ORIGINAL ARTICLE

Modelling malaria incidence in the upper part of southern Thailand

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ABSTRACT

Malaria is a major concern for public health in tropical countries. This disease is related to demographic and geographic factors. The objective of this study was to describe the incidence of malaria among Thai nationals in seven provinces in the upper part of southern Thailand and explore their patterns using statistical modelling. The secondary data were from a malaria online program from 2013 to 2016, which comprised 4,244 new cases of malaria in Thai nationals. Poisson regression and negative binomial regression were used for the analysis. The descriptive results showed that malaria cases clearly peaked during May and June. More than half (61.73%) of the occupations that developed malaria were rubber agriculturalists. *Plasmodium falciparum* was the predominant species in the upper part of southern Thailand at 60.13%. The control measure taken after a malaria outbreak was spraying in 61.97% of the infected areas and in 59.87% of the residential areas of patients. The regression model showed that the factors related to the malaria incidence were the district, sex-age category and year, which clearly illustrated trends and spatial variations. The patterns of malaria incidence rates were separated into three groups. Twenty-two districts were estimated to be high-risk areas of malaria infection. Areas of malaria infection were mostly in the border districts near Myanmar and in areas where land use had changed and deforestation had occurred near the mountain chains. The incidence of malaria was highest in males aged 15–44 years. The trend of malaria incidence in the upper part of southern Thailand tended to decrease from 2013 to 2016. This was possibly due to strong policy control measures, strengthened migrant labour laws, and environmental and behavioural changes. Results of this study can be used for planning, prevention, and control of malaria in the upper part of southern Thailand.

Keywords: malaria; incidence; modelling; Thailand

INTRODUCTION

Malaria is a health problem in tropical countries caused by *Plasmodium* parasites. The disease is transmitted among humans by the female *Anopheles* mosquito. The world malaria report in 2015 showed that the number of new cases and deaths from malaria infection were 212 million and 429,900, respectively[1]. The mortality rate of malaria was the highest in the African region (92%), followed by the Southeast Asian region (6%). In the Southeast Asian region, 1.4 billion people are at high risk of malaria, with 1.5 million confirmed cases and 620 deaths[1]. The disease affected public health and its social and economic burden on the quality of life[2,3].

Malaria in Thailand was found to have high incidence rates in the border provinces near Myanmar, Cambodia, Laos and in the rural forest areas. The upper part of southern Thailand has seven provinces. Chumphon and Ranong provinces share their borders with Myanmar and have both natural routes and official points of entry for migrants entering Thailand. Krabi, Nakhon Si Thammarat, Phang Nga and Surat Thani provinces have rural forest areas. These factors affect the incidence rate of malaria. The dominant malaria species were identified as *Plasmodium falciparum* (50%) and *Plasmodium vivax* (50%)[4].

The transmission of malaria is related to geographic and demographic factors. Occupation, locality of residence, and travel to the risk areas (such as a forest or at the cross-border areas) are the risk factors for malaria infection[5–8]. Moreover, demographic factors such as gender and age are significantly related to malaria[5,9–11]. Males were reported to be significantly more likely to develop malaria than females or older people[5].

This study aimed to describe the incidence of malaria among Thai nationals in seven provinces in the upper part of southern Thailand and explore their patterns using statistical modelling. These results can be used for planning, prevention and control of malaria in the upper part of southern Thailand.

METHODS

Study area

The study sites were in the upper part of southern Thailand, which included seven provinces: Chumphon, Nakhon Si Thammarat, Krabi, Phangnga, Phuket, Ranong and Surat Thani. The size of this area is 41,565.31 km^2 with a population of 4,405,448. Chumphon and Ranong are located near Myanmar, where there are both official border crossing points and natural routes to enter the upper part of southern Thailand. Krabi, Nakhon Si Thammarat, Phang Nga and Surat Thani have several rural forest areas near the mountain chains.

