Estimation of Dengue Virus Incubation Period in *Aedes* Mosquito from Temperature Variability Based on Remotely Sensed Data

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Abstract

There are three systems in the dengue virus transmission cycle: human system, mosquito system, and temperature system. Therefore, the effect of temperature on the dengue virus incubation period was estimated as a spatial estimation. The temperature parameters from ground station in 2004–2013 are estimated by using the statistical technique. The temperature value in the Mueang Chiang Mai district in 2013 was calculated by using Landsat 8-TIRS. Thereafter, the temperatures were estimated as the spatial dimension based on remotely sensed data in every 10 years, that is, 2023, 2033, and 2043. These temperatures are used to estimate the dengue virus incubation period in Aedes mosquito through a suitable equation. It is evident from the study that the dengue virus incubation period in the Aedes mosquito has decreased steadily. The mean dengue virus incubation periods in 2013, 2023, 2033, and 2043 are 11.06 days, 10.30 days, 9.64 days, and 9.06 days, respectively. Furthermore, estimations for the dengue virus incubation period for 2023, 2033, and 2043 point out that the dengue virus incubation period decreases in accordance with priority in time. Areas that are suitable for a dengue virus incubation period of less than 5 days have expanded.

1. Introduction

Dengue Hemorrhagic Fever (DHF) is a tropical disease. As the transmission of the dengue virus is sensitive with temperature variability, the suitable zone for the *Aedes* mosquito was expanded. At present, the transmission of DHF expands toward the middle latitude zone. This is because global warming has caused cold zones to become warm zones. Outbreaks of dengue occur in areas where there have been no incidences before. Temperature is one of the main factors influencing mosquito growth (Levy and Partz, 2015, Martens, 1998, Reiter, 2001 and Charoenpanyanet, 2009 and 2013). High temperatures reduce the duration of the mosquito life cycle. Cooler temperatures, on the other hand, reduce the metabolism of mosquitoes. In Thailand, DHF outbreaks are found frequently in urban areas. Chiang Mai, for example, experienced outbreaks in numerous districts such as Hangdong, Sarapee, Mae Ai, Jong Thong, Hod, Doi Lor, Sanpatong, Doisaket, San Kampaeng, and Mae Rim. The district with the largest outbreak was Mueang, with the number of infected cases during the years 2007–2013 being, respectively, 212; 1,650; 484; 1,858; 123; 495; and 2,239 (Department of Disease Control, 2013). The statistics indicate that the outbreak was most severe in the year 2013. The situation corresponds to a statement by Deputy Director of the Department of Disease Control. He stated that the World Health Organization (WHO) announced DHF to be one of the four major diseases that must be dealt with immediately (besides AIDS, malaria, and tuberculosis). One of the factors that led to the mass DHF outbreaks was climate variability.

This factor received widespread attention since it leads to environmental impacts that affect the living conditions of mankind. Climate variability affects the health of mankind by accelerating the life cycle of insects and the incubating period of diseases, speeding up the spread of those diseases (David et al., 1999, Mead and Earickson, 2000, Beck et al., 2000, Anderson, et al., 2003, Kiszewski and Teklehaimanot, 2004 and Tumwiine, 2007). Diseases carried by insects experience swift modification and spread due to climate fluctuations. Recurring diseases such as malaria and DHF are enhanced, while new diseases can also be developed by climate variability. Swift climate fluctuations increase the prevalence of diseases and negatively affect the health of mankind, influencing the illness rate, mortality rate, and injury rate. Stress levels also increase when individuals are forced to relocate due to severe climate conditions. Temperature influences human behavior and contact to diseases.

The main objective of this study is to identify the relationship of the variables associated with temperature fluctuations to the incubation period of DHF in the *Aedes* mosquito.

According to most of tropical diseases have outbreak in latitude zone. One of latitude zone is Africa. There are many studies related to climatic factors and mosquito life cycle in this zone. Some studies found that El Nino events correlate with changes in the incidence of epidemic diseases. El Nino event is associated with increased risk of some of the vector borne disease (Lindblade et al., 1999 and Lindsay et al., 1998). Moreover, some studies found that climate change effect to average rainfall, temperature, relative humidity and also effect to life cycle of mosquito (Craig et al., 1999, Lotfy, 2014 and Tay et al., 2012 and Charoenpanyanet, 2009 and 2013). For another zone, Sumana (2006) stated that *P. vivax* and *P. falciparum* malaria virus in India develop faster at higher temperatures. *P. vivax* develops at 25–30°C at a range of 8±2 days, whereas P. *falciparum* develops at 30–35°C at a range of 10±2 days. However, these studies did not applied remotely sensed data for analysis or estimation of mosquito life cycle. They derived the correlation and relationship between climatic factors and mosquito system. It could not estimate a spatial expansion of suitable mosquito ecology. For the result of this study that applied remotely sensed data to extract the direct factor of mosquito ecology, it is particularly helpful for assessing the location and extent of dengue virus incubation period in mosquito. And also diverse zones that suitable for tropical disease, especially dengue fever, could be used this method to estimate mosquito incubation period. Therefore, this study aims to use remotely sensed data to estimate temperature variability in 2013, 2023, 2033, and 2043 and estimate dengue virus incubation period in *Aedes* mosquito by using temperature factor in 2013, 2023, 2033, and 2043.

