Modeling *Anopheles* Mosquito Density Spatial and Seasonal Variations using Remotely Sensed Imagery and Statistical Methods

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Abstract

Remotely sensed data and statistical model are integrated to develop the model for predicting Anopheles mosquitoes, which is called "Anopheles Mosquito Density Predictive Model (AMDP model)". It is found that NDVI values that are higher than 0.501, temperature values with the range of 25-29ºC, relative humidity values with the range of 81-85%, and deciduous forest land cover are the best predictors of the Anopheles mosquito density classes in wet season, while NDVI values that are higher than 0.501, temperature values with the range of 25-29ºC, deciduous forest land cover, and elevation 400-700 meters interval are the best predictors for the Anopheles mosquito density classes in dry season. AMDP model was able to predict correctly 79.7% and 73.8% in wet and dry seasons. This model has passed the model calibration and validation procedures. The results indicate that the model could be applied for prediction of the Anopheles mosquito density in other areas, malaria cases and a tool for decision-making system for malaria control planning

1. Introduction

Malaria cases and its consequent deaths have been predominant unsolved public health issues in Thailand for decades, despite cases have fallen gradually since 1999. Malaria transmits through three possible mediums; malaria parasite, human hosts, and *Anopheles* mosquito. One possible way to solve the malaria problem is to have an intervention on any of these mediums. This study focuses on *Anopheles* mosquito medium, a part of the malaria transmission cycle. As the malaria control methods depend on many setting-specific factors such as endemic, vector species and behavior, seasonality, disease patterns, health service factors and more, which they have not been distributed equally in spatial, therefore the accuracy of these predicted information at timely manner are necessary requirements for effective malaria control planning and preparations. Thus, increasing of spatial accuracy and information updates on the vector density are the main issues for the malaria control. In order to support these requirements, remote sensing technology and process model are used to develop the model for predicting *Anopheles* mosquitoes.

The purpose of remotely sensed data in this study is not to detect the mosquitoes but to extract the direct and indirect factors of their ecology and behavior that are components of the rapid epidemiological tool for surveillance of malaria in particular. In addition, remotely sensed data can be used for determining factors affecting vector abundance, the landscape features, and climate factors associate with the risk of malaria. It is also particularly helpful for assessing the location and extent of an influencing factor on mosquito densities. They are vegetation status, temperature, relative humidity, land cover, elevation, and aspect, which are difficult to examine on the ground.

However, by using only remotely sensed data may not obtain enough accuracy for predicting the mosquito densities. This study, therefore uses some others techniques and methods to analyze and test the accuracy. Such as comparison between the parameter values from different methods that are inductive and deductive methods, GIS technique for mapping mosquito density and distribution, and statistical models for testing the overall accuracy of the models.

These techniques sound knowledge of the ecology of mosquito populations. Improved remote sensing would play a key role in the malaria areas for prioritizing of the control measures in a cost effective way. The techniques help to enhance the knowledge of many parameters affect to *Anopheles* mosquito densities, fundamental for mosquito population control program. Those parameters affects to mosquito density could lead the institutions or organization to modify the environment to be an unsuitable habitat of mosquito, or to reduce man mosquito contact in order to reduce the malaria transmission. In that case, development of a model is essential for predicting the environment areas suitably for malaria mosquitoes and the density of mosquitoes. Models have been used as a tool for the understanding of various aspects of vector population dynamics and disease transmission. In particular, the transmission of malaria has been studied extensively with mathematical models (Hay, 1997, Hay et al., 1998, Snow et al., 1998, Srivastava et al., 2001, Anderson et al., 2003 and Omumbo et al., 2005). However, fewer studies have examined to take the next step and to use remote sensing as input to predict both spatial and temporal dynamics of vector populations and disease transmission risk.

2. Study Area

The number of reported malaria cases in Thailand shows that there is a decreasing trend in occurrence during the past two decades, and that it is even disappearing from most of the major cities (Ministry of Public Health, 2003). However, people in rural areas, especially in villages along the Thai–Myanmar and Thai–Malaysia borders and forested mountain areas remain at a great risk (Somboon et al., 1998). In these endemic areas, malaria transmission has been considered to have a close association with the forests and the movement of human population (Ministry of Public Health, 2003). However, little is known about the spatial patterns and dynamics of malaria in Thailand.

This study was conducted in some areas of Sai Yok district in the western part of Kanchanaburi province, Thailand (latitude 14°15′ N and longitude 99°20′ E) (Figure 1).

3. Data and Data Processing

Mosquito Data: was obtained from Vector Borne Disease Control Center 4.1 Kanchanaburi. The data were collected from villages using human bait. The density of adult mosquitoes was collected in the malaria transmission area, with about 26 sites in 26 sub-villages (Table 1 and Figure 2). These sampling sites consisted of about 100% of sub-villages in the study area. The sampling was performed through outdoor biting and resting collections from sunset to sunrise. The collection was carried out both in the wet season (July–August) and in the dry season (January–February) in 2005. The average density of the *Anopheles* mosquito was estimated by averaging the number of female mosquito bites per collector per hour. The mosquito data were not obtained from the ground observation of researchers (due to limitations of budget) but from a local organization. Therefore, the distributions of the mosquito-collecting points were according to the village sites. As a result, they do not form an equal-area grid pattern. GPS was used to collect the coordinates of the mosquito-collecting points. Coordinates of the mosquito-collecting points were determined by field survey done by the researchers and local officers. Each mosquito-collecting point was based on fixed houses/sites that were defined by the local organization. The fixed houses were used as sample sites to collect the mosquitoes in the different periods.