Study design and data sources

This cross-sectional study was performed using the secondary data of new cases of malaria in Thai nationals in seven provinces in the upper part of southern Thailand that were available from a malaria online programme. Confirmed malaria cases were determined by the Vector-Borne Diseases Control Units. The data from 2013 to 2016 were entered into the programme. The reported malaria cases in this study were comprised of 64 districts out of the 74 districts in the upper part of southern Thailand. A total number of 4,244 cases were explored in this study. The outbreak investigation data used to describe the incidence of malaria were year, age, sex, occupation, risk area, infected place, dominant species, mosquito net use, travel and protection measures. Demographics (age and gender), geographics (64 districts), and periods of times (years 2013–2016) were used to explain the relationships with the incidence of malaria. The sexes and ages of the malaria patients were grouped into six sex–age categories: either male or female and age groups 1–14, 15–44, and ≥45 years old. Population data from 2013 to 2016 were derived from the Ministry of Interior. The demographic characteristics were previously published elsewhere[12]. This study performed modelling using the incidence of malaria in upper southern Thailand.

Statistical analysis

Poisson and negative binomial distribution arise naturally as random counts with population-at-risk denominators. The Poisson distribution is defined as the number of events that might occur in a cell (such as a region of space or a period of time). Poisson regression is a model in which the outcomes in cells have an independent Poisson distribution with means given by the formula

$$\lambda = P \times \exp(a + b1 \times x1 + b2 \times x2 + b3 \times x3) \quad (1)$$

where λ is the mean of malaria cases, P is a constant multiplier, such as the population at risk, and x1, x2 and x3 represent the district, sex-age groups and year, respectively. This model can be re-expressed as,

$$\log \lambda\ (\lambda ijt/Pijt) = \mu + \alpha i + \beta j + \gamma t. \quad (2)$$

When the data are overdispersed in the Poisson regression model, the negative binomial regression model can be used. The formulation of the generalised linear model with negative binomial counts is the same as that for the Poisson regression.

Sum contrasts were used instead of conventional contrasts where the first level is left out from the model to be the reference[13-15]. This method provides coefficients in all covariate levels in the model that allows us to compute the estimate and the 95% confidence interval to compare them with the overall mean.

All data analyses used R software including graphical displays[16,17].

RESULTS

Table 1 shows the total number of 4,244 cases of malaria in the upper part of southern Thailand from 2013 to 2016. There were 66.56% males and 33.44% females, and more than half (56.59%) of the cases were in the age group of 15–44 years. Rubber agriculturalist was the most common occupation at 61.73%. Periodic transmission area (A2) showed the highest percentage of malaria. Most of the malaria cases (93.92%) became infected in a village setting, while outside the cottage and forest infections occurred in 3.79% and 1.65% respectively. The dominant species of malaria were *P. falciparum* (60.13%) and *P. vivax* (38.15%). The remaining species, which included mixed-species and *P. malariae*, were very rare. The gametocyte stages were found in 9.6% of the malaria cases. The measures that patients used for protection against mosquito bites were mosquito net (78.49%) and mosquito repellent (84.33%). The percentage of patients who had a history of travel to other places within 14 days before becoming ill was 6.80%. After malaria was reported, the control measures focused on reducing the mosquito-borne disease by chemical spraying in 61.97% of the infected areas and in 59.87% of the residential areas of the patients. Moreover, blood testing was performed in 73.54% of patients to look for new patients in the areas of risk.

Table 1. Distribution of malaria cases in 7 provinces of upper southern Thailand (2013–2016) (4,244 cases)[12].

Characteristics	Total	(%)
Sex		
Male	2,825	66.56
Female	1,419	33.44
Age group (year) (*n* = 4,241)		
0–4	93	2.19
5–14	501	11.81
15–24	724	17.07
25–44	1,676	39.52
>45	1,247	29.40
Occupation		
Rubber agriculturalist	2,620	61.73
Student	755	17.79
Orchard farmer	230	5.42
Others	639	15.06
Risk area		
A1 (Perennial transmission)	685	16.14
A2 (Periodic transmission)	2,886	68.00
B1 (High-risk non-transmission area)	497	11.71
B2 (Low-risk non-transmission area)	176	4.15
Infection place		
Village	3,986	93.92
Cottage	161	3.79
Forest	70	1.65
Unknown	27	0.64
Dominant species		
P. falciparum	2,552	60.13
P. vivax	1,619	38.15
P. falciparum and *P. vivax*	33	0.78
P. malariae	40	0.94
Protective measures against malaria		
Sleeping under a net	3,331	78.49
Mosquito repellent	3,579	84.33
History of travel to other places	288	6.80
Control measures		
Infected area spraying	2,630	61.97
Residential area spraying	2,541	59.87
Blood testing (2 km)	3,121	73.54

Seasonal variations of malaria occurred in the early rainy season in the upper southern part. From 2013 to 2016, the number of malaria cases clearly peaked in May and June and tended to decrease from July to December (Figure 1).

