Spatial Analysis and Modelling of Malaria Trend in Si Sa Ket Province, Thailand

Noradee, S.,[1,2] Uthaipibull, C.,[3] Kanjaras, P.[1,2] and Nithikathkul, C.[1,2*]
[1]Ph.D in Health Science Program, Faculty of Medicine, Mahasarakham University, Mahasarakham, Thailand
E-mail: nithikethkul2016@gmail.com*
[2]Tropical Health Innovation Research Unit, Faculty of Medicine, Mahasarakham University, Thailand
[3]Thailand Center of Excellence for Life Sciences (Public Organization), Thailand
Corresponding Author

DOI: https://doi.org/10.52939/ijg.v19i6.2695

Abstract

Malaria is a public health problem in tropical regions. The Regional Health office has a program to educate residents about what malaria disease is, how to reduce malaria infection and who have no immunity or little to malaria, such as young children and pregnant women or even who have knowledge about malaria. The overall Si Sa Ket malaria prevalence was still high in the Khun Han district, with P. vivax at 74.0 % and P. falciparum at 24.5%. Most of them were agricultural and aged around 16 – 45 years. A factor related to severe malaria in Si Sa Ket province was that infection in males was 2.49x more than in females (95% Confidence interval (CI) = 1.11-2.45), Military personnel were 2.93x more likely to be infected than in other occupations (95%CI = 1.45 - 6.57) and mixed of Plasmodium species infection about 3.34x more than other Plasmodium species (95%CI= 0.31 - 0.73). The outcome of this study can be applied to the malaria surveillance system cooperatively achieved by the Vector-borne Disease Control Project with the Ministry of Public Health of Thailand when comparing infection rates reported in similar studies. In addition, the results of this study indicate overall that the efforts of the Department of Health are going well. The low rate of sick individuals shows that the residents received enough information to get an infection of malaria. This report intends to provide beneficial information to the inhabitants and locals of Si Sa Ket Province Health Department to improve other malaria-prevention programs.

Keywords: Geographic Information System, *Plasmodium* spp., Severe Malaria, Vector Index

1. Introduction

In the global environment of both local and global change scenarios, the physical phenomena and health informatics issues are changing from personal to global. Health records about tropical disease outbreaks and non-communicable diseases among all the national and international health organisations still require new technology approaches to create prevention and control care and integrate multidiscipline networks [1] [2] [3] [4] [5] [6] [7] [8] and [9]. Malaria remains a dangerous disease that affects human health. As well known, malaria was born by *Anopheles mosquitoes that* are infected by *Plasmodium* parasitic protozoa (*P*). Only five *Plasmodium* protozoa are infected in humans, *Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium malariae*, *Plasmodium ovale* and *Plasmodium knowlesi* [10]. This disease can be founded in tropical regions and also in most of South and Central America, Africa, the Middle East, and the Indian subcontinent, southeast Asia and Oceania [11]. Most malaria symptoms are fever and headache because of parasite invasion of red blood cells [10]. In 2018, almost 228 million malaria cases were certified globally, of which 93% were found in Africa, followed by southeast Asia and the eastern Mediterranean regions [12]. In addition, malaria continues to be a critical problem in the world, especially in the Greater Mekong Sub-region (GMS) [13]. The GMS are Cambodia, Yunnan province and Guangxi Zhuang autonomous region, The Lao People's Democratic Republic, Myanmar, Thailand, and Viet Nam [13]. According to the GMS annual malaria report, between 2012 to 2017, malaria cases have been steadily decreasing, including mortality rates from malaria during the same period. On the other hand, artemisinin resistance has been demonstrated in many spaces of the Great Mekong sub-region in the past decade.

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) |

That indicates treatment failure rates occurring in the Great Mekong sub-region. Not only resistance to artemisinin but also resistance to artemisinin-based. combinations were also observed [13]. Once more, resistance to artemisinin-based combination therapies (ACT) has increased in many countries of GMS [14] and [15]. A policy for malaria eradication in the GMS was to eliminate malaria in GMS countries within 2030. Specifically, the critical activities required to fight malarial drug resistance in the region eliminating *Plasmodium falciparum* in 2025 [14]. All countries with decreased malaria burden by operating to elimination. When they have an entire rate of less than 1 case per one thousand people yearly, that is World Health Organization (WHO) guidelines [13]. Thailand has established a strategy to eradicate malaria using Thailand's National Malaria Elimination Strategy (2017–2026), including increasing the zero malaria zone to 100% by 2023 [16]. Malaria incidence in Thailand, the Department of Disease Control (DDC) reports that malaria has steadily decreased over the past five years [12]. The distribution of malaria appears to be mainly around the border area, such as Thailand – Myanmar border and Thailand – Cambodia border. Moreover, the World Health Organization expressed concern over the evolution of artemisinin-resistant *P. falciparum* parasites along the Cambodia-Thailand border, Especially in Si Sa Ket and Ubon Ratchathani [14]. We found many studies which indicate that the prevalence of malaria is affected by environmental factors such as temperature that affects the biological clock of malaria, the parasite cannot grow below 18°C and over 40°C [17] and [18], altitude affects temperature variation through a 200 meter increase in height; the temperature declines every one °C. Therefore, elevation can indirectly affect the prevalence of malaria because of its effect on temperature [19]. Water bodies are a significant factor influencing malaria prevalence and case scenarios. Water bodies are fundamental as larval breeding locations for *anopheles* [20]. This is the first report on malaria phenomena with climate changes and the factors relevant to malaria prevalence in Si Sa Ket province using a geographic information system (GIS) to look for trends in the disease's status and guidelines used to prevent an epidemic. The crucial outcome showed the integration of situations by defining a malaria burden and creating a malaria map in Si Sa Ket Province, Thailand.

2. Material and Methods

This phenomenal malaria prevalence observation by the General Communicable Disease Control Division, Si Sa Ket Provincial Health Office, Si Sa Ket Province, Thailand with the outbreak and environmental factors affecting malaria's prevalence in Si Sa Ket province, Thailand. We combined the malaria cases from government healthcare facilities in Thailand between 2015 and 2020.

2.1 Data Source

2.1.1 Study area

The study area was Si Sa Ket in northeastern Thailand (Figure 2). Si Sa Ket's population are estimated to be 1,458,324 [21]. The site is 22,895 km^2. Si Sa Ket is warm, with an average temperature of 26.8 °C and precipitation of about 1242 mm [22]. Si Sa Ket borders a part of Cambodia. Most of them are engaged in agricultural production.

2.1.2 Malaria Data

A malaria patient was diagnosed by health personnel or a malaria volunteer trained in a malaria treatment procedure [23]. According to the Department of Disease Control, confirmed malaria cases that tested positive specific results for *Plasmodium falciparum*, *Plasmodium vivax*, or both ("Mixed") rapid diagnosis test kits (RDT) were used for active surveillance. Microscopics were used when an RDT had a positive result [24]. Moreover, Malaria parasites can be identified by microscopic. That is the gold standard for malaria diagnosis [24]. Malaria case data were collected from the Active surveillance system, the General Communicable Disease Control Division, Si Sa Ket Provincial Health Office, Si Sa Ket Province, Thailand, for six years (2015 to 2020). Moreover, data concerning Thailand's malaria prevalence was collected from the Thailand malaria elimination program, Department of Disease Control, Ministry of Public Health, Thailand, from 2015 to 2020. All the data were collected from an online database.

