CI). Statistical significance was established at a *p*-value of less than 0.05.

3. Results

Among the 103 buildings observed at Bakauheni Seaport (Table 1), *Aedes aegypti* larval presence was identified in 44 buildings (42.7%), whereas no larvae were detected in 59 buildings (57.3%). In contrast, at Radin Inten II Airport (Table 1), larvae were found in 31 of the 98 buildings (31.6%), while 67 buildings (68.4%) showed no evidence of larval presence.

The majority of buildings at both study sites were within the optimum temperature range, accounting for 58.3% of buildings at Bakauheni Seaport and 70.4% at Radin Inten II Airport. Likewise, optimal humidity conditions were observed more frequently at Bakauheni Seaport (71.8%) than at Radin Inten II Airport (57.1%).

From the perspective of vector control practices, the proportion of buildings implementing physical vector control measures was substantially higher at Radin Inten II Airport (76.5%) than at Bakauheni Seaport (34.0%). A similar pattern was observed for chemical vector control, which was implemented in 68.4% of buildings at Radin Inten II Airport but in only 42.7% of buildings at Bakauheni Seaport. Conversely, the majority of buildings at Bakauheni Seaport had not implemented either physical vector control measures (66.0%) or chemical vector control interventions (57.3%).

Table 1. Variables distribution

Variable	Bakauheni Seaport n (%)	Radin Inten II Airport n (%)
Larval presence		
Larvae present	44 (42.7)	31 (31.6)
Larvae absent	59 (57.3)	67 (68.4)
Temperature		
Optimal	60 (58.3)	69 (70.4)
Not Optimal	43 (41.7)	29 (29.6)
Humidity		
Optimal	74 (71.8)	56 (57.1)
Not Optimal	29 (28.2)	42 (42.9)
Physical vector control		
Implemented	35 (34.0)	75 (76.5)
Not implemented	68 (66.0)	23 (23.5)
Chemical vector control		
Implemented	44 (42.7)	67 (68.4)
Not implemented	59 (57.3)	31 (31.6)

Based on Table 2, the proportion of *Aedes aegypti* larval presence was higher in buildings with optimum temperatures (50.0%) than in those with non-optimum temperatures (32.6%). However, the results of the Chi-square test indicated that temperature was not significantly associated with larval presence at Bakauheni Seaport (p = 0.118). In contrast, humidity demonstrated a statistically significant association with larval presence (p = 0.030). The proportion of buildings with detected larvae under optimum humidity conditions reached 50.0%, whereas only 24.1% of buildings with non-optimum humidity conditions exhibited larval presence.

From the perspective of vector control practices, buildings that did not implement physical vector control measures had a larval presence proportion of 65.7%, substantially higher than in buildings that did implement such measures (30.9%). This association was statistically significant (p = 0.002). Similarly, the proportion of buildings with larval presence was 59.1% among those that did not implement chemical vector control, compared with 30.5% among those that

Table 2. Bivariate analysis at Bakauheni Seaport

Variable	Larvae Present n (%)	Larvae Absent n (%)	Total	p-value
Temperature				
Optimal	30 (50)	30 (50)	60 (100)	0.118
Not Optimal	14 (32.6)	29 (67.4)	43 (100)	
Humidity				
Optimal	37 (50)	37 (50)	74 (100)	0.030
Not Optimal	7 (24.1)	22 (75.9)	29 (100)	
Physical vector control				
Implemented	21 (30.9)	47 (69.1)	68 (100)	0.002
Not implemented	23 (65.7)	12 (34.3)	35 (100)	
Chemical vector control				
Implemented	18 (30.5)	41 (69.5)	59 (100)	0.007
Not implemented	26 (59.1)	18 (40.9)	44 (100)	

did, and the Chi-square test also demonstrated a significant association ($p = 0.007$).

Based on Table 3, temperature was not statistically associated with *Aedes aegypti* larval presence at Radin Inten II Airport ($p = 0.203$). Nevertheless, the proportion of buildings with detected larvae was higher among those with optimum temperatures (36.2%) than among those with non-optimum temperatures (20.7%). A similar pattern was observed for humidity, where the proportion of larval presence under optimum humidity conditions reached 39.3%, compared with 21.4% under non-optimum humidity conditions. However, this difference was not statistically significant ($p = 0.097$). Therefore, temperature and humidity cannot be considered factors associated with larval presence in the airport environment.