Table 1: Anopheles mosquito densities in 2005

	Density (no. females bite/person/hour)/Class	
Sub-village	**Wet season**	**Dry season**
Samukkee Thum	2.43	0
Mu Supan	2.00	1.10
Pu Namron	1.00	4.00
Huai Kawlam	3.09	0
Thung Ma Soe Yo	9.43	0
Khao Yai	11.32	3.40
Ton Tal	13.00	16.12
Bong Ty Bon	35.00	16.00
Thai Mueang	45.29	12.00
Phu Toei	32.00	9.00
Pang Mai	35.00	3.67
Bong Ty Lang	42.12	13.44
Prado Thong	4.00	0
Huai Manow	6.00	0
Hin Kong	2.11	0
Lawa Cave	0.56	0
Hat Ngiu	5.66	1.43
Dong Pong	6.00	0
Pak Lum	0.67	0
Ton Mamuang	9.08	0
Rai Zak	6.78	1.00
Bong Ty Noi	19.45	1.54
Kho Kae	15.00	0
Chy Thung	9.59	1.32
Kaeng Pralom	3.33	0
Mae Nam Noi	8.62	0

Landsat 5 TM Data: covering the study area were used to analyze and extract the vegetation status, temperature, relative humidity, and land cover. Landsat 5 TM acquired on February 14, 2004; June 05, 2004; February 16, 2005; and August 27, 2005 were used as representative of the seasonal data. They are in Path: 130 and Row: 50.

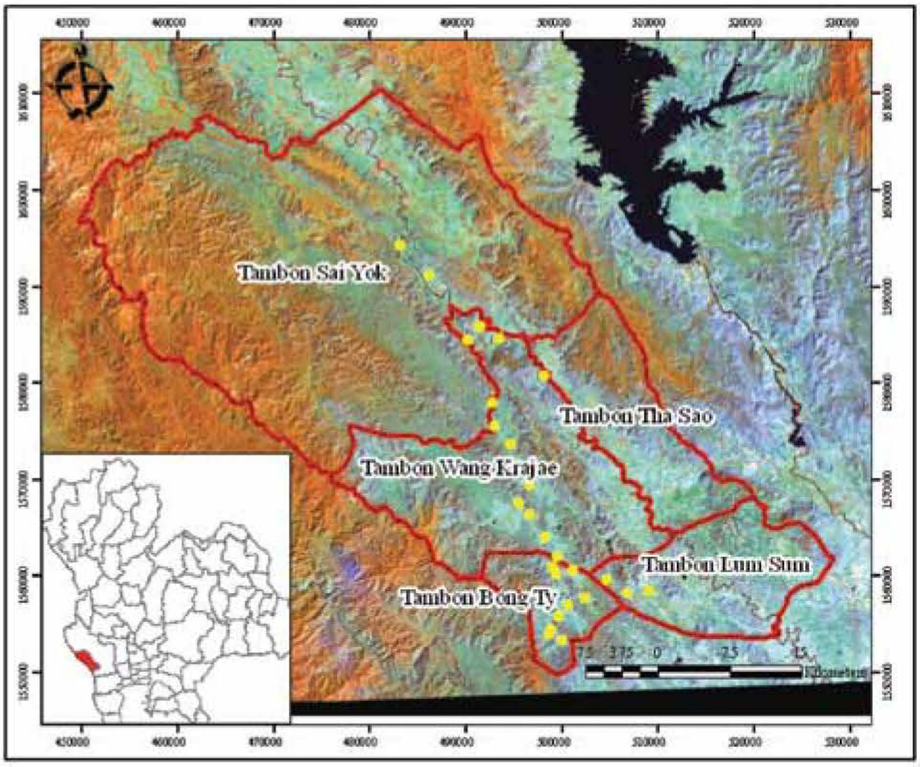


Figure 1: The false color composite of Landsat 5 TM: RGB=453 in the study area

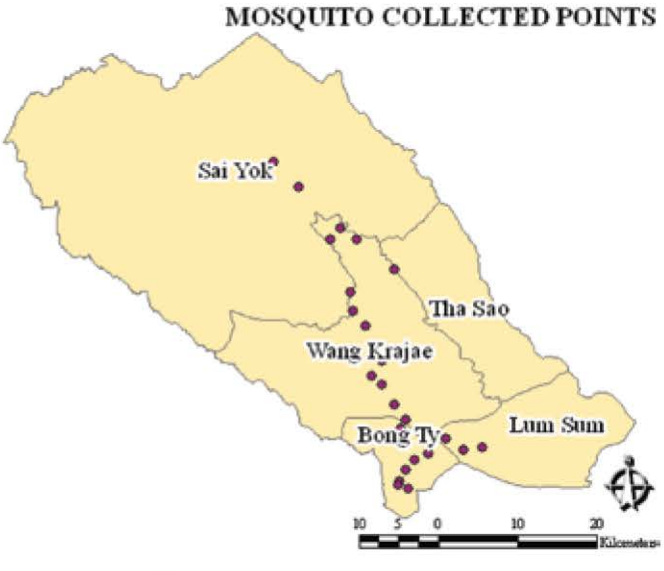


Figure 2: The total of 26 mosquito-collecting points

DEM of the study area was constructed based on a topographic map of 1:50,000 with a contour interval of 30 meters. The purpose of DEM construction is to extract topographic factors that are associated with mosquito population. The satellite imagery preprocessing procedures in this study consisted of geometric correction, atmospheric correction, and imagery sub-setting. The influence factors are extracted from remotely sensed data using different methods. They are as follows.