2. Materials and Methods

2.1 Study Area

Mueang Chiang Mai District, Chiang Mai province, is the study area of this study. It covers an area of around 180 sq km (Figure 1) and located between 18°42′N-18°52′N and 98°51′E-99°3′E. This area is chosen for the study as this area recorded the highest dengue case in Chiang Mai province in 2013.

2.2 Data to be Used

There are two types of data to be used in this study. They are as follows:

(1) Daily temperature data in 2004–2013 come from the Chiang Mai meteorological office. This data were collected by ground station in the study area. They were used to estimate incubation period of the dengue virus in *Aedes* mosquito by converting into weekly temperature data.

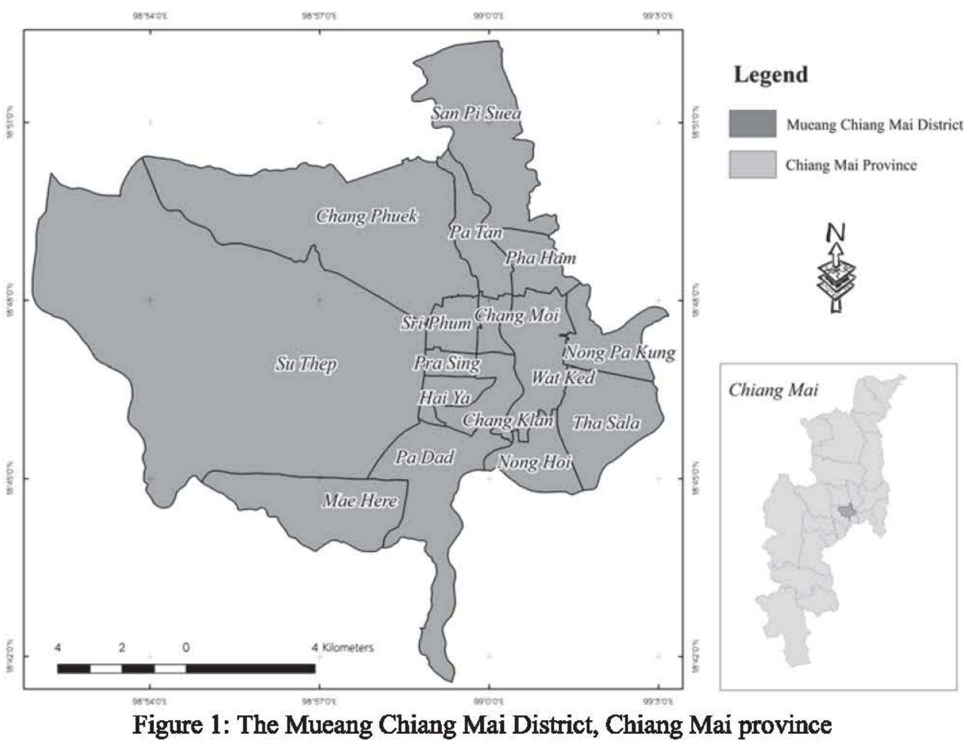

Figure 1: The Mueang Chiang Mai District, Chiang Mai province

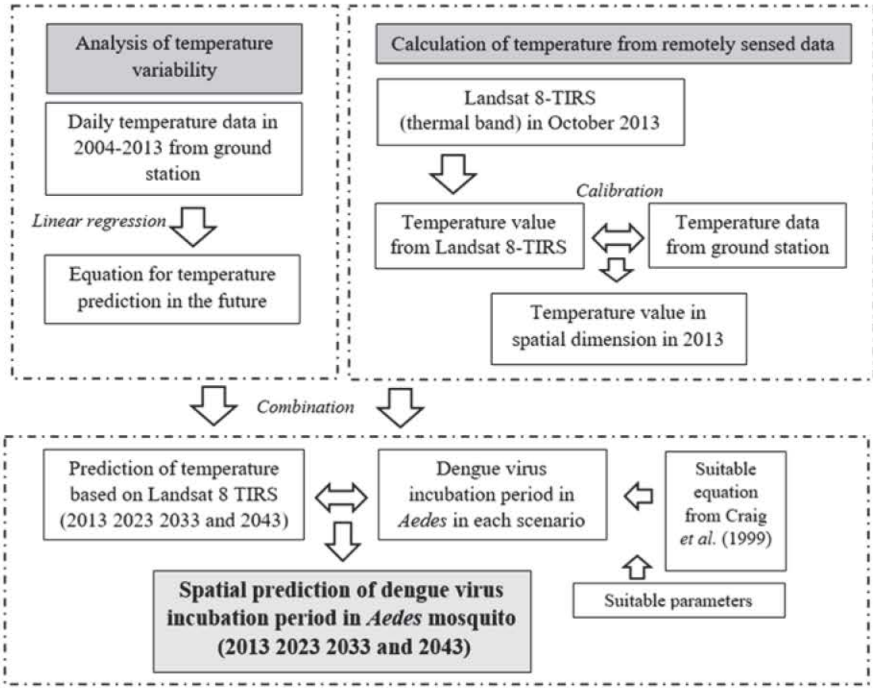

Figure 2: Frame work of the study

(2) Landsat 8-TIRS, the thermal band, was downloaded. The data were acquired in October 2013 as the representative of data. The data covering the study area were used to analyze and extract temperature variability in 2013 and estimate in 2023, 2033, and 2043. It is in Path: 130 and Row: 50. The spatial resolution is 100 meters.

2.3 Frame Work of the Study

The framework of this study consists of three main steps (Figure 2). The first step is the creation of the equation to estimate temperature variability in the future by using the statistical technique. This is followed by calculation and estimation of temperature from Landsat 8-TIRS in the thermal band. The last step is estimation of the spatial pattern of the dengue virus incubation period in the *Aedes* mosquito in the years 2013, 2023, 2033, and 2043.