In contrast, vector control measures were significantly associated with the presence of *Aedes aegypti* larvae. Among buildings where physical vector control was not implemented, the proportion of larval presence reached 52.2%, whereas it was only 25.3% in buildings where physical vector control measures were implemented ($p = 0.030$). Similarly, the proportion of buildings with larval presence that did not implement chemical vector control was 48.4%, substantially higher than in buildings implementing chemical control (23.9%; $p = 0.028$).

Table 3. Bivariate analysis at Radin Inten II Airport

Variable	Larvae Present n (%)	Larvae Absent n (%)	Total	p-value
Temperature				
Optimal	25 (36.2)	44 (63.8)	69 (100)	0.203
Not Optimal	6 (20.7)	23 (79.3)	29 (100)	
Humidity				
Optimal	22 (39.3)	34 (60.7)	56 (100)	0.097
Not Optimal	9 (21.4)	33 (78.6)	42 (100)	
Physical vector control				
Implemented	19 (25.3)	56 (74.7)	75 (100)	0.030
Not implemented	12 (52.2)	11 (47.8)	23 (100)	
Chemical vector control				
Implemented	16 (23.9)	51 (76.1)	67 (100)	0.028
Not implemented	15 (48.4)	16 (51.6)	31 (100)	

Based on Table 4, humidity showed a statistically significant association with *Aedes aegypti* larval presence, with a *p*-value of 0.003, an odds ratio (OR) of 10.652, and a 95% confidence interval (CI) of 2.212–51.299. These findings indicate that locations with optimal humidity had approximately 10.6 times higher odds of larval presence.

In contrast, temperature did not show a significant association with larval presence (p = 0.396), indicating that temperature was not a significant determinant in this model. Moreover, physical vector control (p = 0.165) and chemical vector control (p = 0.128) were not significantly associated with larval presence. Consequently, in the initial multivariate model, humidity emerged as the only environmental determinant significantly related to *Aedes aegypti* larval presence at Bakauheni Seaport.

Table 4. Initial Multivariate Logistic Regression Model at Bakauheni Seaport

Variabel	B	SE	Wald	p-value	OR	95% CI
Temperature	0.505	0.595	0.72	0.396	0.604	0.188-1.937
Humidity	2.366	0.802	8.702	0.003	10.652	2.212-51.299
Physical vector control	1.071	0.771	1.93	0.165	2.918	0.644-13.215
Chemical vector control	1.21	0.796	2.311	0.128	3.353	0.705-15.951

The final multivariate logistic regression model (Table 5), obtained after a stepwise variable selection process, identified two variables significantly associated with *the presence of Aedes aegypti* larvae: humidity and chemical vector control. The humidity variable remained statistically significant, with a p-value of 0.001 and an odds ratio (OR) of 7.438 (95% CI: 2.258–24.497). This finding indicates that optimal environmental humidity increased the odds of larval presence by approximately 7.4 times compared with nonoptimal humidity conditions, after controlling for other variables in the model.

Furthermore, chemical vector control also demonstrated a statistically significant association, with a p-value < 0.001 and an OR of 6.776 (95% CI: 2.412–19.036). These results indicate that the absence of chemical vector control increased the likelihood of larval presence by nearly 6.8 times compared with locations where chemical control was implemented. Consequently, based on this final model, environmental humidity and chemical vector control were identified as the primary determinants of *Aedes aegypti* larval presence at Bakauheni Seaport, whereas temperature and physical vector control did not show independent significant effects after adjustment for other variables.

Table 5. Final multivariate logistic regression at Bakauheni Seaport

Variabel	B	SE	Wald	p-value	OR	95% CI
Humidity	2.007	0.608	10.886	0.001	7.438	2.258-24.497
Chemical vector control	1.913	0.527	13.182	<0.001	6.776	2.412-19.036

Based on Table 6, the results of the initial multivariate logistic regression analysis indicated that temperature had a p-value of 0.376, humidity had a p-value of 0.213, physical vector control had a p-value of 0.322, and chemical vector control had a p-value of 0.552. Consequently, none of the independent variables analyzed showed a statistically significant association with *Aedes aegypti* larval presence at Radin Inten II Airport in the initial model.