2.1.3 Population density and mapping

Population data were collected from the Department of provincial administrators, ministry of Interior, available from 2015 to 2020 [21]. The Thailand map and Si Sa Ket province boundary map were obtained from http://www.DIVA-GIS.org [25]. Population data and maps were collected from an online database.

2.1.4 Environmental variables

In this study, two types of environmental data were used. Dynamic variables included ecological conditions expected to vary in this study. The author collected only two variables, average land surface temperature and average rainfall. Ecological data were received from Thailand's Meteorological Department and http://www.Climate Data.org from 2015 to 2020 [22] and [26], and fifteen field meteorological stations in Si Sa Ket province were collected. Static variables included variables related to geography and physiography that were not expected to vary from year to year. In this study, only an altitude was used. The altitude map was collected from http://www.DIVA-GIS.org [25].

2.2 Data Analyse

2.2.1 Socio-demographic, prevalence and severe risk factors

Statistical analysis used frequencies and percentages to describe malaria distribution. Malaria prevalence rates were determined (as the number of cases per 1,000 people yearly) for Thai and foreigners in Si Sa Ket province. This study aims to explain factors related to severe malaria. Multivariable logistic regression was used. First, fisher's exact test was used to show the relationships between factors and severe malaria. Then, univariable logistic regression was used to explore factors affecting severe malaria. Univariable analysis was performed using odds ratio (OR) and 95% confidence intervals (CI). Next, we took variables with results P-value<0.25 into the last multivariable analysis model. A step-backwards elimination technique was used to describe a robust model from the initial to the last model. The variables that remained significant (P-value<0.05) were kept in the model, using adjusted odds ratio (AOR) and 95% confidence intervals (95%CI) were also calculated. STATA version 17 was used for this analysis.

2.2.2 Spatial data

The data was modified to create geographic information using ArcGIS 10.5. meteorological data, including average rainfall data and average temperature from ClimateData.org and The Meteorological Department of Thailand from 2015 to 2020 [22] and [26], were used to explore the distribution of malaria and factors related to the malaria epidemic in Si Sa Ket Province.

The research assistant was trained to collect the coordinates position of malaria patients in study areas. They have used interpolation analysis, especially inverse distance weight (IDW), to illustrate malaria prevalence and average rainfall in study areas. Fifteen field meteorological stations were used for interpolation analysis. An overlay technique was performed to represent a relationship between population density and malaria prevalence. Moreover, correlation analysis explored factors such as average land surface temperature influencing malaria prevalence. The altitude map was collected from http://www.DIVA-GIS.org [25]. The elevation map described the relationship between malaria prevalence and altitude.

3. Result

3.1 Socio-demographic and Malaria Incidence Rate in Si Sa Ket Province

1,259 malaria cases were reported to Si Sa Ket's active surveillance system, Ministry of Public Health, from 2015 to 2020 (0.47/1000 population) (Table 1). The highest prevalence was presented in 2015, with 0.95 /1000 population (574 malaria), while in 2020, the lowest rate was reported, with 0.02 (20 malaria). The overall malaria prevalence was high in Khun Han district, followed by Phusing and Kantharalak districts. Most of the patients were in agriculture sector and lived around the Thai-Cambodia border. Adults aged 16–45 had a chance of malaria risk among other groups. Most patients were more infected with *P. vivax* than *P. falciparum*. Since 2019, Thailand has replaced malaria medication, a previous study found that drug efficacy decreased in 2019. Si Sa Ket and Ubon Ratchathani province used Artesunate – Pyronaridine as the first-line drug. Therefore, malaria prevalence dropped (Table 1). Figure 1 illustrates the weekly malaria epidemic curve from 2015 to 2020.

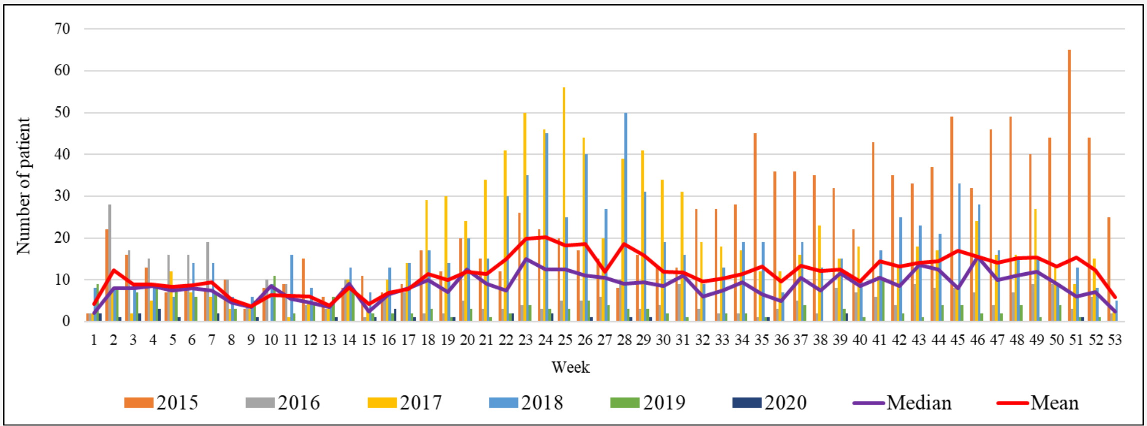


Figure 1: A malaria epidemic curve (weekly report) in Si Sa Ket Province during 2015 – 2020

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) | © Geoinformatics International

Table 1: The prevalence rate (case/1,000 population) of malaria in Si Sa Ket Province during 2015 - 2020