2.4 Methods

The methods of this study consist of two main steps. They are; 1) estimation of temperature variability based on temperature data of 10 years (2004-2013) and remotely sensed data and 2) estimation of dengue virus incubation period in *Aedes* mosquito based on remotely sensed data.

2.4.1 Estimation of temperature variability: This step includes creation of equation to estimate temperature variability, calculation of temperature from remotely sensed data in 2013, and estimation of temperature in 2023, 2033, and 2043.

2.4.2 Creation of the equation to estimate temperature variability in the future. This step used daily temperature data of 10 years (3,654 days) from related organization. Daily temperature data were converted into weekly temperature data. Daily average temperature data every 7 days are calculated average value. This value is used as weekly temperature data to analyze by using linear regression. Correlation equation of temperature and week of the year were created (Figure 3 and Equation 1).

This technique is the basic types of regression to examine a set of predictor variables do a good job in estimating an outcome variable (Hastie et al., 2008). This equation could be used to estimate temperature variability in the future.

$$Y = 0.001\ (X) + 26.54$$

Equation 1

where Y = temperature (°C), X = week of the year (start in the 1st week in 2004).

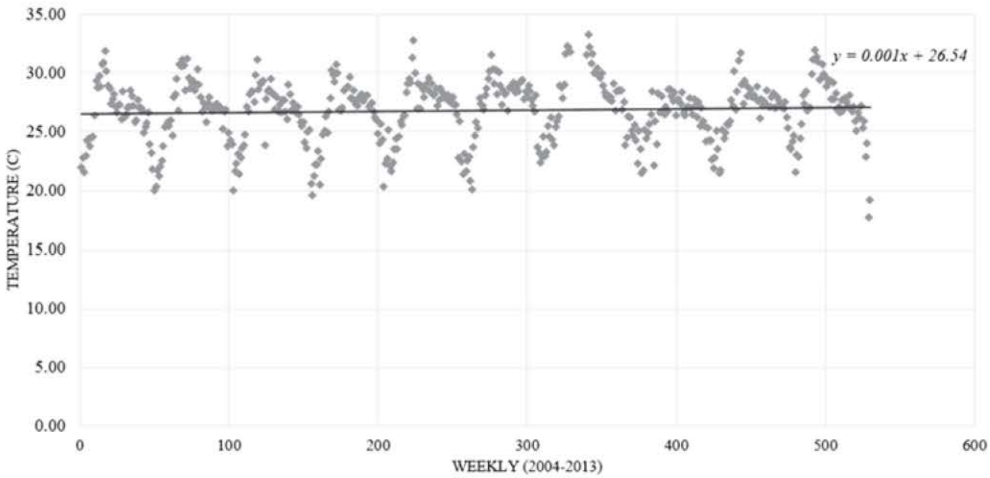

Figure 3: The scatter presents the weekly temperature in 2004–2013 and the trend line shows the temperature trend in the future.

