

Variation in the Influence of Climate Parameters on Dengue Fever

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ABSTRACT: Dengue haemorrhagic fever (DHF) is the highest viral infection due to its fatality in humans. Initially, dengue only occurred in the tropics and has spread to sub-tropical areas. This disease is transmitted through the bite of vector mosquitoes, *Aedes aegypti*, and *Aedes albopictus*, so the presence of these vectors is important in the spread of dengue disease. The existence of this vector is influenced by environmental conditions. Creating a suitable environment for vector mosquitoes is determined by climatic factors, especially rainfall, temperature, and humidity. Various studies have shown that these climatic factors' influence can vary from region to region. This article discusses the variations in the influence of these climatic factors on the incidence of DHF to enrich knowledge about the epidemiology of dengue infection. This study concludes that temperature and rainfall could have a positive or negative effect on the incidence of DHF, while humidity consistently had a positive effect on the incidence of DHF. The climate factor does not stand alone and does not directly affect the process of DHF transmission. The influence appeared through the vector's life and the virus's multiplication in the vector's body.

KEYWORDS: *Aedes*, dengue fever, humidity, influence variation, rainfall, temperature

1. INTRODUCTION

Dengue fever is one of the highest mosquito-borne diseases and has become a health problem in tropical and subtropical regions. The spread of this disease is classified as the fastest in the world, among other mosquito-borne diseases. The spread is related to climate factors and population mobility.[1] Global climate change and the current globalized living system will result in the easier spread of DHF globally [2], so it can threaten the health of the world's population.

This disease is caused by an infection of the *Flaviviridae* virus and is transmitted through the bite of the *Aedes aegypti* and *Aedes albopictus*. [2] Transmission of dengue infection is determined by mosquito vectors, viruses, and a supportive environment. [3] A supportive environment is a good environment for vector mosquitoes' life. Thus, they can live longer and become hosts for virus multiplication until they reach sufficient numbers for transmission. To become a DHF vector, a mosquito must at least be aged throughout the incubation period of the virus in the mosquito's body (extrinsic incubation period) and be in a healthy condition. [4] Transmission occurs when infected female mosquitoes suck the humans' blood (*Ae. aegypti*) or animals and humans (*Ae. albopictus*) for reproductive purposes (egg maturation) [5] before the eggs are laid.

The life of the *Aedes* mosquito is influenced by the availability of clear water for laying eggs [6], a shady and damp environment as a resting place [7], and proximity to humans as objects of blood-sucking for protein sources. [8] Factors that support the life of vector mosquitoes include human behavior that causes the creation of comfortable breeding places [9] for mosquitoes and climatic factors that provide a suitable environment for the development of mosquitoes, namely humidity, temperature, and rainfall. The three main climatic factors widely studied concerning the DHF incident show different correlation results between one region and another. Therefore, it is interesting to discuss further the differences. Based on the background above, this paper aims to examine the variation in the correlation between climatic factors and the incidence of DHF in various places. It is expected that this paper can add insight into why there are differences in the results of the climate correlation test with the incidence of DHF

2. DENGUE TRANSMISSION

In the transmission of dengue infection, the virus in the patient's body will enter the body of the mosquito vector through the blood-sucking process. In the mosquito's body, the virus will proliferate until it reaches an infective number before being transmitted to the body of a potential sufferer through mosquito bites. The incubation period in the mosquito's body (EIP) is between

8-12 days. The length of the incubation period is affected by the ambient temperature. The optimal temperature for EIP is 30 °C for 2-15 days (average 6.5 days). At lower temperatures, the incubation period will be longer. [10]

For the virus to proliferate in the mosquito's body, the survival factor of the mosquito plays a very significant role. Mosquitoes with high body resistance can provide opportunities for viruses to proliferate so that they reach infective numbers. Mosquito resistance is influenced by climatic factors and geographical conditions where they live. Optimal humidity and environmental temperature supported by a shady environment and protected from direct sunlight will increase the resistance of the mosquito's body. The optimal humidity for the life of Aedes mosquitoes is 70-80 %, while the optimal temperature for Aedes breeding is 22-36 °C. [11]