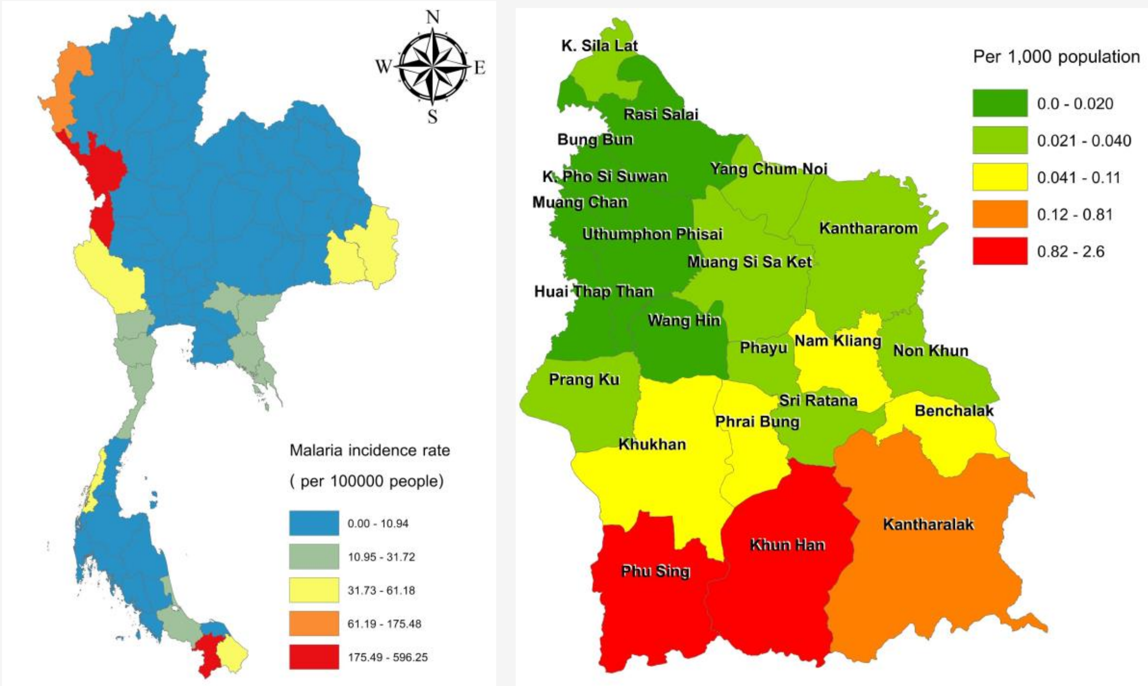
District	2015	2016	2017	2018	2019	2020	Avg. PR.
Mueang Si Sa Ket	0.21	0.01	0.06	0.06	0.00	0.00	0.06
Yang Chum Noi	0.13	0.00	0.00	0.07	0.00	0.00	0.03
Kanthararom	0.11	0.01	0.05	0.04	0.01	0.00	0.04
Kantharalak	1.83	0.43	1.25	1.55	0.28	0.04	0.89
Khukhan	0.21	0.03	0.18	0.09	0.01	0.01	0.09
Phrai Bueng	0.29	0.03	0.08	0.40	0.03	0.00	0.14
Prang Ku	0.05	0.02	0.15	0.02	0.00	0.00	0.04
Khun Han	8.01	2.59	5.80	5.95	1.33	0.14	3.96
Rasi Salai	0.04	0.01	0.00	0.00	0.00	0.00	0.01
Uthumphon Phisai	0.04	0.01	0.02	0.02	0.00	0.01	0.02
Bueng Bun	0.00	0.00	0.22	0.00	0.00	0.00	0.04
Huai Thap Than	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Non Khun	0.15	0.00	0.05	0.00	0.00	0.00	0.03
Si Rattana	0.02	0.04	0.02	0.08	0.00	0.00	0.03
Nam Kliang	0.23	0.02	0.05	0.09	0.00	0.00	0.06
Wang Hin	0.03	0.03	0.00	0.00	0.00	0.00	0.01
Phu Sing	4.13	1.49	4.57	2.72	0.66	0.16	2.28
Mueang Chan	0.00	0.00	0.06	0.00	0.00	0.00	0.01
Benchalak	0.08	0.00	0.22	0.08	0.03	0.03	0.07
Phayu	0.12	0.06	0.03	0.00	0.00	0.00	0.04
Pho Si Suwan	0.04	0.00	0.04	0.00	0.00	0.00	0.01
Sila Lat	0.10	0.00	0.10	0.00	0.00	0.00	0.03
Total	0.95	0.28	0.73	0.69	0.14	0.02	0.47

Avg. = average, PR = prevalence rate (per 1,000 population)

Table 2: Socio-demographic characteristics of admission malaria in Si Sa Ket province

Characteristics	Normal malaria cases (%)	Severe malaria cases (%)	P-value
Sex			
Female	64 (36.8)	110 (63.2)	<0.01
Male	331 (26.3)	926 (73.67)	
Age group (years)			
Newborn to 15-year-old	19 (26.8)	52 (73.24)	0.825
16- to 45-year-old	254 (27.1)	682 (72.9)	
More than 45-year-old	122 (28.8)	302 (71.2)	
Occupation			
Student	21 (23.6)	68 (76.4)	<0.000
Farmer	211 (30.6)	478 (69.4)	
Government officer	47 (35.6)	85 (64.4)	
Military personnel	24 (10.6)	203 (89.4)	
Other	92 (31.3)	202 (68.7)	
Nationality			
Thai	388 (27.8)	1,007 (72.2)	0.347
Foreigner	7 (19.4)	29 (80.6)	
Malaria species			
Pf	101 (25)	303 (75)	<0.000
Pv	134 (21.9)	479 (78.1)	
Mixed and other	53 (41.7)	74 (58.3)	

Pf = Plasmodium.falciparum, *Pv = Plasmodium vivax*, Mixed = Mixed of *Plasmodium falciparum* and *Plasmodium vivax* or *Plasmodium malariea;* p-value significant at < 0.05



(a) (b)

Figure 2: Study area and the overall incidence during 2015 to 2020 (a) Thailand map (b) Si Sa Ket map

In general, malaria is a seasonal epidemic. It slightly increases starting from the rainy season starting from week 18. The peak of the malaria season was found to be May to June and October. Table 2 shows no factors related to severe malaria, age (P-value = 0.825) and nationality (P-value = 0.347). The factors related to severe malaria are sex (P-value < 0.01), occupation (P-value<0.001) and malaria species (P-value<0.001).

3.2 Geographical Malaria Distribution in Si Sa Ket Province

Malaria in Thailand, It's still high along border areas such as Thai-Myanmar, Thai-Malaysia, and Thai-Cambodia, especially Thai-Myanmar (Figure 2). Moreover, the Thai-Cambodia border remains antimalarial drug-resistant. In Si Sa Ket situation, the districts with high levels of malaria phenomenon were along the national border (Thai -Cambodia) in the southern section, such as at Khun Han, Phu Sing and Kantharalak. Most districts had a low incidence of malaria. People's movements were a significant problem affecting the incidence of malaria. People in low-endemic areas travelled to regions with high malaria incidence because of occupational demands, bringing malaria back to their homes. Therefore, malaria spreads in every district of Si Sa Ket province (Figure 2). Figure 3 shows a decrease in the malaria incidence during the last two years in 2019 and 2020. We also investigated are related to the distribution of malaria, population density, and factors. Figure 4 illustrates that malaria prevalence significantly decreased from 2015 to 2020, particularly in the southern part of the study area. From 2015 to 2018, malaria incidence was proportional to population density; however, after 2018, the correlation no longer exists because of lower malaria infection rate after 2018 as shown in Figure 5. Altitude is another factor that affects the malaria infection rate. Figure 6 demonstrates that the higher the elevation, the lower the malaria infection rate.