2.4.3 Calculation of temperature from Landsat 8-TIRS in the thermal band (band 10). The temperature value from Landsat 8-TIRS in October 2013 was calculated by conversion of digital numbers to radiance and then conversion of radiance to brightness temperature. Calculation of the temperature value from Landsat 8-TIRS in 2013 was carried out by using the following steps:

1) Conversion of digital numbers to radiance (Equation 2):

$$L_\lambda = \frac{(LMAX_\lambda - LMIN_\lambda)}{65535} * DN + LMIN_\lambda$$

Equation 2

where L_λ = Spectral Radiance at sensor (W/ (m².sr. µm)), $LMIN_\lambda$ = Minimum spectral radiance (W/ (m².sr. µm)), $LMAX_\lambda$ = Maximum spectral radiance (W/ (m².sr. µm)), DN = Digital Number

2) Conversion of radiance to brightness temperature (Equation 3):

$$Tb = \frac{K_2}{\ln(\frac{K_1}{L_\lambda}+1)}$$

Equations 3

where Tb = brightness temperature (K), L_λ = TOA spectral radiance (Watts/(m2 * srad * µm)), K_1 = Band-specific thermal conversion constant, K_2 = Band-specific thermal conversion constant.

2.4.4 The temperature value from Landsat 8-TIRS in 2013 that was calculated brightness temperature (Tb) from previous step was calibrated with temperature data from ground station. This is for accuracy assessment for the major temperature variability in the year of 2013. Estimation of temperature from Landsat 8-TIRS in 2023, 2033, and 2043 was carried out by using the equation (1) and combination with the calculation result of the temperature value in 2013 from topic 2.4.3.

Calculation of the dengue virus incubation period in *Aedes* mosquito; this step includes calculation of the dengue virus incubation period in *Aedes* mosquito (days) by using equation from Craig et al., (1999) and estimation of dengue virus incubation period in *Aedes* mosquito by using Landsat 8-TIRS. Calculation of the dengue virus incubation period in *Aedes* mosquito from the suitable equation that was modified from Craig et al., (1999). Craig et al., (1999) studied the effect of temperature on the duration of the sporogonic cycle for malaria (Equation 4):

$$N = \frac{DD}{T - Tmin}$$

Equation 4

where N = incubation period of the dengue virus in *Aedes* mosquito (days), DD = cumulative temperature throughout the period of dengue fever development = 78, T = daily average temperature (Celsius), and Tmin = minimum temperature for dengue fever incubation (*Aedes* mosquito = 20°C).

From Equation (4), DD is defined as the mean temperature required for *Aedes* mosquito for incubation (26°C) multiplied by the maximum number of days required for the eggs to develop into larvae (3 days). The temperature at which parasite development occurs is obtained with reference from Lauren et al., (2013). This study reveals that:

"*mosquitoes infected with a low dose of dengue virus and maintained at 20°C, 24°C, 26°C, and 30°C indicated that the infection rate ranged from 25% to 75%, depending on the incubation period.*" In this study, therefore, 20°C was defined as the temperature at which parasite development occurs. Estimation of dengue virus incubation period in *Aedes* mosquito by using Landsat 8-TIRS with raster calculation was done. The results from topic 1.3 and 2.1 were used to estimate the dengue virus incubation period in *Aedes* mosquito in the years 2013, 2023, 2033, and 2043.

3. Results

The results of this study can be divided into two main issues, as followed by the steps of the study. The steps are as follows: (1) estimation and calculation of temperature variability and (2) spatial estimation of dengue virus incubation period in *Aedes* mosquito.

3.1 Estimation of Temperature Variability

Daily temperature data were converted to weekly temperature data and the line graph for displaying the temperature variability in 2004–2013 was created (Equation 1 and Figure 3). The graph from Figure 3 shows the temperature variability in the Mueang Chiang Mai district within 10 years. It shows the fluctuation in the mean temperature over 10 years. There is a sharp increase between the 1st and the 17th weeks of each year, of 32°C. Thereafter, the temperature is observed to have dropped to around 20°C. In the 50th week, or by the end of each year, the temperature is seen to rise. This means that natural fluctuation in the surface temperature has an impact on the seasonal pattern. Furthermore, the graph reveals the equation to estimate the trend of temperature in the future as the following equation. From the equation (4), it is evident that the temperature in 10 years' duration increases by 0.519°C, or increases 0.0519°C per year. The temperatures in 2004 and 2013 can be calculated with the equation, and are obtained as 26.532°C and 27.051°C, respectively. This equation could also be used to estimate the temperature in the future, as shown in Table 1. Temperature estimation from Equation 1 found that the yearly temperature in 2013, 2023, 2033, and 2043 increased steadily and continuously. The average yearly temperature in 30 years from the present, that is, during the period 2013-2043, might undergo an increase of 1.56°C. However, this equation is used for the estimation of average yearly temperature; it is not used for estimating yearly maximum and minimum temperatures. Moreover, this calculation is based on the week that starts with the first week of 2004; if the week on which the calculation is based is changed, the estimation results will also change.