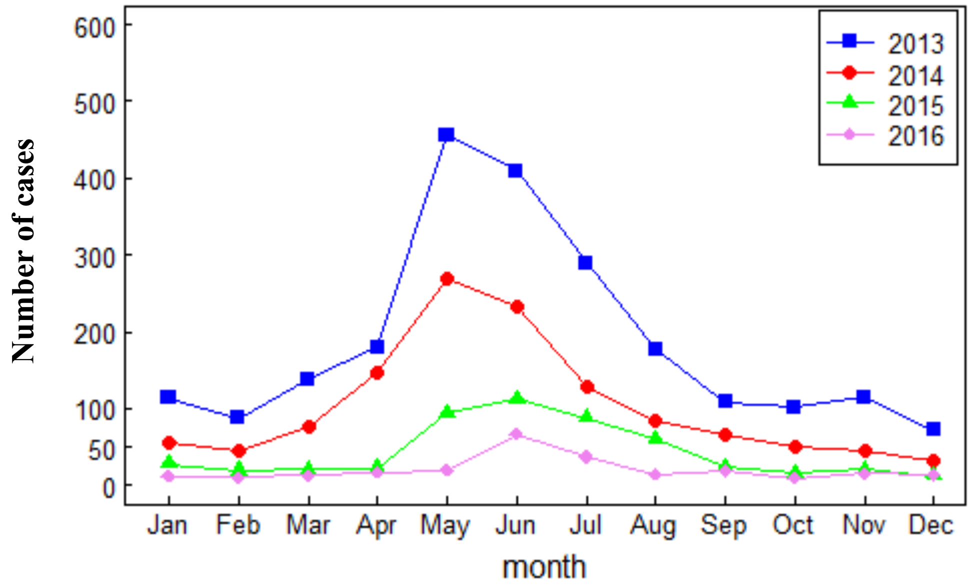

Figure 1. Malaria in the upper part of southern Thailand (2013–2016) by month.

The incidence of malaria was the highest in Ranong Province, followed by Surat Thani, Chumphon and Phang Nga. The lowest incidence was in Phuket Province (Figure 2).

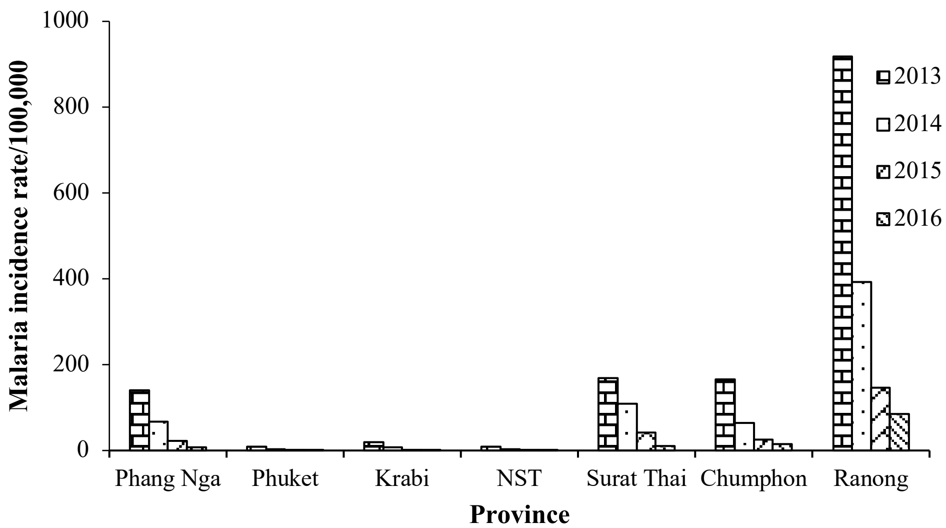

Figure 2. Incidence rates of malaria in the upper part of southern Thailand (2013–2016).