3.3 Risk Factors of Severe Malaria Cases in Si Sa Ket Province

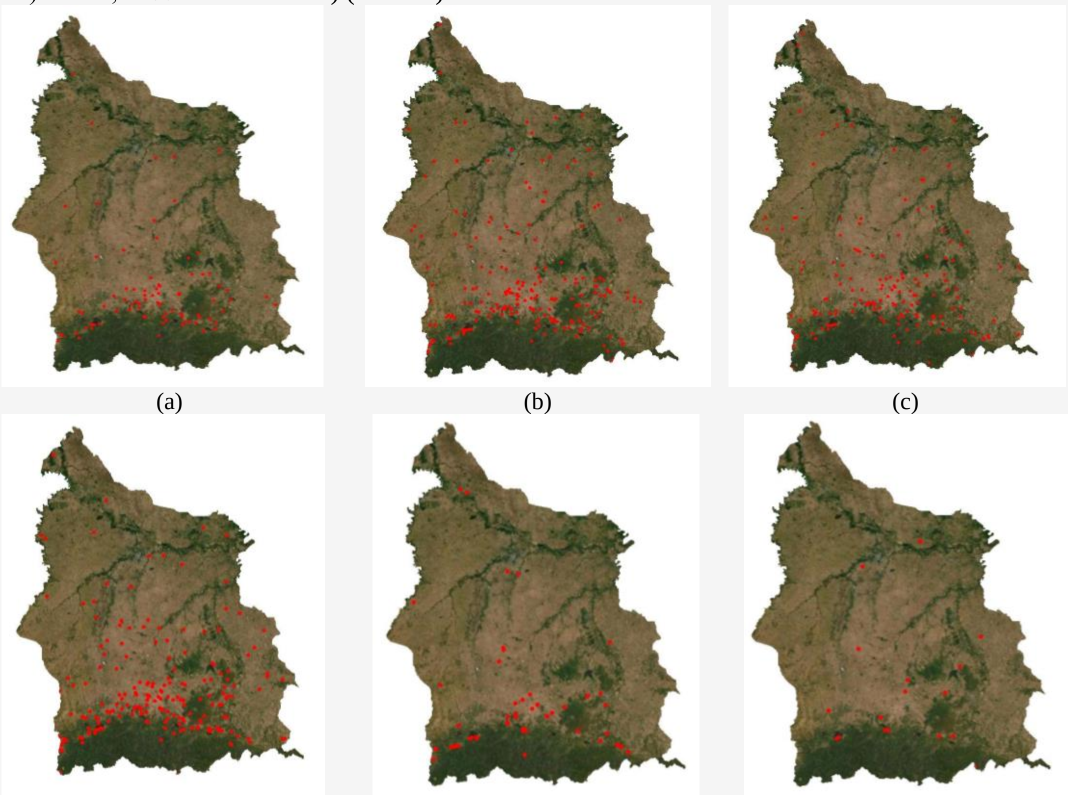
Table 2 shows factors related to severe malaria. There was no statistically significant age (p-value = 0.825) and nationality (P-value = 0.347). In the univariable analysis, we found that some variables are influenced to severe malaria, male (P-value < 0.01, 95% Confidence interval (CI) = 1.17 - 2.27), occupation: military personnel (P-value < 0.01, 95% Confidence interval (CI) = 1.37 - 4.99) and malaria type: Mixed (P-value < 0.001, 95% Confidence interval (CI) = 0.3 - 0.71). And then, they added all the variables into a multivariable logistic regression analysis for a robust model. We found that the male sex was more chance of severe malaria than the female: 2.49x (P-value = 0.013, Adjust Odds Ratio (AOR) = 2.49; 95%CI = 1.11-2.45).

ISSN: 1686-6576 (Printed) | ISSN 2673-0014 (Online) | © Geoinformatics International

Military personnel were 2.93x (P-value <0.01, Adjust Odds Ratio (AOR) = 2.93; 95%CI = 1.45-6.57) more likely to be severe malaria than students. *Plasmodium falciparum* had lower odds of being the causative agent of malaria in a severe malaria case than Mixed and others (P-value < 0.01, Adjust Odds Ratio (AOR) = 3.34, 95%CI = 0.31-0.73) (Table 3).

3.4 Environment Variables and Malaria Incidence

In addition to environmental factors, meteorological factors were associated with malaria incidence in the province. Table 4 shows that malaria incidence was negatively related to population density with no statistical significance (P-value > 0.05).



(a) (b) (c) (d) (e) (f)

Figure 3: The malaria distribution in Si Sa Ket Province (a) 2015, (b) 2016, (c) 2017, (d) 2018 (e) 2019, (f) 2020

Table 3: Factors related to severe malaria cases in Si Sa Ket province

Characteristics	Univariable		Multivariable	
	OR (95%CI)	**P value**	**AOR (95%CI)**	**P value**
Sex				
Female	Ref.		Ref.	
Male	2.87 (1.17 - 2.27)	<0.01	2.49 (1.11 - 2.45)	0.013
Occupation				
Student	Ref.		Ref.	
Farmer	1.36 (0.42 - 1.17)	0.174	0.92 (0.41 - 1.38)	0.357
Government officer	1.89 (0.3 - 1.02)	0.059	1.2 (0.32 - 1.32)	0.232
Military personnel	2.91 (1.37 - 4.99)	<0.01	2.93 (1.45 - 6.57)	<0.01
Other	1.39 (0.39 - 1.17)	0.165	0.89 (0.39 - 1.42)	0.373
Species				
Pf	Ref.		Ref.	
Pv	1.16 (0.89 - 1.6)	0.245	1.21 (0.89 - 1.64)	0.225
Mixed and other	3.58 (0.3 - 0.71)	<0.001	3.34 (0.31 - 0.73)	<0.01

OR = Odd ratio; AOR = Adjust Odd ratio; Ref. = reference; *Pf* = *Plasmodium falciparum*, *Pv* = *Plasmodium vivax*, Mixed = Mixed of *Plasmodium falciparum* and *Plasmodium vivax* or *Plasmodium malariea;* p-value significant at < 0.05

Table 4: Spearman rank correlation of malaria cases and other ecological factors at Si Sa Ket, Thailand

Factors	Observe	Correlation	P-value
Average temperature	60	0.0064	0.961
Average rainfall	60	0.1284	0.328
Population density	60	-0.15	0.506