As mentioned above, the one factor influencing *Aedes* mosquito growth is temperature. This topic, therefore, focuses on the calculation of temperature from remotely sensed data by using Equation 1 and Equation 2. This technique is very useful for deriving the temperature values of areas that do not appear in the temperature measurement jurisdiction at the ground station. Remotely sensed data could be used for deriving the temperature values in every pixel. For this study, Landsat 8-TIRS in the thermal band is chosen, which would help in deriving the temperature value every 30 meters. Temperature calculation results from the remotely sensed data were calibrated with temperature values from the ground station. This is for deriving the accurate temperature values. It is evidenced from the study that the average temperature value on October 11, 2013, at 4 p.m. in Mueang Chiang Mai district was 33.70°C. The temperature values were divided into four classes based on the suitable temperature for a lay egg of *Aedes* mosquito, which is 28.00–30.00°C. As for the other three classes, they were divided by using the statistical values of the data. They are as follows: (1) less than 21.03°C, (2) 21.03–27.99°C, (3) 28.00–30.00°C, and (4) more than 30.00°C (Figure 4).

From Figure 4, it is evident that the temperature value with the range of 28.00–30.00°C in 2013 is the largest area in Mueang Chiang Mai district. It covers about 21 % of the total area. It is noteworthy that this temperature range is the most suitable for the laying of egg of the *Aedes* mosquito. This area appears in orange color in the map, and it consists of the inner downtown of Mueang Chiang Mai district and the Chiang Mai international airport's runway. The region also includes the areas of Sri Phum district, Pra Sing district, and Hay Ya district, and expands to the peripheral area of Mueang Chiang Mai district.

Table 1: Estimation of yearly temperature, from equation (4)