3.1 Normalized Different Vegetation Index (NDVI)
NDVI represents the quality and the activity level of the vegetation. Vegetation is usually seen in green. It is also an important factor that impacts the behavior of *Anopheles* mosquitoes.

Pre-processed imageries were used to calculate the vegetation status through NDVI in band 3 and band 4.

3.2 Temperature

Mosquito distribution could be limited by temperature, and tropical vectors could be expected to move further into cooler areas. Thermal band, which was converted from DN to radiance, was entered into Land Surface Temperature (LST) extraction. This procedure includes the following steps: converting from spectral radiance to effective at satellite temperature, Land Surface Emissivity (LSE) calculation, and LST calculation (Craig et al., 1990 and Sobrino et al., 2004).

3.3 Relative humidity

The measurement of space-borne remote sensing of relative humidity in this study is based on an assumed relationship between the ground-measured relative humidity and the reflectance values (Vasconcelos and Nova, 2003). Band 5 and band 7 of Landsat 5 TM, shortwave infrared and middle infrared, were selected to be used in the extraction of the reflectance values.

3.4 Land cover

Mosquito densities vary in different land cover types. Land cover may be important for explaining and understanding malaria mosquito ecology (Wood et al., 1992a, 1992b and 1992c, Rodriguez et al., 1996 and Malone et al., 2003). The supervised classification method was used to classify the land cover types. This was done by defining regions of interest (ROIs) that represent each of the land cover types.

3.5 Elevation

Temperature is also directly related to elevation, which affects mosquito survivorship. Numbers of mosquitoes are very low at a higher elevation during the cooler winter months and because of thermal constraints on development of the parasite in the mosquito vector.

3.6 Aspect

Aspect of land surface is the terrain orientation, and it ranges from 0 degrees to 360 degrees. It is thus related to solar exposure, which may affect mosquito population survivorship. DEM was utilized to extract the aspect in the study area. Also, aspect values do not vary in a season. However, this study did not use slope as one of the influencing factors because aspect is the compass direction that a slope faces.

4. Methods for Model Development

4.1 Finding Correlation between Anopheles Mosquito Densities and its Influencing Factors using Pearson's Correlation Coefficient

Each influence factor created buffer zones to determine the correlation between *Anopheles* mosquito densities and the factors. Mosquito-collecting points were used as the center of the buffer zones. Even though each species of the *Anopheles* mosquito has different behavior and different flight range, this study considered the average flight range of all the species of the *Anopheles* mosquito. Based on the average flight range of the *Anopheles* mosquito, a buffer of 2000 meters was defined for analysis in this study (Thomas and Lindsay, 2000). However, a buffer of 1000 meters was defined to compare the different correlations between the influencing factors and the mosquito densities. Both wet and dry seasons are also defined for analysis. The mean annual temperature of the wet and the dry seasons in the study area are in the ranges of 20–35°C and 24–33°C, respectively, and the amount of rainfall per month of the wet and the dry seasons are 14.4 mm and 95.3 mm, respectively. Pearson's correlation coefficient (r) was used to find the significant correlation between the *Anopheles* mosquito densities and the different influencing factors. Pearson's correlation coefficient can determine the extent to which values of two variables are proportional to each other. *Anopheles* mosquito density classes were defined as dependent variables instead of the actual number of mosquitoes which can be classified into interval variables. The influencing factors were defined as independent variables.

4.2 Model Development

Development of the model focuses on generality, reality, and precision. Based on the overall goal of the study, the model development framework was designed as shown in Figure 3.

4.3 Statistical Model Formulation

Based on the results of the relationship between the *Anopheles* mosquito density and its influencing factors, two statistical models, discriminant analysis and multiple regression analysis, were applied to develop the model.

4.4 Model Calibration

Calibration is the process of modifying the input parameters of the model until the output from the model matches an observed dataset. Calibration can be tested using the goodness-of-fit statistic. The goodness-of-fit statistic examines the difference between the observed *Anopheles* mosquito densities and the expected *Anopheles* mosquito densities.

4.5 Model Prediction

The complete AMDP model that was derived from the model calibration procedure would be used to test the probable density of the *Anopheles* mosquito both in the study area and in the study areas.

4.6 Model Validation

Model validation refers to the processes and techniques that the model represents in a reality-based system, or the proposed reality-based system, to a sufficient level of accuracy. One goal of the validation process is to gain the credibility. A comparison of the possible density of the *Anopheles* mosquito with the data obtained by observation was carried out.

5. Results

5.1 Correlation between Anopheles Mosquito Densities and Its Influencing Factors

The results obtained of the correlation between the *Anopheles* mosquito density and the various influencing factors using Pearson's correlation coefficient indicate that five factors are to be analyzed in the next steps. They are vegetation status, temperature, relative humidity, land cover, and elevation (Table 2 and Figure 4).