The Poisson regression model, which included variables of district, sex–age and years is shown in the left panel of Figure 3. A normal quantiles plot for deviance residuals showed that the model did not quite fit because the residuals did not perfectly follow a straight line. This indicated that the Poisson model did not fit the data. Furthermore, the ratio of deviance to *df* was greater than 1, which indicated overdispersion. This implied that the observed data involved excessive zero counts. Thus, the negative binomial model was used. Normal quantiles plots for deviance residuals from the negative binomial are shown in the right panel of Figure 3. It provides a reasonably good fit that is better than the Poisson regression model. So, the negative binomial model was appropriate for the data.

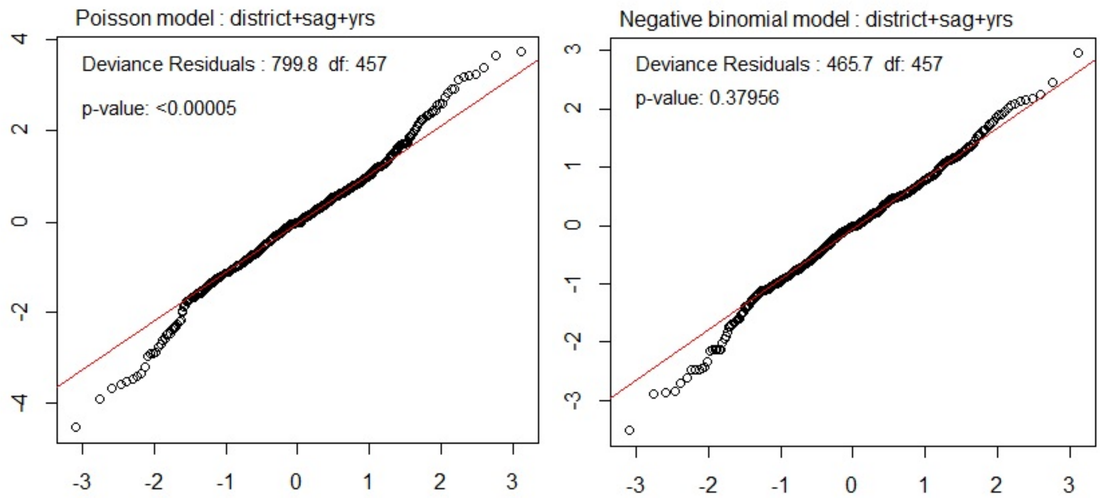

Figure 3. Residuals plot of malaria cases in the upper part of southern Thailand (2013–2016).

Geographical variations of the district effects are shown as a thematic map in Figure 4. The district coefficients from the negative binomial model were classified into three levels: above average (red); average (yellow); and below-average (green). The areas that had no malaria cases during 2013–2016 are shown in white. Thus, the thematic map was classified into four levels. The red districts implied that the malaria cases were proportionally the highest among all cases. It shows that 22 districts were above average, 30 districts on average and 12 districts were below average. Ten districts had no malaria cases in this study.

The 22 districts that were above average included 11 districts in Surat Thani Province (Thachana, Chaiya, Wipawadee, Kirirat Nikom, Bann Naderm, Chaiburi, Prasang, Wiang Sa, Kanchanadit, Donsak and Koh Pha-Ngan), 3 districts in Ranong Province (Kraburi, La-Oun and Muang), 3 districts in Phang-Nga Province (Kuraburi, Takuapa and Muang), 2 districts in Chumphon Province (Tha-Sae and Patiew), 2 districts in Nakhon Si Thammarat Province (Sichon and Phipoon) and 1 district in Krabi Province (Ao-Luek).