Table 6. Initial Multivariate Logistic Regression Model at Radin Inten II Airport

Variabel	B	SE	Wald	p-value	OR	95% CI
Temperature	0.546	0.616	0.785	0.376	1.726	0.516-5.775
Humidity	0.677	0.543	1.553	0.213	1.968	0.679-5.711
Physical vector control	0.859	0.866	0.982	0.322	2.360	0.432-12.897
Chemical vector control	0.473	0.796	0.353	0.552	1.605	0.337-7.640

Only one variable was identified as significantly associated with *the presence of Aedes aegypti* larvae at Radin Inten II Airport (Table 7): chemical vector control. The chemical vector control variable showed a *p*-value of 0.016, with an odds ratio (OR) of 3.425 and a 95% confidence interval (CI) of 1.260–9.314. These findings indicate that the absence of chemical vector control increased the likelihood of *Aedes aegypti* larval presence by approximately 3.4 times compared with locations where chemical vector control was implemented, after controlling for other variables in the model.

Table 7. Final Multivariate Logistic Regression Model at Radin Inten II Airport

Variabel	B	SE	Wald	p-value	OR	95% CI
Physical vector control	1.231	0.510	5.819	0.016	3.425	1.260-9.314

4. Discussion

At Bakauheni Seaport, the multivariate analysis revealed that humidity and chemical vector control were the primary determinants of *Aedes aegypti* larval presence. The dominant influence of humidity may be explained by the environmental characteristics of seaports in coastal areas, which generally exhibit relatively high humidity levels, particularly in warehouses, enclosed storage areas, spaces beneath buildings, and containers that receive limited direct sunlight. Such conditions can prolong the survival of mosquito eggs and larvae and enhance the activity of adult mosquitoes in seeking resting and oviposition sites. Biologically, high humidity reduces the risk of egg desiccation and extends the lifespan of adult mosquitoes, thereby increasing the likelihood of sustaining the mosquito reproductive cycle (Brady et al., 2013, 2014; Negev et al., 2015; Regis et al., 2008; Yushananta et al., 2020).

This finding is consistent with previous research identifying humidity as an important determinant of the presence of Aedes aegypti larvae. (Dewi Wiyata et al., 2023; Gómez-Vargas et al., 2024; Gunasari et al., 2024; Lemos-Silva et al., 2025). In contrast, temperature frequently fails to demonstrate a significant association when its variability is relatively narrow and remains within the optimal range for mosquito development (Kesetyaningsih et al., 2018; Nik Abdull Halim et al., 2022; Singh & Chaturvedi, 2022; Tang et al., 2018). The lack of a significant relationship between temperature and larval presence in this study may be attributed to the relatively homogeneous temperature conditions across the observation sites at Bakauheni Seaport, rendering temperature insufficiently sensitive to discriminate between the presence and absence of larvae. Furthermore, these results reinforce the concept that microclimatic conditions exert a greater influence than average ambient temperature in settings characterized by relatively uniform operational environments.

The significant association observed for chemical vector control indicates that the application of larvicides and insecticides at Bakauheni Seaport continues to exert a protective effect against *Aedes aegypti* larval presence. Nevertheless, these findings should be interpreted with caution. Repeated use of chemical agents without rotation of active ingredients may contribute to the development of vector resistance, reduce the effectiveness of interventions, and increase adverse environmental impacts (Anin et al., 2023; Pavunraj et al., 2017; Silalahi et al., 2022; Windyaraini et al., 2019; Yanti S et al., 2012; Yushananta, 2021). Therefore, chemical vector control should be implemented based on the results of entomological surveillance and supported by periodic evaluations of vector susceptibility (Anin et al., 2023; dos Santos Dias et al., 2017; Espinosa et al., 2016; Govindarajan et al., 2016; Gunasari et al., 2024; Khan, 2023; Silalahi et al., 2022).

Field observations conducted during the study identified the presence of water-holding containers within operational areas of the port, discarded containers surrounding buildings, and standing water accumulating in equipment that was not routinely used. These findings suggest that the characteristics of Bakauheni Seaport as a high-mobility ferry crossing not only increase the risk of human movement but may also facilitate the interregional dispersal of vectors and mosquito eggs. Consequently, vector control strategies at seaports should prioritize the management of humid environments, the elimination of potential breeding sites, and the implementation of well-regulated chemical control measures.