Year	Temperature (°C)
2013	27.051
2023	27.570
2033	28.089
2043	28.608

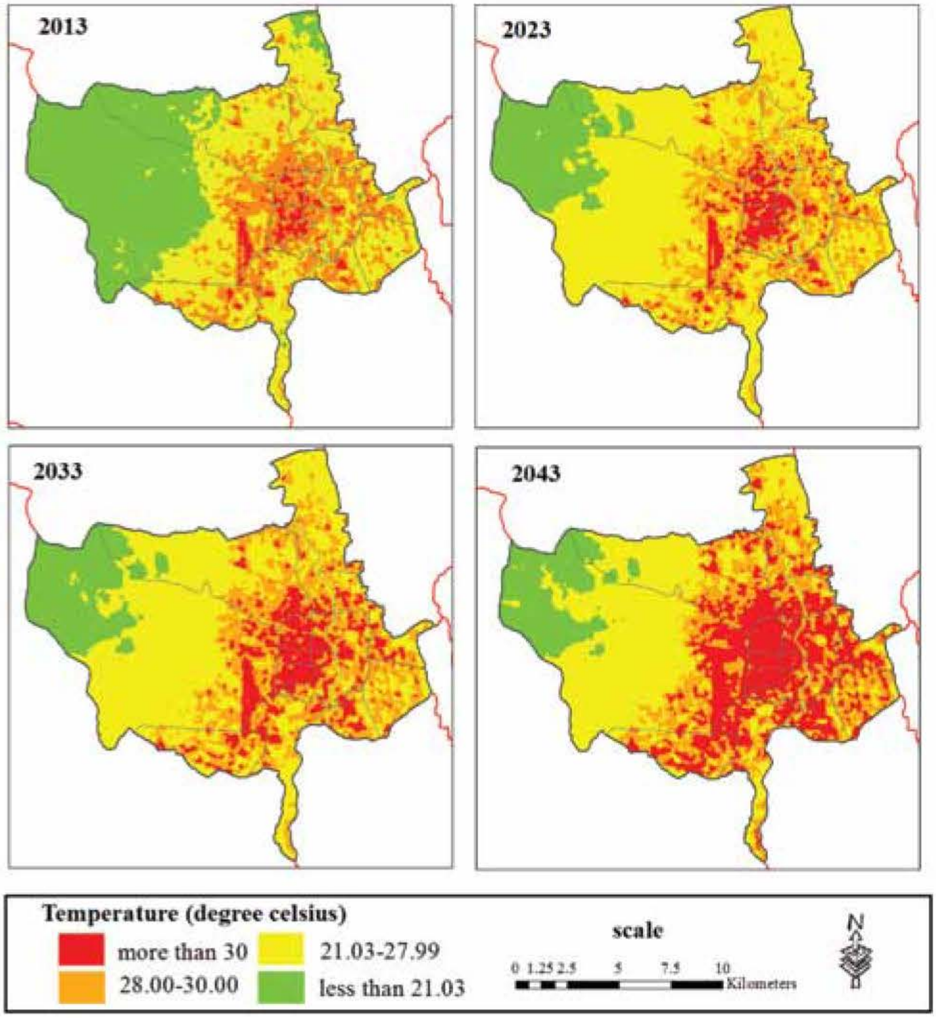

Figure 4: The comparison of temperature changes in the years 2013, 2023, 2033, and 2043

It should be noted, however, that temperature values in the ranges of more than 30.00°C and 21.03–27.99°C are also suitable for laying the eggs of *Aedes* mosquito. They appear in red and yellow colors, respectively. They cover the areas of Sun Pi Suea district, Chang Pueak district, Su Thep district, and Pa Dad district. Hence, the study area covers the biggest area with the temperature values suitable for laying the eggs of *Aedes* mosquito, 21.03–27.99°C, 28.00–30.00°C, and more than 30.00°C. They cover a total of 65% of the total area. At the same time, temperature values within the range of less than 21.02°C, presented in green color, expand to the forest zone toward the west of the study area. They are in Su Thep district, Chang Pueak district, and Sun Pi Suea district. All these relate to the concept of *Aedes* mosquito growth. *Aedes* mosquito cannot grow in areas of elevation more than 1000 meters above mean sea level. This area is in the west of Mueang Chiang Mai district. Another result of this study is the relationship between temperature value and land cover. The built-up area within urban area in the study area have the highest temperature values. On the other hand, agricultural areas have moderate-to-high temperature values and forest areas have low temperature values.

The estimation of temperature variability discussed in the previous section can be analyzed and a map created of the surface temperature for a period of the next 30 years. This period comprises decades ending in 2023, 2033, and 2043 (Figure 4). The map reveals that temperature values in the range of more than 30.00°C, which is represented by the red color, increases with priority in time. It expands from the inner downtown of the study area. As for temperature values within the range of 28.00–30.00°C, which is represented by the orange color, the area representing these temperatures is replaced with the area of temperature values in the range of more than 30.00°C, and it expands to the peripheral area of the Mueang Chiang Mai district. The area covers temperature values within the range of 21.03–27.99°C, which is represented by the yellow color, and expands into the forest area of the study area. This has an effect on the area with temperature values in the range of less than 21.02 in that the temperature decreases continuously.

3.2 Estimation of Dengue Virus Incubation Period in Aedes Mosquito

As previously mentioned, the incubation period of the dengue virus in *Aedes* mosquito has not been recorded. The topic, however, is important for studies since *Aedes* mosquito serves as a crucial part of the DHF cycle. Fluctuations in the virus' incubation period, especially in cases where the incubation period is reduced, will lead to accelerated growth of the mosquitoes which directly affects the outbreak of the virus. The incubation period can be classified into two categories depending on the host. Incubation in mosquitoes takes 8-10 days, whereas incubation in humans takes 3-14 days — most cases being 5-8 days. This research only studies the incubation period of the dengue virus in *Aedes* mosquito.

This analysis of the relationship between climate variability and dengue virus incubation period in *Aedes* mosquito incorporated the studies of Watts et al., (1987), which identified the ideal temperature for dengue virus incubation as 26°C, 30°C, 32°C, and 35°C. At these temperatures, the rates of infection and outbreak ranged from 67 % to 95 %, respectively. The researchers used these results as reference for forecasting the incubation period of the dengue virus, applying the studies of Craig et al., (1999) in the Equation 4. Climate variability during the years 2004-2013 and the forecast for increasing average annual temperature were used to develop a temperature figure for determining the expected incubation period of the dengue virus in *Aedes* mosquito, which is the total number of days of development from eggs to maturity. In general, *Aedes* mosquito takes approximately 2-3 days to emerge from eggs to larval form, 5-7 days from larva to develop into chrysalis, and 1-2 days for the chrysalis to develop into a mature mosquito. The entire process takes approximately 8-12 days. Ideal temperature and humidity conditions will accelerate this cycle of development. On the other hand, unsuitable environmental conditions will lengthen the development cycle, which can even take a total of 3 weeks. The incubation period of the dengue virus in *Aedes* mosquito was calculated based on the average monthly temperature as a standard (Table 2).