Table 2: Pearson's Correlation Coefficient regarding *Anopheles* Mosquito Densities and Factors within Buffer of 1000 Meters

		Wet season		Dry season	
Factor	**Category**	**Pearson correlation**	***Sig.* (2-tailed)**	**Pearson correlation**	***Sig.* (2-tailed)**
NDVI	>0.501	.953**	.000	.720**	.000
	0.01-0.200	-.859**	.000	-.629**	.001
Temperature	25-29 °C	.944**	.000	.615**	.001
	15-24 °C	-.831**	.000	-.539**	.004
Relative humidity	>85%	-.840**	.000	-.763**	.000
	81-85%	.889**	.000	.477*	.014
	75-80%	-.866**	.000	-.450*	.021
Land cover	Wetland and standing water	.953**	.000	.776**	.000
	Deciduous forest	-.767**	.000	-.759**	.000
	Grass land	-.840**	.000	-.763**	.000
	Built-up land	-.792**	.000	-.594**	.001
Elevation	400-700 m.	-.862**	.000	-.549**	.004
	<400 m.	.907**	.000	.612**	.001
Aspect	North, Northeast	.885	.345	.021	.672
	East, Southeast	-.234	.543	-.323	.453
	West, Northwest	.632	.693	.793	.264
	South, Southwest	.246	.211	.385	.134

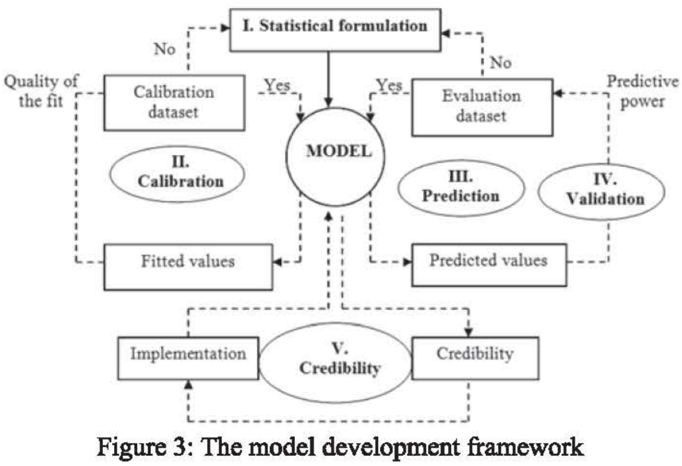


Figure 3: The model development framework

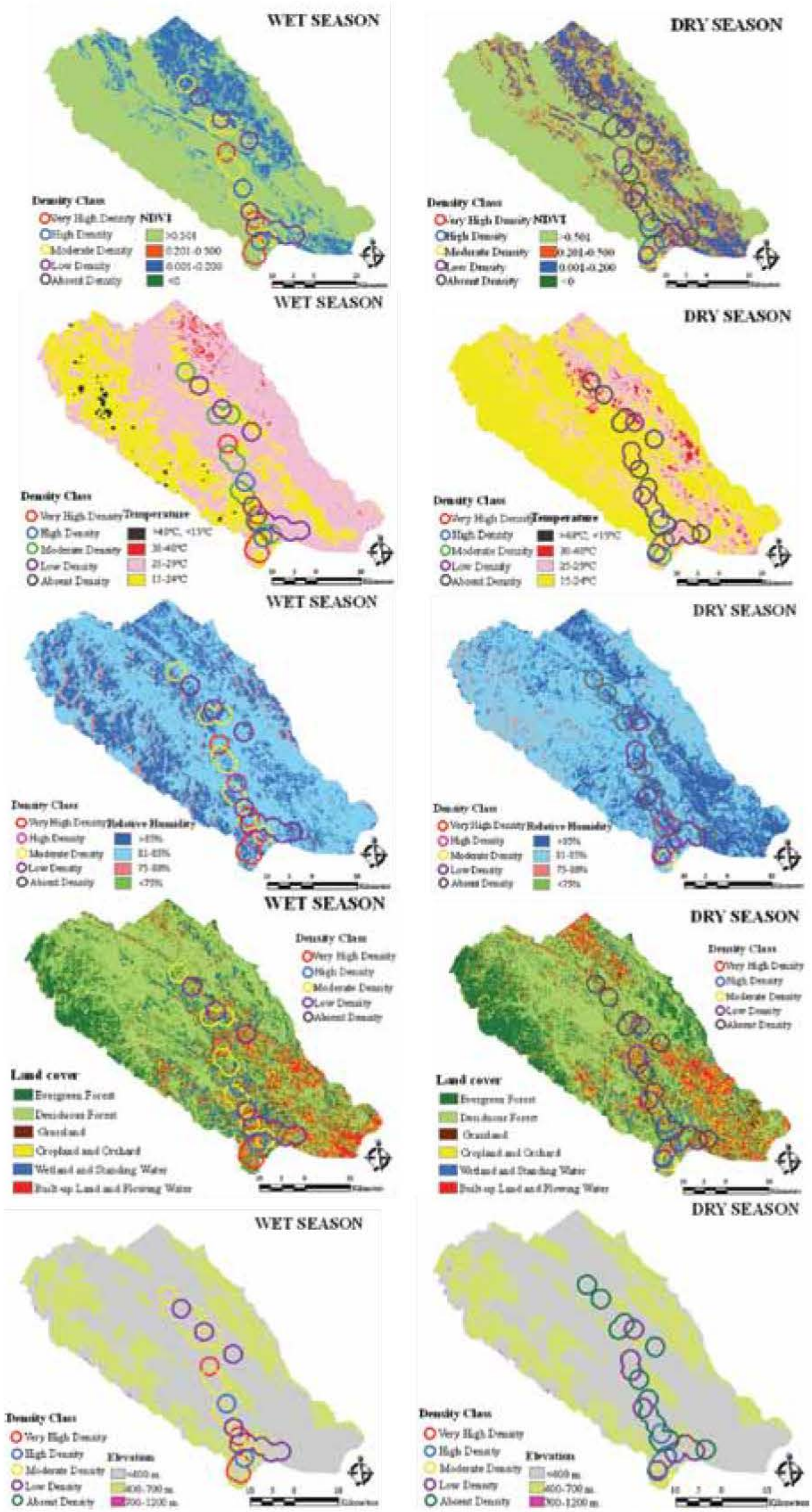


Figure 4: Association between the influencing factors and the *Anopheles* mosquito density within a buffer of 1000 meters for different seasons