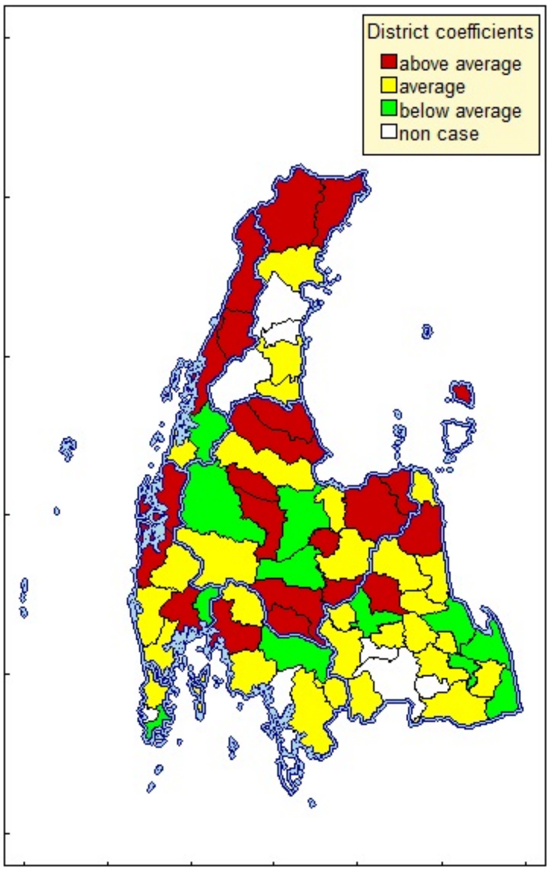

Figure 4. Thematic map of district coefficients in the upper part of southern Thailand.

Figure 5 shows the crude malaria incidence rate by year in the left panel and by sex–age in the right panel with bar charts and the adjusted values with 95% confidence intervals as black lines. The average lines by the year and sex–age are shown with red lines. The values derived from the crude incidence rates and adjusted rates from the model were different, which indicated variations among the groups that corresponded to confounding. The values above the average line reflect the groups that were more likely to have a greater risk of malaria infection.

The left panel of Figure 5 shows that the 95% confidence interval of the year 2013 is marginally higher than the mean, whereas in the years 2015 and 2016, the means were marginally lower. The right panel of Figure 5 shows that the incidence rate in the male age group 0–14 years was marginally lower than the mean. The crude incidence rates were similar with the adjusted rates, which indicated no confounding, whereas confounding occurred in the female groups, especially in the group over 45 years old.

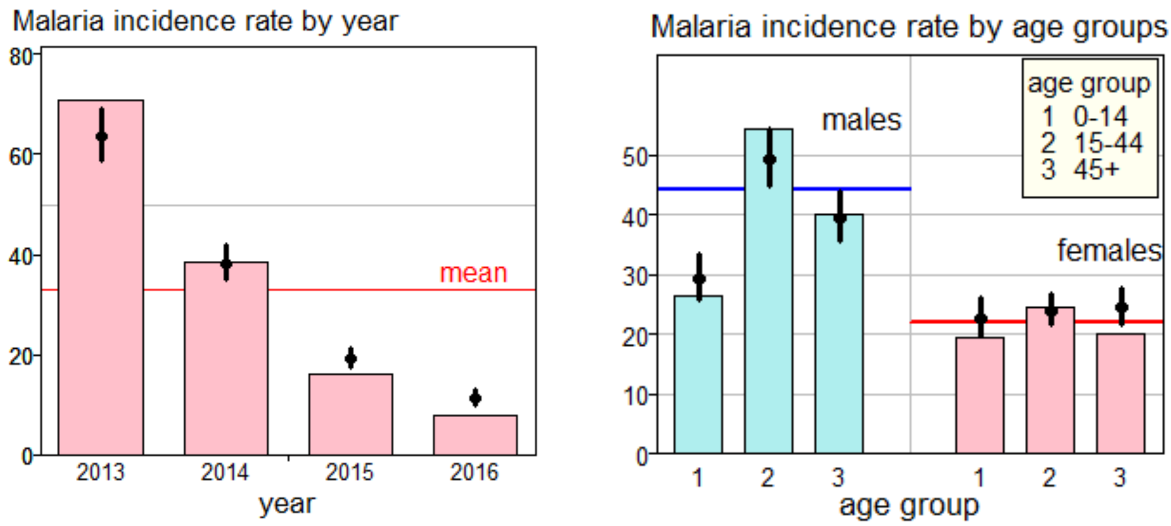

Figure 5. Malaria incidence rates by years and sex-age groups.