The table displays the calculation results of the average incubation period of the dengue virus in *Aedes* mosquito during the years 2004–2013, using the average monthly temperatures to substitute in the formula. The results indicate that the months of December–January are unsuitable for dengue virus incubation. The month of April, on the other hand, is the most ideal month for dengue virus incubation, taking approximately 6–11 days for development. This is followed by the months of May and June, respectively. Average temperatures and incubation periods of dengue virus in *Aedes* mosquito appears to be a decreasing trend in the incubation period. In the year 2004, the average incubation period was 12.44 days — a statistic which became just 11.06 days in the year 2013 (Table 3). Since the statistics displayed in the table are annual averages, there may be periods where the incubation period falls below the duration displayed due to temperatures reaching above the average level. An example is the period between May 1 and May 7, 2010, where the incubation period is as low as 5.40 days due to ideal conditions.

Table 2: Average Incubation Period (days) of Dengue Virus in Aedes mosquito during Years 2004–2013

	Jan.	Feb.	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
2004	32.5	22.3	9.8	7.6	10.1	11.6	12.6	11.8	13.4	14.2	18.6	78.0
2005	43.3	15.3	11.5	8.6	9.1	10.3	10.5	12.6	13.0	13.0	17.0	43.3
2006	65.0	16.6	10.1	9.3	12.0	10.3	12.2	13.0	11.6	13.4	19.5	41.1
2007	70.9	22.9	11.8	8.1	12.0	10.0	11.1	11.3	11.3	13.4	25.2	41.1
2008	33.9	17.3	10.0	7.9	10.5	9.8	10.0	10.7	11.1	11.6	18.6	48.8
2009	55.7	14.4	11.0	8.1	9.2	10.1	10.0	9.8	9.8	10.5	15.3	31.2
2010	19.0	17.3	10.0	6.7	6.8	8.0	9.1	11.0	17.3	11.3	16.3	22.3
2011	28.9	17.3	14.4	10.7	10.7	10.0	10.1	11.3	10.8	12.0	15.6	26.0
2012	25.2	15.3	10.4	8.3	9.1	9.5	10.3	10.1	10.3	10.5	11.1	18.6
2013	24.4	11.3	10.3	7.0	8.0	8.8	9.9	10.7	10.4	10.8	12.2	78.0

Table 3: Average Temperatures and Incubation Periods of Dengue Virus in *Aedes* mosquito

Year	Average Temperatures (°C)	Incubation Periods of Dengue Virus in *Aedes* mosquito (days)
2004	26.27	12.44
2005	26.83	11.42
2006	26.49	12.02
2007	26.28	12.42
2008	26.95	11.22
2009	27.24	10.77
2010	27.90	9.87
2011	26.03	12.94
2012	26.98	11.17
2013	27.05	11.06
2014	27.10	10.99
2015	27.16	10.89
2016	27.20	10.83
2017	27.26	10.74
2018	27.31	10.67
2019	27.36	10.60
2020	27.42	10.51
2021	27.47	10.44
2022	27.52	10.37
2023	27.57	10.30