The aspect correlating with *Anopheles* mosquito densities is dropped because it is not a significant correlation between the density classes of the *Anopheles* mosquito in all categories. Moreover, the result can be assumed that distances more than 1000 meters from the mosquito-collecting points become less significant as a correlation between the *Anopheles* mosquito density and its influencing factors. The association between the influencing factors and *Anopheles* mosquito densities within a buffer of 1000 meters for the different seasons, as illustrated in Figure 4, can be explained. NDVI values higher than 0.501 show the strongest positive correlation with *Anopheles* mosquito density in both wet and dry seasons. In addition, temperature values within the range of 25–29°C have the strongest positive correlation with *Anopheles* mosquito density in both wet and dry seasons. Likewise, wetland and standing water have the strongest positive correlation with *Anopheles* mosquito density in both wet and dry seasons. Elevation values lower than the 400 meter range interval show the strongest positive correlation with *Anopheles* mosquito density in both wet and dry seasons.

Conversely, relative humidity values within the range of 81–85% have the strongest positive correlation with *Anopheles* mosquito density in the wet season. In contrast, relative humidity values higher than 85% have the strongest negative correlation with *Anopheles* mosquito density in the dry season.

5.2 Modeling Anopheles Mosquito Density Prediction

5.2.1 Model formulation

Based on the results of the relationship between *Anopheles* mosquito density and the factors that influence it, as discussed in the previous step, a buffer of 1000 meters was assigned to test the statistical models. Remotely sensed data were selected as imagery sample for testing the statistical model. Sixteen variables were the input parameters for developing the model.

Two statistical models, discriminant analysis and multiple regression analysis, were applied to develop the model. Sixteen independent variables were formed into three factors (Table 3). Factor1, 2, and 3, there are six, five, and two independent variables are highly correlated, respectively. Factor1, Factor2, and Factor3 are assumed as new independent variables and are entered into the model development procedure. The factor scores of the variables are presented as the rotated component matrix.

The results from the testing of the two statistical models reveal that Factor1 and Factor2 are the best predictors of *Anopheles* mosquito density. In addition, discriminant analysis is selected to develop the model for predicting *Anopheles* mosquito density.

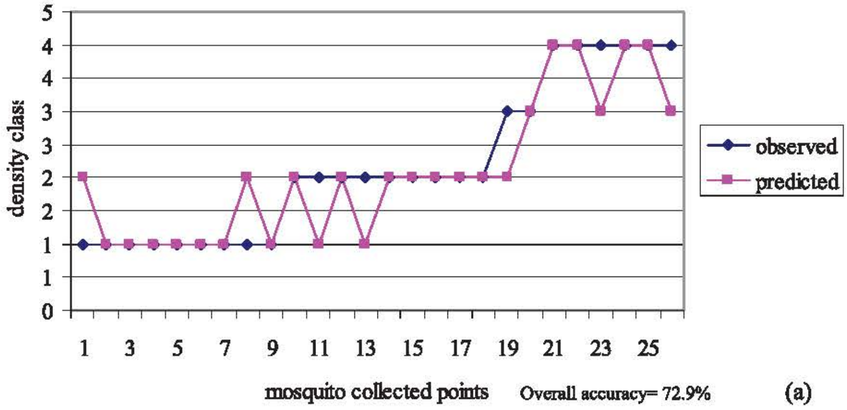
Table 3: Rotated component matrix

Variable	Component		
	Factor1	Factor2	Factor3
X1: NDVI values > 0.501	.935		
X3: Temperature values 25-29°C	-.931		
X4: Temperature values 15-24°C	.919		
X7: Relative humidity values 81-85%	-.913	-.250	
X9: Deciduous forest	.906	.242	
X12: Elevation 400-700 m. interval	-.876	-.332	
X2: NDVI values 0.001-0.200		-.864	-.414
X5: Relative humidity values >85%		.803	
X7: Relative humidity values 75-80%		.796	.238
X8: Wetland and stagnant water		.788	.220
X10: Grassland	.517	.707	.252
X11: Built-up land and flowing water	-.307	-.452	-.602
X13: Elevation <400m.			.954

5.2.2 Model calibration

The discriminant analysis model was utilized to predict the *Anopheles* mosquito density classes for wet and dry seasons. This study was adjusted by removing the factor from the model. The predicted density classes were compared with the observed density classes. The results reveal that after removing Factor2 from the model, the overall accuracy of the model increased. The overall accuracy values in the wet and the dry seasons are 72.9% and 68.2%, respectively (Figure 5). The next steps are, therefore, tests to remove some variables inside Factor1 for retrieval of the highest overall accuracy of the model. The final result after the removal of the variables is as demonstrated in Table 4. Table 4 demonstrates that no variable has been dropped from the model in either of the seasons. The results from this section conclude that the independent variables in the wet season model are NDVI values higher than 0.501, temperature values within the range of 25–29°C, relative humidity values within the range of 81–85%, and deciduous forest land cover, with 79.7% overall accuracy of the model. In comparison, the independent variables in the dry season model are NDVI values higher than 0.501, temperature values within the range of 25–29°C, deciduous forest land cover, and elevation within the 400–700 meter interval, with 73.8% overall accuracy of the model. The model is developed based on a set of observations for which the classes are known, as are the independent variables of these classes. The models derived from the previous section (Table 4) were examined and tested for accuracy. The variables were extracted from remotely sensed data and the area within a buffer of 1000 meters entered into the model for discriminant analysis. Once the classification scores for the case are computed, it is easy to classify the case. The classification functions were used to predict the mosquito density class.