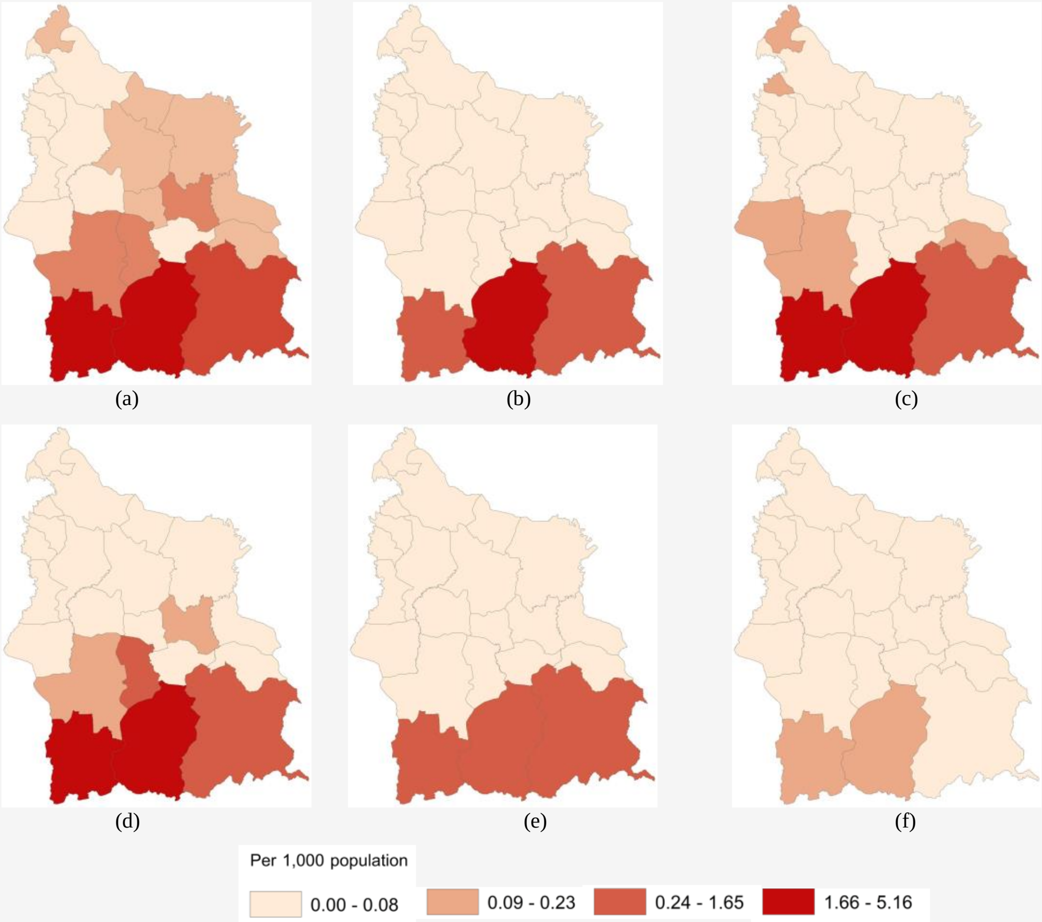
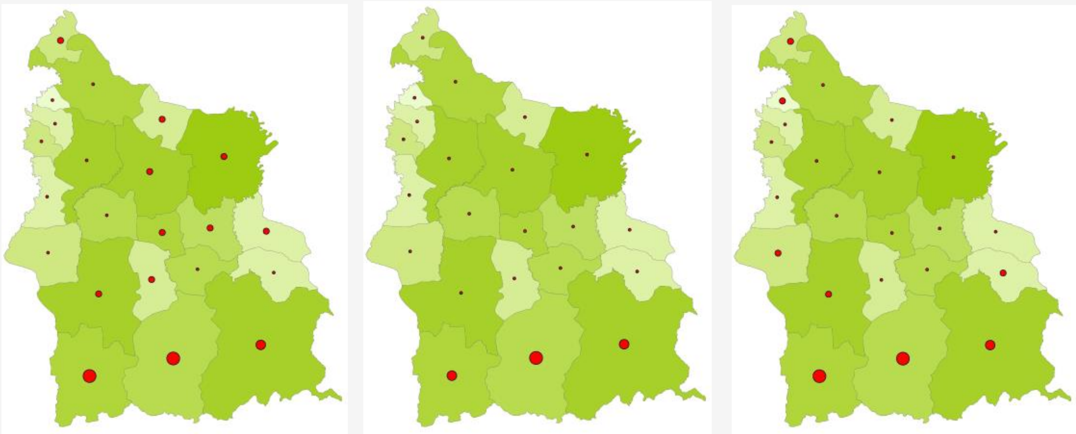


Figure 4: Malaria prevalence in Si Sa Ket province (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e)2019, (f) 2020



(a) (b) (c)

Figure 5: Malaria incidence and population density in Si Sa Ket Province (2015 – 2020), (a) 2015, (b) 2016, (c) 2017

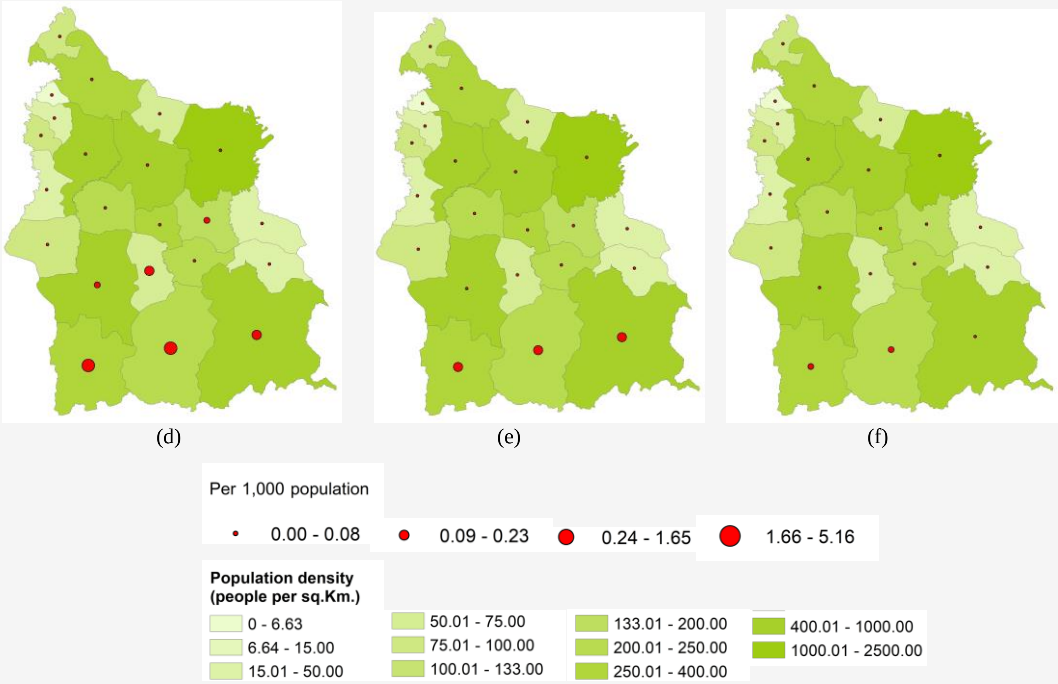


Figure 5: Malaria incidence and population density in Si Sa Ket Province (2015 – 2020), (d) 2018 (e) 2019 (f) 2020