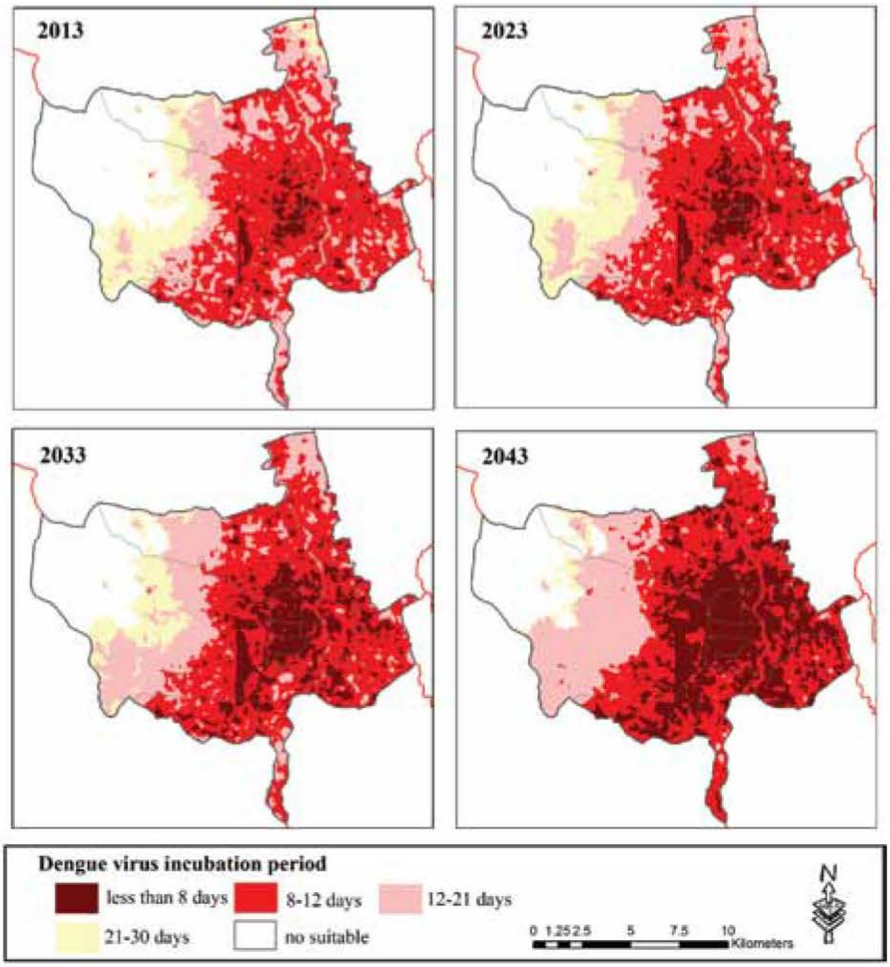

Figure 5: The dengue virus incubation period in the years 2013, 2023, 2033, and 2043

Moreover, the temperature of Mueang district in Chiang Mai during the year 2013 calculated by satellite photography was used as the basis to forecast the dengue virus incubation period (Figure 5). The incubation period of the dengue virus was divided into five categories: (1) Less than 8 days (very low incubation period), (2) 8-12 days (normal incubation period), (3) 12-21 days (incubation period at a certain range of temperature), (4) 21–30 days (incubation period during periods of unsuitable temperatures), and (5) unable to incubate. The forecast compares statistics of the years 2013, 2023, 2033, and 2043, where the temperature is expected to increase by 0.0519°C annually, with the objective of observing the decrease in the dengue fever incubation period.

The figure displays clear shifts in the dengue virus incubation period, especially for cases where the incubation period falls below 8 days (brown). In the year 2013, these cases are usually found within the city moat and other areas. After 10-year intervals (years 2023 and 2033), it is expected that the outbreak will increasingly spread to other areas. In the year 2043, cases of very low incubation period will be found in all plains of Chiang Mai. Areas with incubation period in the range of 6–12 days (red) will be replaced by incubation period of 8 days, which will continue spreading to replace areas with incubation period of 12–21 days. Areas with incubation period in the range of 12–21 days (pink) experience a decrease in the urban plains of Chiang Mai but undergo expansion in areas with an increase in elevation. The expansion is expected to take place in areas with an elevation of 120–400 meters to those with an elevation of 400–940 meters in 10-year intervals. Areas with an incubation period of 21–30 days (yellow), however, are expected to experience a continuous decline due to replacement by the 12–21 incubation period.

Areas where incubation is unsuitable (white) are found at elevations above 940 meters, where previous studies indicate that those regions are still free from DHF cases. Regional studies on dengue fever incubation periods will help prevent future outbreaks, especially in communities with stagnant water. Results of this analysis closely resemble areas of the previous outbreaks presented earlier in the research.

4. Conclusion and Discussion

Results of the study on the relationship between temperature variability and dengue fever incubation period indicate an increasing spread of cases with incubation period less than 5 days in the years 2013, 2023, 2033, and 2043. In the next 30 years, *Aedes* mosquito is expected to develop dengue virus in a short span, sharply increasing the number of mosquitoes. This study corresponded to the findings of David et al., (2001), an ecologist from Cornell University. David stated that global warming will create ideal conditions for dengue fever incubation, leading to greater infections of numerous diseases such as malaria, roseola, cholera, and food poisoning. A study by Janssen and Martens (1997) also indicated higher cases of malaria when the temperature increases by 0.5°C. This research also corresponded to the findings of a study by Benedict et al., (2006), which used average temperature and average precipitation level to estimate the number of people at risk of malaria infection. The study indicated that a temperature increase of 15°C will also increase the rate of malaria infection. Campbell and Diarmid (2007) found that climate variability led to an increase of precipitation by 20 % and an increase of malaria infection when the temperature increases by 1–3°C. Sumana et al., (2006) stated that *P. vivax* and *P. falciparum* malaria virus develop faster at higher temperatures. *P. vivax* develops at 25–30°C at a range of 8±2 days, whereas P. *falciparum* develops at 30–35°C at a range of 10±2 days. The result of this study could be used to apply in other area within tropical zone for surveillance of *Aedes* mosquito. This is the primary step to estimate where *Aedes* mosquitos prefer by using only temperature factor. It would be good if other factors, for example rainfall and relative humidity, should be included to estimate dengue virus incubation period.

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