Furthermore, the density of vector mosquitoes can also affect transmission. The higher the mosquito vector density is, the higher the probability of dengue disease transmission will be. Mosquito density describes the high reproductive cycle of mosquitoes. The reproductive cycle of the Aedes mosquito is directly related to the frequency of sucking human blood, where blood sucking is the main process of dengue virus transmission. The life cycle of vector mosquitoes is influenced by environmental temperature. The optimal temperature for mosquito breeding is 22-36 °C. The breeding cycle will be longer at a lower temperature. [11] The relationship between temperature and the transmission frequency can be explained as follows: temperature affects the maturation of eggs in the mosquito's body after mating between male and female mosquitoes and before the eggs are laid in breeding places.[12] The egg maturation process requires high protein; thus, female mosquitoes suck blood to meet these protein needs. In one mating, the maturation and the laying of eggs can occur several times. The period between the initial blood-sucking and the next blood-sucking is called the gonotrophic cycle, so the ambient temperature affects the frequency of mosquito blood-sucking.

Aside from being influenced by temperature, mosquito density is also influenced by the existence of breeding places. Breeding places will increase the density of mosquitoes as they provide a space for mosquitoes to lay their eggs. Breeding places will increase during the rainy season, especially outside the home. Thus, rainfall and rainy days will be positively correlated with mosquito density. However, rainfall can negatively correlate with mosquito density under certain conditions. It can happen during high rainfall so that it will wash away the breeding places and their larvae (Figure 2).

In addition to rainfall which directly affects the number of breeding places, indirect rainfall also affects the life of vector mosquitoes. In this case, rainfall and solar radiation will shape a place's temperature and humidity. Temperature and humidity then affect the life of mosquitoes and the proliferation of viruses in the mosquito's body. Thus, the climatic factor plays a dominant role in the spread of dengue infection.

Dengue vector mosquitoes are *Ae. aegypti* and *Ae. albopictus*. *Aedes aegypti* acts more as a vector in urban areas in the tropics, while *Ae. albopictus* acts more as a vector for dengue in suburban areas in the tropics or dengue in sub-tropical areas. It is probably because *Ae. albopictus* is more resistant to environments with lower temperatures than *Ae. aegypti*. According to Brady et al, the temperature of 4°C and 42-43°C is suitable minimum and maximum critical temperatures at which survival of *Ae. aegypti* minimal (<24 hours). Similar observations for *Ae. albopictus* suggest values between -5°C and 40-40.6°C [Figure 1]. [36] *Aedes albopictus* also prefers to breed in vegetation or other natural bodies of water outside the house, meanwhile *Ae. aegypti* prefers artificial ones and or inside the house.

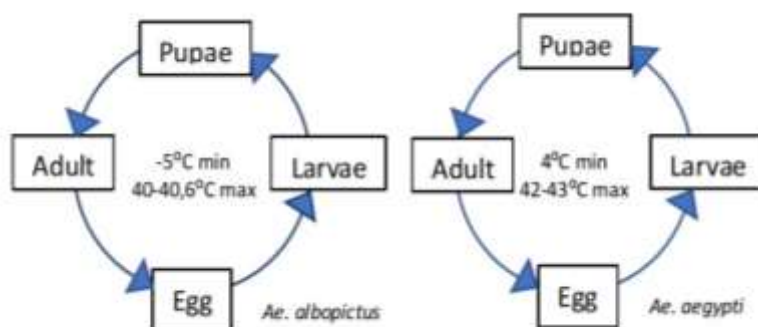


Figure 1. The life cycle of *Ae.albopictus* and *Ae.aegypti* with temperature range for adult live (< 24 hours). [36] *Aedes albopictus* has a lower ambient temperature range than *Ae. aegypti*



3. DENGUE VECTOR CAPACITY

The ability of mosquitoes to transmit the dengue virus is expressed in vector capacity. Vector capacity is the average potentially infective mosquito bite after biting one sufferer.[13] Vector capacity is used to evaluate the ability of a vector population to transmit pathogens.[14] In the system of *Ae. aegypti* – dengue virus, daily survival rate, and extrinsic incubation period (EIP) of the pathogen are the most important parameters in vector capacity. [15-16] The equation of vectorial capacity is

$$C = ma^2p^n b / - \ln p$$

where m is vector density, a is the daily probability of being fed upon (host preference index multiplied by frequency of feeding), p is mosquito daily survival, n is the length of the extrinsic incubation periods (EIP) in days, and b is vector competence. [13] The daily survival rate of Aedes mosquitoes is the proportion of mosquitoes that live long enough to transmit the dengue virus. The extrinsic incubation period (EIP) of the pathogen is the time required for the virus's development in the mosquito vector's body to reach infective numbers. The vector capacity of Aedes mosquitoes will be higher if the daily survival rate of Aedes mosquitoes is high and the EIP is shorter. High vector capacity will result in increased transmission of DHF.