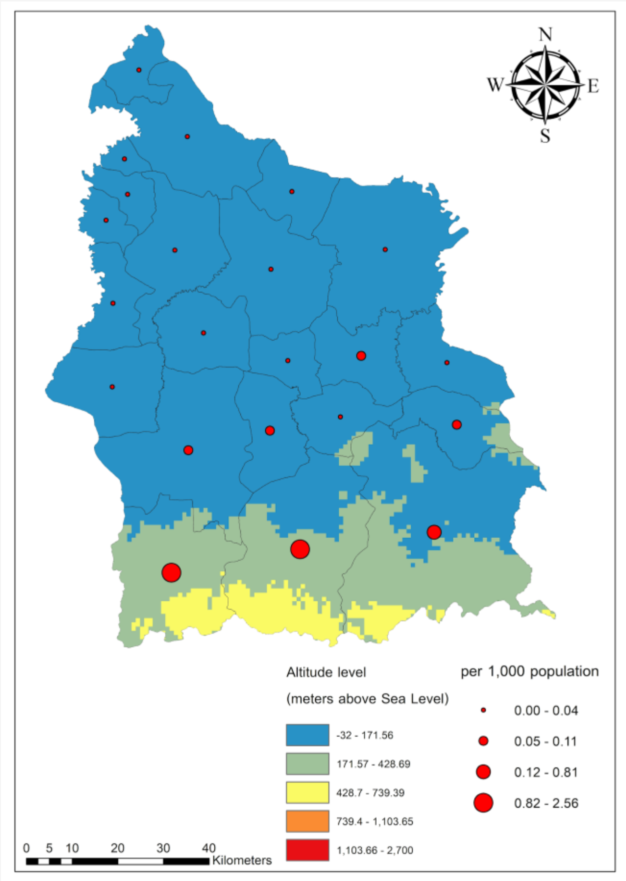


Figure 6: Average malaria incidence during 2015 - 2020 and altitude in Si Sa Ket province

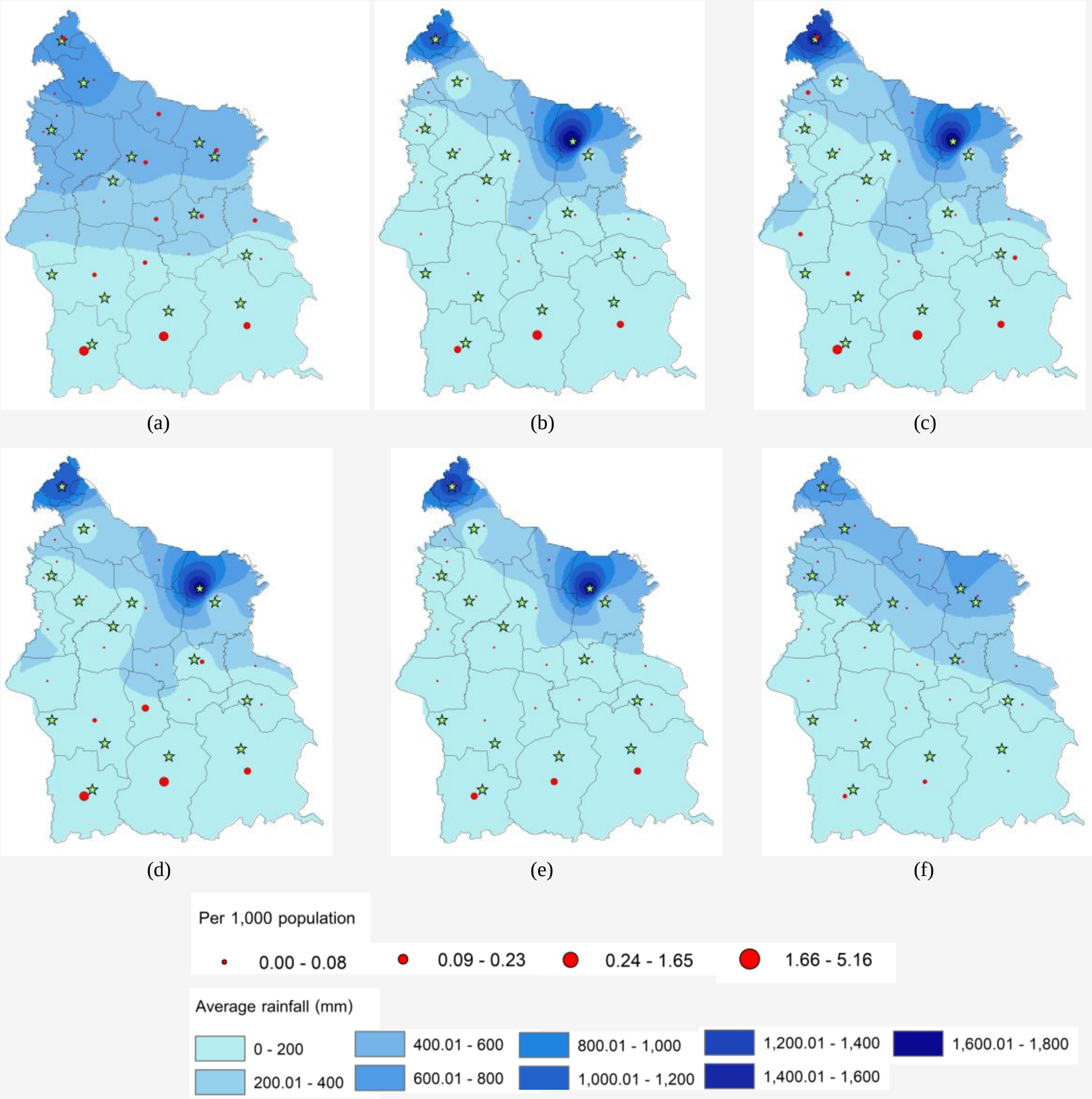


Figure 7: The average rainfall per year and malaria incidence in Si Sa Ket Province during 2015 – 2020, (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019, (f) 2020

The average temperature was a mild positive relationship to malaria incidence with no statistical significance (P-value > 0.05). Average rainfall was a soft positive relationship to malaria incidence with no statistical significance (P-value > 0.05) (Figure 7). Likewise, water is a significant factor in the *Anopheles* mosquito's reproduction. Generally, *Anopheles* mosquitoes prefer to lay their eggs in highland, densely forested areas with slow-flowing water (Figure 7).

4. Discussion and Conclusion

This report combines spatial and climatic data to describe malaria trends and epidemiology in Si Sa Ket province from 2015 to 2020. Moreover, create and generate a spatial environmental map of malaria incidence. Our crucial findings showed that malaria has decreased over the entire study period. The average annual incidence of malaria reported in Si Sa Ket province was 0.47 per 1000 population between 2015 to 2020. It dramatically decreased from 2018 to 2020. "World Malaria Day 2018", Thailand recognizes 35 malaria-free provinces. Furthermore, The Ministry of Public Health emphasizes that participation from local agencies is critical to eliminating malaria [13]. Factors are related to the admission of malaria cases. This study describes that >70% of malaria cases were male. Military personnel had more chance of being admitted with severe malaria than other occupations. Border across.