The results of the density classes for the wet season model are that it was able to identify correctly 85.5% of the very high, 74.2% of the high, 78.9% of the moderate, and 80.5% of the low densities. The results of the density classes for the dry season model are that it was able to identify correctly 67.3% of the high, 77.4% of the moderate, 67.3% of the low, and 75% of the absent densities. Additionally, the *Anopheles* mosquito density predictive model (AMDP model) can be expressed from two tables above.



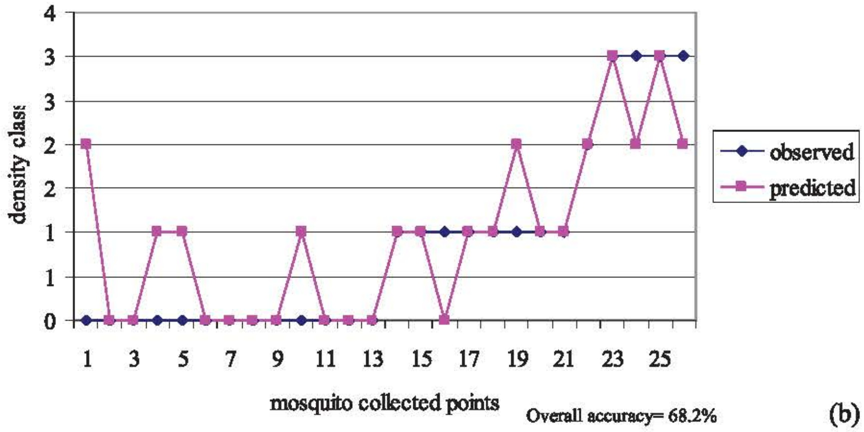


Figure 5: Comparison of observed and predicted *Anopheles* mosquito densities in wet (a) and dry (b) seasons

Table 4: Comparison of old and new overall accuracy levels after removal of variables third time

Removed variable	Overall accuracy (%)	
	Wet season (79.7%)	Dry season (73.8%)
NDVI value higher than 0.501	78.8	70.2
Temperature =25-29°C	77.2	71.5
Temperature =15-24 °C	Removed	removed
Relative humidity =81-85%	79.0	removed
Deciduous forest	78.1	71.6
Elevation 400-700 meters interval	removed	72.7

Wet season:

Very high = -4111.781 + (1204.325*X1) + (858.387*X2) + (763.105*X3) + (149.921*X4) Equation 1
High = -3591.773 + (1076.713*X1) + (841.501*X2) + (694.869*X3) + (252.761*X4) Equation 2
Moderate = -3033.363 + (1010.136*X1) + (761.168*X2) + (641.553*X3) + (197.207*X4) Equation 3
Low = -1923.962 + (794.067*X1) + (689.073*X2) + (372.014*X3) + (249.997*X4) Equation 4

Where: X1 = NDVI values higher than 0.501, X2 = temperature values within the range of 25-29°C, X3 = relative humidity within the range of 81-85%, and X4 = deciduous forest land

Dry season:

High = -2215.559 + (732.191*X1) + (846.035*X2) + (176.092*X3) + (1046.644*X4) Equation 5
Moderate = -2187.320 + (631.863*X1) + (847.034*X2) + (211.247*X3) + (967.025*X4) Equation 6
Low = -1164.562 + (629.670*X1) + (758.325*X2) + (190.924*X3) + (179.569*X4) Equation 7
Absent = -2130.345 + (325.525*X1) + (647.993*X2) + (101.449*X3) + (756.024*X4) Equation 8

Where: X1 = NDVI values higher than 0.501, X2 = temperature values within the range of 25-29°C, X3 = deciduous forest land, and X4 = elevation within 400-700 meter interval.

In the wet season model, NDVI values being higher than 0.501 (*r*=.953, *sig*.=.000) was found to have the strongest correlation with *Anopheles* mosquito density, followed by temperature values being within the range of 25–29°C (*r*=.944, *sig*.=.000), relative humidity being within the range of 81–85% (*r*=.889, *sig*.=.000), and deciduous forest land cover (*r*=–.767, *sig*.=.000), in that order. In comparison, in the dry season model, deciduous forest land cover (*r*=–.759, *sig*.=.000) was found to have the strongest correlation with *Anopheles* mosquito density, followed by NDVI values being higher than 0.501 (*r*=.720, *sig*.=.000), temperature values being within the range of 25–29°C (*r*=.615, *sig*.=.001), and elevation being within 400–700 meter interval (*r*=–.549, *sig*.=.004), in that order.