In contrast to the seaport setting, the multivariate analysis at Radin Inten II Airport identified physical vector control as the dominant factor influencing *the presence of Aedes aegypti* larvae. This finding suggests that within the relatively well-managed airport environment, the success of larval control is determined more by the consistent implementation of source-reduction practices than by microclimatic conditions.

Airports possess environmental characteristics that differ substantially from those of seaports. More organized infrastructure, well-designed drainage systems, and stricter operational oversight contribute to relatively homogeneous temperature and humidity conditions across buildings. These circumstances may explain why temperature and humidity did not exhibit statistically significant associations with larval presence in this study. In other words, physical environmental conditions were no longer the primary distinguishing factors; rather, breeding site management practices emerged as the critical determinants (Ayun & Pawenang, 2017; Daswito et al., 2024; Fentia, 2017; Hariyanti, 2024; Nurrochmawati et al., 2017; Sallata et al., 2013; Sari et al., 2017; Tosepu, Tantrakarnapa, Nakhapakorn, et al., 2018)

Consistent implementation of physical vector control measures, including draining and covering water-holding containers, eliminating standing water, improving drainage systems, and removing discarded items that may serve as mosquito breeding sites, was shown to reduce the risk of larval presence. These findings support the concept that source reduction represents the most sustainable approach to vector control because it directly interrupts the vector life cycle (Costello et al., 2009; Espinosa et al., 2016; Gubler, 2013; Li et al., 2018; World Health Organization, 2003).

Conditions identified at Radin Inten II Airport included operational water-holding containers, certain drainage channels that could retain water, ornamental plant pots, and unused equipment that could facilitate the accumulation of standing water. Although these potential breeding sites were relatively few, they could nevertheless serve as suitable habitats for *Aedes aegypti* if not managed routinely. Therefore, physical vector control should be incorporated into standard operating procedures and implemented periodically by airport management. These findings are consistent with studies by Gunasari et al. (2024) and Hidayah et al. (2021), which reported that in environments with well-established management systems, such as airports, breeding-site management is the primary determinant of larval presence rather than climatic factors (Handayani et al., 2021; Tasane, 2015; Utama & Inayah, 2022). Chemical vector control remains necessary; however, it is more appropriately applied as a surveillance-based complementary intervention when increases in larval density or outbreak situations are identified (World Health Organization, 2011; Yushananta et al., 2020).

The findings of this study further indicate that vector control strategies at points of entry cannot be uniformly applied across different settings. Seaports require greater emphasis on the management of humid environments and the rational use of chemical control measures, whereas airports should prioritize the consistent implementation of physical control interventions. Consequently, adopting approaches tailored to the specific characteristics of each location is expected to enhance the effectiveness of vector control programs and strengthen early warning systems against the risk of dengue transmission through transportation routes.

5. Conclusions

Humidity and chemical vector control were identified as the primary determinants of *Aedes aegypti* larval presence at Bakauheni Seaport. In contrast, at Radin Inten II Airport, physical/mechanical vector control played a more prominent role than the other factors examined. Moreover, this study demonstrated differences in the characteristics of risk factors and the effectiveness of control measures between seaports and airports as high-mobility points of entry.

These findings suggest that vector control strategies should not be uniformly implemented at all points of entry. However, they should instead be tailored to the environmental characteristics and management systems of each setting. At Bakauheni Seaport, control efforts should focus on managing high-humidity areas and implementing rational, targeted chemical interventions that are periodically evaluated to prevent the development of insecticide resistance. In contrast, at Radin Inten II Airport, strengthening physical control measures through source reduction, routine inspections of water-holding containers, drainage maintenance, and management of objects or containers that may serve as breeding sites should be prioritized in operational procedures.

The implications of this study highlight the need for the Port Health Office of develop risk-based vector control policies in collaboration with port and airport authorities. Such policies should incorporate regular entomological surveillance, mapping of potential breeding sites, strengthened cross-sectoral collaboration, and the implementation of the principles of Integrated Vector Management (IVM) tailored to the specific characteristics of each point of entry.

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