It is a significant problem in the spread of malaria. There are reports of studies on population movement.

That is related to malaria concentration. For some reason, humans can be a reservoir host for malaria [27] and [28]. Malaria screening and control units in partnership with related corporations like the Military should be undertaken [29]. A type of malaria can be related to severe malaria. This study shows the odds of severe in patients with more than one malaria species. In contrast, the study of Wangdi and Lon found that the most severe malaria will be *P. falciparum* [30] and [31]. The hotspots of indigenous malaria were in the southern part of Si Sa Ket province. This part of Si Sa Ket province is a forest area and national border. The main occupation is agriculture. Thus, patients with severe malaria were military personnel. These groups are at a higher risk for malaria disease [32]. Environmental factors such as temperature are crucial in a malaria transmission cycle and mosquito survival [33] and [34]. This study found that average temperature and average rainfall had a mild positive relationship with malaria but no statistical significance. Likewise, some studies have explained rainfall as a crucial factor in malaria transmission [35] and [36].

Temperature < 16 °C had detrimental effects on mosquito endurance, and temperature also decreased with increasing altitude [37] and [38]. This study found that areas at higher altitudes had a high burden of malaria. In conclusion, malaria remains a public health problem. The outcome of this research can be supported by a malaria monitoring system. This study indicated that health agencies are achieving relative success. Because malaria rates were lower than in other studies. We hope to provide helpful info to local and Si Sa Ket Province stakeholders to expand malaria prevention programs or mobile applications for malaria combat. Moreover, Geographic information system applications remain a crucial tool for disease control.

Acknowledgement

The authors greatly appreciate the grant from Research Affairs Division, Faculty of Medicine, Mahasarakham University. Our thanks are also extended to the General Communicable Disease Control Division, Si Sa Ket Provincial Health Office, Si Sa Ket Province, Thailand, for the malaria data and their generous assistance in carrying out this project to the volunteers of those villages.

Reference

[1] Wongpituk, K., Kalayanarooj, S. and Nithikathkul, C., (2020). Geospatial Analysis of DHF Surveillance Model in Si Sa Ket Province, Thailand using Geographic Information System. *International Journal of Geoinformatics*, Vol. 16(3). 97-104.

[2] Toemjai, T., Thongkrajai, P. and Nithikathkul, C., (2022). Factors Affecting Preventive Behaviour Against Leptospirosis among the Population at Risk in Si Sa Ket, Thailand. *One Health*, Vol. 14. https://doi.org/10.1016/j.one hlt.2022.100399.

[3] Thessingha, C., Wongsawad, C., Homchampa, P., Laothiang, P. and Nithikathkul. C., (2019). Soil-Transmitted Helminthiases and Risk Factors among Thai Hill-Tribe Preschool-Age Children in Remote Area of Thailand. *Journal of the Medical Association of Thailand.* Vol. 102(8), 56-62.

[4] Soncharoen, P., Jongthawin, J. and Nithikathkul, C., (2022). Influent Factor Toward Based Helminth Infections among of Thai-Cambodian Border in Phusing District, Sisaket Province, Thailand. *International Journal of Geoinformatics.* Vol. 18(5). https:// doi:10.52939/ijg.v18i5.2375.

[5] Nithikathkul, C., Wongsaroj, T., Buntilov, V. and Limsomboon, J., (2012). Geographic Information System of Fish-Borne Parasitic Zoonoses Metacercaria from Water Reservoirs under his Majesty's Recommended Project, Phitsanulok, Thailand. *International Journal of Geoinformatics.* Vol. 8(3), 53-57.

[6] Nithikathkul, C., Trevanich, A., Wongsaroj, T., Wongsawad, C. and Reungsang P., (2017). Health Informatics Model for Helminthiasis in Thailand. *Journal of Helminthology.* Vol. 91(5). https://doi:10.1017/S0022149X16000 614.

[7] Kanjaras, P., Bumrerraj, S., Seng, R., Noradee, S. and Nithikathkul, C., (2023). Geospatial Analysis and Modeling of Melioidosis Prevention and Control in Si Sa Ket Province, Thailand. *International Journal of Geoinformatics.* Vol. 19(1), 57–65, https://doi: 10.52939/ijg.v19i1.2501.

[8] Buntilov, V., Wattanayingcharoenchai, S., Nithikathkul, C. and Wongsaroj, T., (2011). A Geographic Information System for Estimating the Prevalence of Helminthiasis Infections in the North-Eastern Thailand. *32nd Asian Conference on Remote Sensing 2011, ACRS 2011*. Vol. 2, 1170-1175.

[9] Nithikathkul, C., Reungsang, P., Trivanich, A., Homchumpa, P., Tongsiri, S. and Wongsawad, C., (2014). Geographic Information of Fish-Borne Parasitic Metacercaria in Chi River, Mahasarakham, Thailand. *International Journal of Geoinformatics.* Vol. 10(1), 25-29.

[10] Center of Disease Control and Prevention, (2018). CDC - Parasites – Malaria. [Online].

Available: https://www.cdc.gov/parasites/malaria/index.html.

[11] Kachur, S. P., (2022). Malaria. *Maxcy-Rosenau-Last Public Health & Preventive Medicine, 16e*, Boulton M.L. and R.B. Wallace Eds. New York: McGraw Hill.

[12] World Health Organization, World Malaria Report, (2018). Switzerland: World Health Organization, 2018.

[13] World Health Organization, (2018). *Countries of the Greater Mekong are Stepping up to End Malaria*. Switzerland.

[14] Imwong, M., Suwannasin, K., Kunasol, C., Sutawong, K., Mayxay, M., Rekol, H., Smithuis, F. M., Hlaing, T. M., Tun, K. M., van der Pluijm, R. W., Tripura, R., Miotto, O., Menard, D., Dhorda, M., Day, N. P. J., White, N. J. and Dondorp, A. M., (2017). The Spread of Artemisinin-Resistant *Plasmodium falciparum* in the Greater Mekong Subregion: A Molecular Epidemiology Observational Study. *The Lancet Infectious Diseases*. Vol. 17(5). 491-497. https://doi:10.1016/S1473-3099(17)30048-8.

[15] Phyo, A. P., Nkhoma, S., Stepniewska, K., Ashley, E. A., Nair, S., McGready, R., ler Moo, C., Al-Saai, S., Dondorp, A. M., Lwin, K. M., Singhasivanon, P., Day, N. P. J., White, N. J., Anderson, T. J. C. and Nosten, F., (2012). Emergence of Artemisinin-Resistant Malaria on the Western Border of Thailand: A Longitudinal Study. *The Lancet*. Vol. 379, 1960-1966. https://doi:10.1016/S0140-6736(12) 60484-X.

[16] Ministry of Public Health, (2018). National Malaria Elimination Strategy, Thailand 2017 – 2026. Nonthaburi, Thailand.