4. EFFECT OF RAINFALL ON VECTOR CAPACITY

During the rainy season, many pools of clear water outside the home, such as used goods, tree holes, or tree fronds, collect rainwater and become uncontrolled breeding places.[17] An increase in the number of breeding sites will cause the mosquito population to increase, thereby increasing the possibility of transmission.

However, research in various places showed that rainfall could be positively or negatively correlated with the incidence of DHF or even not correlated. In Indonesia, the influence of the rainfall index (ICH) on the incidence of DHF in each province can be different, depending on the climate that prevails in that area. [18] However, research in Southern Taiwan showed that high rainfall negatively correlated with Aedes density. [19] Likewise, El Nino events (low rainfall) in Peru can increase the risk of dengue outbreaks in coastal areas and high mountains. [20] The research results in India are proportionally opposite, where rainfall is the single factor in increasing the incidence of DHF. [21] Likewise, in the Philippines, rainfall also positively correlates with the incidence of DHF. [22] Unlike other studies, the increased dengue cases in Sri Lanka are not correlated with rainfall. [23]

In relation to that case, two aspects might cause the correlation between rainfall and DHF incidence to differ from one region to another. First, it may be caused by rainfall's influence, which is not directly on vector capacity, but rainfall affects temperature and humidity. Temperature and humidity are directly related to vector capacity. Second, rainfall can positively affect the incidence of DHF but can also harm the incidence of DHF depending on the amount of rainfall.

The effect of rain on the increase in the number of DHF cases is as follows: rain can increase air humidity [24], thereby increasing mosquito survival. In rainy conditions accompanied by sunlight, rain can increase temperature and humidity, thereby optimizing the resistance of the mosquito body [25] and external incubation of the virus (EIP). [26] Rainfall in the range from 0.0 to 45.84 mm in Palembang is an ideal condition for the development and survival of Aedes mosquitoes. [27] Rainfall can also increase the number of Aedes mosquito breeding places, especially outdoors [28], thereby increasing the mosquito population. However, high rainfall will decrease the mosquito population due to damage to breeding places, killing and washing away the larvae and pupae of Aedes mosquitoes. [19, 29]

In cases where rain lasts a long time, rain can affect the decrease in ambient temperature [30], which will prolong the mosquito reproductive cycle and EIP. [26] In addition to reducing mosquito populations, a long reproductive cycle also affects the frequency of blood-sucking mosquitoes, as female mosquitoes suck blood for reproductive purposes (egg maturation). [7]

Based on the explanation above, it can be concluded that rainfall can have an impact on increasing the number of DHF incidents but can also have an impact on reducing the number of DHF incidents. It is what causes the effect of rainfall to vary on the incidence of DHF in several studies in various regions, and the effect appears to be local.

5. EFFECT OF TEMPERATURE ON VECTOR CAPACITY

The ability of mosquitoes to transmit the dengue virus is expressed in vector capacity. Vector capacity is the average potentially infective mosquito bite after biting one sufferer.[13] The vector capacity is determined by the amount of virus when the mosquito bites. Two important aspects play a role here: the number of viruses in the mosquito's body and the frequency of mosquito



bites. The amount of virus in the mosquito's body is a product of virus multiplication, while the frequency of mosquito bites is related to the reproductive cycle, as female mosquitoes suck blood for reproductive purposes (egg maturation).