As far as probable density from this study is concerned, very high *Anopheles* mosquito density means the density is in the range of 18.01–45.29 number of female bites/person/hour, followed by high, moderate, low, and absent in the ranges of 11.01–18, 4.01–11, 4.01–11, and 0 number of female bites/person/hour, respectively. These results mean that very high *Anopheles* mosquito density areas are the risk areas for malaria transmission as they can produce a vector that is one of the components of malaria cycle.

5.2.3 Model prediction

The discriminant analysis model resulting from the analysis was entered into the map calculator module of Spatial Analysis and used to create the probable maps of the *Anopheles* mosquito densities (Figure 6). As the wet season AMDP model does not have the absent density class and the dry season AMDP model does not have the very high-density class, the area in these probable maps do not appear to have the absent and the very high probable densities in the wet and the dry seasons. The probable density of the *Anopheles* mosquito in the wet season indicates that the very high probable density (51.94% of total area) appears to exist in the largest area, followed by the high (18.92% of total area), the moderate (16.24% of total area), and the low probable densities (12.90% of total area), in that order. In comparison, the probable density value of the *Anopheles* mosquito in the dry season indicates that low probable density (56.79% of total area) appears to exist in the largest area, followed by the moderate (31.35% of total area), the absent (10.47% of total area), and the high probable densities (1.39% of total area), in that order (Table 5). For wet and dry seasons, temperature values within the range of 25–29°C is the risk climate characteristic affected high mosquito density.

Table 5: Probability of *anopheles* mosquito density in study area

	Wet season		Dry season	
Probable density	**Area (sq km)**	**% of total area**	**Area (sq km)**	**% of total area**
Very high	1153.86	51.94	0.00	0.00
High	420.41	18.92	30.61	1.39
Moderate	360.73	16.24	696.59	31.35
Low	286.63	12.90	1261.75	56.79
Absent	0.00	0.00	232.68	10.47
Total	2221.63	100.00	2221.63	100.00

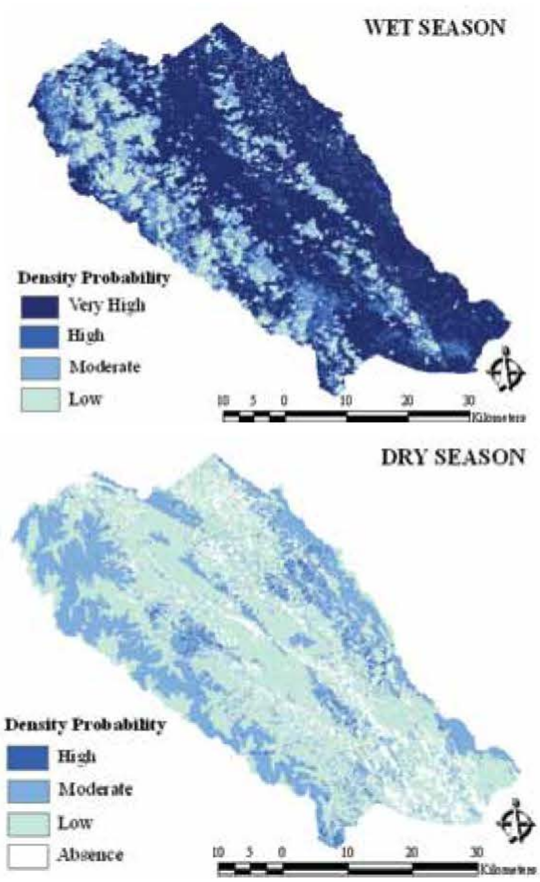


Figure 6: The probable density of the *Anopheles* mosquito in different seasons

5.2.4 Model validation

Comparison of predicted *Anopheles* mosquito densities (Figure 6) with the densities obtained was done by observation in order to validate the model. The sub-village sites were overlaid with the probable maps of *Anopheles* mosquito densities for different seasons. The model predicted the high density in all the observed sites in the wet season correctly, while none of the density classes in all observed sites were predicted correctly by the model in the dry season. There were five and seven sub-villages, respectively, in the wet and the dry seasons, which the model incorrectly predicted. The results of the tests of accuracy between them are as displayed in Figure 7.

Figure 7 demonstrates that $R^2 = 0.8548$ and $R^2 = 0.7746$, respectively, in the wet and the dry seasons. According to these models, the predicted *Anopheles* mosquito densities correlate more closely with the observed *Anopheles* mosquito densities in the wet season models than in the dry season models. Note that R^2 is not a goodness-of-fit test but, rather, an attempt to measure the strength of association.

5.2.5 Vector control measure

The mosquito densities that were found in this study could be combined with the basic technical elements of Global Malaria Control Strategy (GMCS) of WHO for vector control. Local organizations in the study area, Vector Borne Disease Control Center 4.1 Kanchanaburi, carried out organized vector control with a view to implementing selective vector control as defined in the GMCS and the national malaria program (Table 6).

Officials of the local organizations were interviewed on the criteria for a decision-making system to plan the vector control measures to be adopted in the study area. The result indicates that the actual implementation plans of the local organization have been designed on sub-villages in which malaria is endemic in order to have in place a selective implementation plan and sustainable vector control aimed at disease prevention. Selectivity in vector control requires appropriate decisions taken on what control methods to use, and when and where to use them to maximize cost-effectiveness. Identification of situations in which vector control is not required is also important. The selection takes into cnsideration the magnitude of the malaria problem, epidemiology, and the levels of transmission and risks encountered by priority groups or areas requiring protection.

The relationship levels of the different sub-villages are shown in Table 7. There are three levels of relationship. They are "positive relationship," "more negative relationship," and "most negative relationship."