DISCUSSION

Compared with the other age groups, males in the age group 15–44 years had the highest incidence rate of malaria which was in accordance with the results of Messina et al.[5] and Cotter et al.[10]. The occupation was an important factor related to malaria infection, especially the rubber tappers who work and stay overnight in a rubber plantation; they can be associated with a malaria infection[18].

The malaria cases were mostly in the early rainy season. This result conformed to the Midekisa et al.[19] study that reported that the malaria incidence rate increased in this season. The early rainy season increases the temperature and humidity, which affects the life cycle of the mosquito vectors. These reasons confirmed a study by Jawara et al.[20], which found that the number of *Anopheles* spp. increased in the early rainy season. However, these results were different compared with Park et al.[21] and Touré et al.[22], who found the malaria incidence rate peaked in the rainy season.

Spatial distribution is an important factor for a malaria outbreak. Studies by Sriwichai et al.[8] and Hanandita and Tammpubo[23] found that populations that lived in a dense forest or border crossings or resided in a village were at a high risk of malaria infection. Most of these areas are perennial transmission (A1) areas and periodic transmission (A2) areas.

The predominant species of malaria varied by location, population status, season and mosquito vectors[8,24]. The results of this study were different compared with the report by Sriwichai et al.[8], who studied the Thai–Myanmar border of northwestern Thailand. They found that the presence of *P. vivax* was greater than *P. falciparum*. The *P. vivax* cases were less significant in the migrant population, while the *P. falciparum* cases were significantly associated with the migrant population and the season of agricultural activity.

Several methods were used for protection against the mosquito bites, such as sleeping under a mosquito net and using a mosquito repellent. Owning a mosquito bed net was important in preventing a malaria infection[25], especially the insecticide-treated nets which are most effective for protection from mosquito bites[25,26]. However, a study by Nonaka et al.[27] found that the sharing of a mosquito net by five people had more malaria infections than two people who share a mosquito net. In addition, mosquito repellent can reduce outdoor biting from malaria vectors[6]. A mosquito repellent must be used by outdoor farmers who work during the night.

For the control of malaria parasite transmission, the policy of the Ministry of Public Health recommends spraying the areas of infection, spraying the indoor areas of a residence, and blood testing to look for new cases. Approximately 40% of the malaria patients were in areas that had little spraying and little residential indoor spraying. Since the patients were absent from home during the spraying, permission to spray was not available. The populations who live in areas of risk need to learn the possible causes of malaria and the modes of transmission, which are important for the prevention and control of the malaria disease[28].

The thematic map of 71 districts of the upper southern is a large area, which is a limitation of this study. The higher rates of malaria cases were mostly in the border provinces near Myanmar. This finding was similar to the results from Bhumiratana et al.[29] (2013) who studied cross-border migration and the migrant population, which is a significantly important reservoir for malaria transmission. Moreover, land-use changes and deforestation have increased the abundance of mosquitoes and vector species dynamics[30,31]. For these reasons, above-average rates of malaria cases have occurred in some districts. Adult males in the age group 15–44 years who worked during the night at agriculture sites had a high risk of malaria infection; this result was similar to a study by Hariana et al.[18].

However, during the study period, the overall incidence rate of malaria illustrated a downward trend from 2013 to 2016. This may be due to the national malaria control and the elimination policies of Thailand, which have significantly reduced the incidence and mortality rates during the past five decades[32]. Furthermore, the labour migration law in Thailand was strengthened. Migrants who work in the agricultural or industrial system in Thailand must be registered under the migrant labour system, have a medical examination, and obtain health insurance. This policy has reduced the number of illegal foreign workers in the upper part of southern Thailand. Moreover, some of the areas in this study have changed from rural agriculture to suburban.

CONCLUSION

This study presents the rates of incidence of malaria and describes the effects of demographic and geographic factors on the incidence of malaria in seven provinces in the upper part of southern Thailand. The incidence of malaria varied with the season. Also, the occupation of rubber agriculturalists was a high risk of contracting a malaria infection. The negative binomial model showed that the district, sex–age, and time period (year) were related to the incidence of malaria. Twenty-two districts in six provinces were at high risk of malaria. Males in the age group 15–44 years were also at high risk. However, over time, the incidence of malaria has tended to gradually decrease. The results of this study can be useful for the planning and preparation of preventive measures to reduce the incidence of malaria infection.

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