Furthermore, warm environmental temperatures ($>37\text{ }^{\circ}\text{C}$) can accelerate the mosquito breeding cycle, increase the frequency of blood-sucking mosquitoes and accelerate the extrinsic incubation of the virus by accelerating the multiplication of the virus in the mosquito's body. [31, 32] The optimal temperature for *Aedes* life is $28 \pm 2\text{ }^{\circ}\text{C}$ [25], also for the frequency of bloodsucking ($> 26\text{ }^{\circ}\text{C}$), so that at this temperature, DENV transmission can occur within one week. [33] At temperatures $\leq 21\text{ }^{\circ}\text{C}$, the virus's incubation period will be longer [33], and even at temperatures $20\text{ }^{\circ}\text{C}$, the lowest spread of DENV occurs. [34]

On the other hand, high fluctuations in ambient temperature will reduce mosquito survival [35], thereby reducing vector capacity. Regarding the effect of temperature fluctuations on virus incubation in the mosquito's body, there are two different opinions. According to Lambrecht et al. [35], daily temperature fluctuations can inhibit extrinsic incubation. However, according to Carrington et al. [33] temperature fluctuations can accelerate extrinsic incubation (in the laboratory). The influence of daily temperature fluctuations on extrinsic incubation can technically result in differences in the analysis of the effect of temperature on the incidence of DHF. If the data used does not accommodate daily temperature fluctuations, for example, using monthly average temperature data, the results will be different from temperature data that consider the effect of daily temperature fluctuations on DHF.

In one region of the country, the effect of temperature on DHF can differ from one local area to another, where temperature can be either positively associated in one area or negatively associated in another area. Moreover, some areas do not show an association between temperature and DHF incidents. However, the high average temperature is generally positively associated with dengue. [34] It is likely to occur because the effect of temperature on the vector's capacity is non-linear, where the ambient temperature only affects a certain range, namely the ambient temperature of $26\text{-}30\text{ }^{\circ}\text{C}$. At temperatures of $26\text{-}28\text{ }^{\circ}\text{C}$, it is related to the frequency of blood-sucking, while at $30\text{ }^{\circ}\text{C}$, it is related to accelerated extrinsic incubation of the virus. [10, 26] However, at extremely high temperatures ($35\text{ }^{\circ}\text{C}$), mosquitoes are inactive and even die [36]. Low temperatures ($<24\text{ }^{\circ}\text{C}$) can prolong the reproductive cycle and extrinsic incubation [26], even mosquitoes can die at extremely low temperatures of $13.8\text{ }^{\circ}\text{C}$. [37]

The non-linear effect of temperature on mosquito survival and extrinsic incubation of the virus causes the analysis results to differ from one region to another. In areas with temperatures outside the optimum temperature range for dengue transmission, the effect of temperature on the incidence of DHF may be small or even invisible.

Another phenomenon that might cause the results of the analysis of temperature with the incidence of DHF to differ from region to region is the difference in the types of vector species that play a role. There are 2 species of *Aedes* mosquitoes can transmit the DEN virus; namely *Aedes aegypti* and *Aedes albopictus*. Both have different properties, where *Ae aegypti* is more susceptible to low temperatures than *Ae. albopictus*. [38] These different properties cause the effect of temperature on the incidence of DHF in an area also depends on the type of mosquito vector that plays a role. Usually, DHF occurs in areas with low temperatures, and the *Aedes albopictus* mosquito acts as a vector. Meanwhile, DHF occurs in areas with warm temperatures, and *Aedes aegypti* acts as a vector. The different types of vector species that play this role can affect the results of the analysis of the association between temperature and DHF events. It causes differences in the analysis results on the association between one region and another, especially areas that geographically have significant temperature differences, such as mountainous areas and coastal areas or tropical and sub-tropical regions.

In the mountainous area of Sleman Regency, DIY Province, Indonesia, it is estimated that the incidence of DHF is an imported case from an endemic area in the surrounding urban areas. It is based on evidence that the number of cases in the mountainous areas in Sleman Regency (Pakem Sub-District) is only a few and sporadic, and the ambient temperature is below the optimum temperature ($24\text{ }^{\circ}\text{C}$). In contrast, in the surrounding urban areas, it shows a high number of cases in almost every transmission season. [39] Meanwhile, in Peru, the mountainous region is a highly endemic area for DHF and is thought to be a source of infection in the incidence of DHF in coastal areas. It is based on the phenomenon that the incidence of DHF in coastal areas is always preceded by high cases in the mountains, and it correlates with temperature cycles in the region. [40]

6. EFFECT OF HUMIDITY ON VECTOR CAPACITY

Air humidity is the amount of water vapor content in the air. In general, the type of humidity used in expressing air humidity is relative humidity. Relative air humidity is the ratio of the water vapor content to the maximum amount of water vapor that can be

accommodated in the air at the same temperature, expressed in units of %. The amount of humidity in an area is determined by several factors, including the amount of solar radiation, the influence of land or sea, the influence of altitude, and the influence of wind. It causes humidity in one region to be different from other areas.