[17] Paaijmans, K. P., Blanford, S., Bell, A. S., Blanford, J. I., Read, A. F. and Thomas, M. B., (2010). Influence of Climate on Malaria Transmission Depends on Daily Temperature Variation. *Proc. Nat. Acad. Sci. USA*, Vol. 107(34), 15135-15139. https://doi.org/10.1073/pnas.100642210.

[18] The Open University, (2022, December 22). Study Session 6 Factors that Affect Malaria Transmission. [Online]. Available: https://www.open.edu/openlearncreate/mod/oucontent/view.php?id=89&printab le=1.

[19] Jean, P., (1992). Animal Production in the Tropical. Basing Stoke, UK: MacMillan.

[20] Dlamini, S. N., Franke, J. and Vounatsou, P., (2015). Assessing the Relationship between Environmental Factors and Malaria Vector Breeding Sites in Swaziland using Multi-Scale Remotely Sensed Data. *Geospatial Health*, Vol. 10(1). https://doi:10.4081/gh.2015.302.

[21] Department of Provincial Administration, (2020). Registry Statistic System. [Online]. Available: http://stat.dopa.go.th/stat/statnew/statMenu/newStat/home.php.

[22] Climatedata.org, (2020). Climate Si Sa Ket 2015 - 2020. [Online]. Available: http://en.climate-data.org/saia/thailand/Si-Sa-Ket-Province/Si-Sa-Ket-37437/.

[23] Wayant, N. M., Maldonado, D., Rojas de Arias, A., Cousiño, B. and Goodin, D. G., (2010). Correlation between Normalized Difference Vegetation Index and Malaria in a Subtropical Rain Forest Undergoing Rapid Anthropogenic Alteration. *Geospat Health*, Vol. 4(2). https://doi:10.4081/gh.2010.199.

[24] Center of Disease Control and Prevention, (2018). Malaria Diagnostic Tests. [Online]. CDC. Available: https://www.cdc.gov/malaria/diagnosis_treatment/diagnostic_tools.html.

[25] DIVA-GIS, (2020). Thailand boundary. [Online]. Available: https://data.biogeo.ucdavis.edu/data/diva/adm/THA_adm.zip

[26] Northeastern Meteorological Center, (2020). Meteorological and Environmental Data on Si Sa Ket Province 2015 – 2020. Ubonratchathani, Thailand: Thai Meteorological Department.

[27] Saita, S., Silawan, T., Parker, D. M., Sriwichai, P., Phuanukoonnon, S., Sudathip, P., Maude, R. J., White, L. J. and Pan-ngum, W., (2019). Spatial Heterogeneity and Temporal Trends in Malaria on the Thai–Myanmar Border (2012–2017): A Retrospective Observational Study. *Tropical Medicine and Infectious Disease*, Vol. 4(2). Available: https://www.mdpi.com/2414-6366/4/2/62.

[28] Bhumiratana, A., Intarapuk, A., Sorosjinda-Nunthawarasilp, P., Maneekan, P. and Koyadun, S., (2013). Border Malaria Associated with Multidrug Resistance on Thailand-Myanmar and Thailand-Cambodia Borders: Transmission Dynamic, Vulnerability, and Surveillance. *BioMed Research International*. Vol. 2013. https://doi:10.1155/2013/363417.

[29] Fahmi, F., Pasaribu, A. P., Theodora, M. and Wangdi, K., (2022). Spatial Analysis to Evaluate Risk of Malaria in Northern Sumatera, Indonesia. *Malaria Journal*, Vol. 21(1). https://doi:10.1186/s12936-022-04262-y.

[30] Wangdi, K., Furuya-Kanamori, L., Clark, J., Barendregt, J. J., Gatton, M. L., Banwell, C., Kelly, G. C., Doi, S. A. R. and Clements, A. C. A., (2018). Analysis of Clinical Malaria Disease Patterns and Trends in Vietnam 2009–2015.

Malaria Journal, Vol. 17(1). https://doi:10.1186/s12936-018-2478-z.

[31] Lon, C., Timmermans, A., Buathong, N., Nou, S., Se, Y., Sitthy, N., Chann, S., Kraesub, S., Wongstitwilairoong, T., Walsh, D. S., Tyner, S., Fukuda, M., Callender, D., Sherwood, J., Koy, L., Char, M., Bethell, D. and Saunders, D., (2013). Severe Malaria in Battambang Referral Hospital, an Area of Multidrug Resistance in Western-Cambodia: A Retrospective Analysis of Cases from 2006–2009. *Malaria Journal*, Vol. 12(1). https://doi:10.1186/1475-2875-12-217.

[32] Herdiana, H., Cotter, C., Coutrier, F. N., Zarlinda, I., Zelman B. W., Tirta, Y. K., Greenhouse, B., Gosling, R. D., Baker, P., Whittaker, M. and Hsiang, M. S., (2016). Malaria Risk Factor Assessment Using Active and Passive Surveillance Data from Aceh Besar, Indonesia, a Low Endemic, Malaria Elimination Setting with Plasmodium Knowlesi, Plasmodium vivax, and Plasmodium Falciparum. *Malaria Journal*, Vol. 15(1). https://doi:10.1186/s12 93 6-016-1523-z.

[33] Noden, B. H., Kent, M. D. and Beier, J. C., (1995). The Impact of Variations in Temperature on Early Plasmodium falciparum Development in Anopheles stephensi. *Parasitology*, Vol. 111(5). https://doi:10.1017/s0031182000077003.

[34] Brooker, S., Clarke, S., Njagi, J. K., Polack, S., Mugo, B., Estambale, B., Muchiri, E., Magnussen, P. and Cox, J., (2004). Spatial Clustering of Malaria and Associated Risk Factors During an Epidemic in a Highland Area of Western Kenya. *Tropical Medicine & International Health*, Vol. 9(7). https://doi.org/10.1111/j.1365-3156.2004.01272.x.

[35] Craig, M. H., Snow, R. W. and le Sueur, D., (1999). A Climate-based Distribution Model of Malaria Transmission in Sub-Saharan Africa. *Parasitology Today*, Vol. 15(3). https://doi:10.1016/S0169-4758(99)01396-4.

[36] Thomson, M. C., Mason, S. J., Phindela, T. and Connor, S. J., (2005). Use of Rainfall and Sea Surface Temperature Monitoring for Malaria Early Warning in Botswana. *Am J Trop Med Hyg.*, Vol. 73(1). 214-221.

[37] Sena, L., Deressa, W. and Ali, A., (2014). Dynamics of *Plasmodium falciparum* and *Plasmodium vivax* in a Micro-Ecological Setting, Southwest Ethiopia: Effects of Altitude and Proximity to a Dam. *BMC Infectious Diseases.* Vol. 14(1). https://doi:10.1186/s12879-014-0625-x.

[38] Woyessa, A., Deressa, W., Ali, A. and Lindtjørn, B., (2012). Prevalence of Malaria Infection in Butajira Area, South-Central Ethiopia. *Malaria Journal*, Vol. 11(1). https://doi:10.1186/1475-2875-11-84.