A "positive relationship" means that the actual implementation plans correlate with the *Anopheles* mosquito density. In comparison, the "more negative relationship" and the "most negative relationship" mean that the actual implementation plans do not correlate with the type of *Anopheles* mosquito density. In such cases, the actual implementation plans are the difference between two classes in the more negative relationship and the difference between three classes in the most negative relationship. For example, there are "very high" implementation plans in the wet season of the Mu Supan sub-village, but there is "low" actual mosquito density class as in this case, there are three different classes.

Table 6: Comparison of national and local vector control measures in study area

Action	National vector control measure	Local vector control measure
Indoor Residual Spraying (IRS)		
- Regular spray	✓	✓
- Special spray	✓	-
- Focal spray	✓	-
Insecticide-Treated Nets (ITNs)	✓	✓
Fogging	✓	-
Biological	✓	-
Environmental management	✓	-
Larviciding	✓	-
Man mosquito contact reduction		
- Mosquito repellent	✓	✓
- Mosquito nets	✓	✓
- Health education	✓	✓
- Public Relation (PR)	✓	✓

Table 7: Relationship between actual implementation plans and *anopheles* mosquito density

Sub-village	Wet season		Dry season	
	Actual density	Probable density	Actual density	Probable density
Samukkee Thum	+	+	+	+
Mu Supan	-/-	-/-	-	-
Pu Namron	+	+	+	+
Huai Kawlam	-/-	-/-	-/-	-/-
Thung Ma Soe Yo	-	-	-/-	-/-
Khao Yai	-	+	-	-
Ton Tal	+	+	+	+
Bong Ty Bon	+	+	+	+
Thai Mueang	+	+	+	+
Phu Toei	+	+	+	-
Pang Mai	+	+	-	-
Bong Ty Lang	+	+	+	+
Prado Thong	-/-	-	-/-	-/-
Huai Manow	-	-	-/-	-
Hin Kong	-/-	-/-	-/-	-/-
Lawa Cave	+	+	+	+
Hat Ngiu	+	+	+	+
Dong Pong	+	+	+	+
Pak Lum	+	+	+	+
Ton Mamuang	+	+	+	+
Rai Zak	+	+	+	+
Bong Ty Noi	+	+	+	-
Kho Kae	+	+	-	+
Chy Thung	+	+	+	+
Kaeng Pralom	+	+	+	+
Mae Nam Noi	+	+	+	+

As mentioned above, there are two issues to be compared in this section. They are as follows: (1) the actual implementation plans and the actual densities of *Anopheles* mosquito and (2) the actual implementation plans and the probable densities of *Anopheles* mosquito. First, the comparison between the actual implementation plans and the actual densities of *Anopheles* mosquito found that there is negative relationship between the implementation plans and the actual densities of nine sub-villages, in which there is strong vector control measure but the low actual density of the *Anopheles* mosquito. According to these results, there are three sub-villages in which there is a very high negative relationship; they are Haui Kawlam, Hin Kong, and Prado Thong. There are three sub-villages in which there is high negative relationship; they are Mu Supan, Thung Ma Soe Yo, and Huai Manow. There is one sub-village in which there is a moderate negative relationship, and that is Khao Yai. There are two sub-villages where there is the low negative relationship; they are Pang Mai and Kho Kae.

Another issue is that there is negative relationship between the implementation plans and the probable densities of ten sub-villages, in which there is strong vector control measure but low probable density of the *Anopheles* mosquito. This reveals that there are two sub-villages where there is very high negative relationship; they are Haui Kawlam and Hin Kong. There are three sub-villages in which there is high negative relationship; they are Mu Supan, Thung Ma Soe Yo, and Prado Thong. There is one sub-village in which there is moderate negative relationship, and that is Huai Manow. There are four sub-villages in which there is low negative relationship; they are Pang Mai, Khao Yai, Phu Toei, and Bong Ty Noi.

6. Conclusions and Outlook

The predictive model of *Anopheles* mosquito density now represents an important tool in the discipline. These approaches combine occurrence data with environmental factors (both biotic and abiotic factors) to develop a model. The development of the AMDP model was based on five procedures. They are a statistical model formulation, model calibration, model prediction, model validation, and model credibility. As revealed by the results from the previous sections, 16 factors were defined as the input parameters for the selection of the statistical model. The average flight range of mosquitoes and a buffer of 1000 meters were used as the sample zones around the collecting points to test and develop the model for the different seasons. However, factor analysis was selected to solve the multicollinearity problem.

The result of factor analysis indicates that 16 parameters were grouped into three factors. Two of them were found to be the best predictors to develop the model. Discriminant analysis was conducted to find out the best statistical model for fitting the AMDP model.

The procedure of model calibration was carried out using factor adjustment and removal of variables. For the final model, the variables entered in the discriminant analysis gave about 79.7% and 73.8% accuracy levels of the factors as regards mosquito density. Therefore, these factors were sufficient to develop the AMDP model. In the wet season, the AMDP model appeared to vary, depending on whether the NDVI values were higher than 0.501, the temperature values were within the range of 25–29°C, the relative humidity values were within the range of 81–85%, and there was deciduous forest land cover. As for the dry season, the AMDP model appeared to vary, depending on whether the NDVI values were higher than 0.501, the temperature values were within the range of 25–29°C, there was deciduous forest land cover, and the elevation levels were in the 400–700 meter interval.

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