In the *Aedes aegypti* – dengue virus system, the daily survival rate and incubation period of the extrinsic virus in the mosquito's body are the factors that most influence vector capacity. [15, 16] The daily survival rate is affected by humidity. [41] Optimal humidity is needed for the trachea to function properly so that the mosquito can survive [25], and it affects the volume and osmolarity of hemolymph in the hemocoel of adult mosquitoes. [41]

Furthermore, the optimal humidity for *Aedes* mosquitoes is 70-80 %. Mosquitoes with high resistance are needed for viruses to multiply and reach enough numbers for infection. The virus (EIP) incubation time in the *Aedes* mosquito ranges from 8-12 days [35], so female mosquitoes must survive beyond the EIP period. Female mosquitoes with high body resistance and short EIP will increase vector capacity.

Based on the explanation above, it can be concluded that environmental humidity plays a role in increasing the resistance of the mosquito's body so that it can reach the life span needed for virus multiplication, leading to enough amount for infection (extrinsic incubation period).

Moreover, the results showed a positive correlation between relative humidity and the incidence of DHF in various regions of the world. Research in Jakarta revealed that air humidity is positively correlated with the incidence of DHF [42], also in Manado [43], in Singapore [44], in Surabaya [45], and in Guangzhou, China. [46] It occurs possibly due to the obvious influence of air humidity on mosquito survival through optimal tracheal function. In a more complex result, research in Thailand proved that there is a combination of weather conditions between optimal temperature and humidity. This combination indicates that the optimal weather for dengue transmission is an average temperature of 28–30 °C with humidity above 80%, a minimum temperature of 24.5–26.5 °C with a humidity of 62%, and a maximum temperature close to 32.5 °C with humidity maximum of 92%. [47]

The relationship between environmental parameters and DHF discussed in the previous sub-chapter is illustrated in Figure 2. The complexity of the relationship between climate parameters and the involvement of geographic and land use conditions is likely to cause variations in the effect of climate parameters on DHF events in various locations.

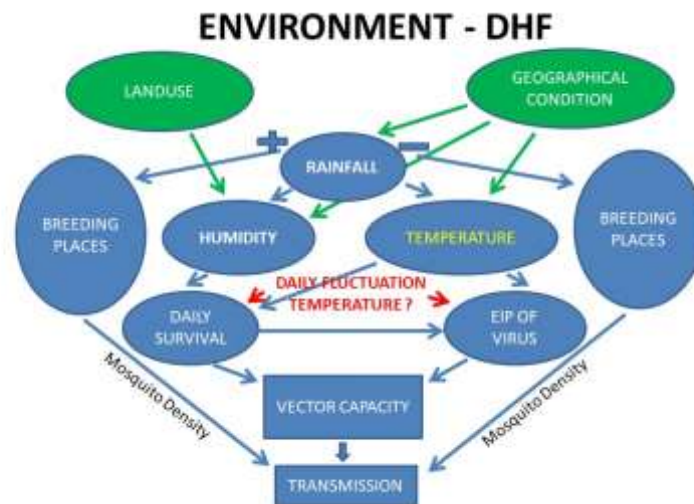


Figure 2. Correlation Between Rainfall, Temperature and Humidity with Dengue Hemorrhagic Fever Occurrence

7. CONCLUSION

Climatic factors that influenced the incidence of DHF included rainfall, temperature, and humidity. The effect of rainfall and temperature on the incidence of DHF varied from region to region, while humidity appeared to have a more consistently positive effect on the incidence of DHF in various regions. It indicated that the climate factor did not stand alone. It was interrelated, and its influence on the incidence of DHF was not direct but through the vector's life and the virus's development in the vector's body. The

complexity of this correlation opens many possibilities for further disclosure to obtain more complete and comprehensive information related to the influence of climate on the incidence of DHF.

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