Spatial-Temporal Distribution Pattern of Dengue Fever and Spatial Relationship of the *Aedes* Mosquito Larvae Index in Phuket Province

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Abstract

Dengue fever is influenced by physical environmental factors that control the population dynamics of Aedes mosquito vectors. Studying the spatial distribution patterns of dengue patients using geographic information system tools, combined with surveys of Aedes mosquito larvae index through public health methods, can help understand the phenomenon and the spatial relationships with land use patterns. This study aims to investigate the spatial and temporal distribution of dengue fever in Phuket Province and examine the spatial relationship of the Aedes mosquito larvae index. A broad overview of the entire province using dengue patient data from 2007 to 2017 revealed a significant outbreak in 2013, with the majority occurring during the rainy season, and only a few cases in other seasons. Furthermore, village-level patient data were linked with Geographic Information Systems (GIS) data to map the epidemic locations, showing that the highest number of cases were consistently found in Mueang Phuket District every year. However, when considering the incidence rate per 100,000 people, a different pattern emerged, indicating the highest outbreak concentration in two specific villages within Thalang District. Field data collection of the Aedes mosquito larvae index in six communities showed a significant spatial relationship with land use characteristics in the surrounding area when considering the Aedes species. In the end of the rainy season, Aedes aegypti was predominantly found in urban areas, while both Aedes aegypti and Aedes albopictus were found in semi-rural and forested areas. Additionally, in both the summer and rainy seasons, both species could be found in the same containers. This indicates that besides the natural habitat in natural water containers, Aedes albopictus also lay eggs in the containers around human dwellings. Aedes albopictus is not only a vector for dengue fever, but also for Chikungunya and Zika viruses, which increases threat to humans. Therefore, communities near agricultural and forested areas should exercise extra caution. Public health authorities are supposed to plan the prevention of dengue fever and other mosquito-borne diseases to ensure a balance among health, society, economy and the environment.

Keywords: *Aedes* Mosquito Larvae Index, Dengue Fever, Geographic Information Systems, Spatial Relationship, Spatio-temporal Distribution Patterns

1. Introduction

Dengue hemorrhagic fever is a mosquito-borne disease transmitted by *Aedes aegypti* and *Aedes albopictus* mosquitoes to humans. Both mosquito species can spread the dengue virus (DENV), Zika virus (ZIKV), and Chikungunya virus (CHIKV). The spread of dengue in endemic or at-risk areas is related to the urban cycle. It is believed that physical environmental factors, climate change and alterations in rainfall patterns, affect control *Aedes* vector population dynamics. As is obvious, climate change and alterations in rainfall patterns affect *Aedes* vector abundance and spatio-temporal distribution, as water-holding containers increase [1] and [2]. DENV transmission dynamics in at-risk areas impacted by environmental changes often involve multiple risk factors, including population density, population migration, *Aedes* vector population density, *Aedes* larval habitats, animal reservoir host density and distribution, insecticide resistance in *Aedes* vectors, and land use and land cover.

DENV transmission in urban and semi-urban areas primarily follows the urban cycle rather than the sylvatic cycle, involving human-mosquito contact and animal reservoir hosts or called vertical transmission. *Aedes aegypti* plays a significant role in spreading DENV in urban and semi-urban areas, while *Aedes albopictus* is crucial in rural and forested areas [3]. Surveys of *Aedes* breeding sites in residential and commercial environments are vital for dengue prevention campaigns and environmental improvements [4][5][6][7] and [8].

Either natural or human-induced factors can cause ecological changes directly or indirectly. Some changes cause unbalance to ecosystem and affect health. Direct drivers of change are land use and land cover, deforestation for agriculture, filling in wetlands for urban expansion, excessive consumption or exploitation in fisheries, food, and climate change, all of which have great impact on the ecosystem. Indirect drivers of changes are population structure, society, and economy. If the area is at risk of landscape change, changes in Land use and land cover patterns, it will result in population dynamics of *Aedes* mosquito vectors as there are changes in *Aedes* vector abundance and Spatio-temporal distribution. This is because of the increases of population density, population migration and water-holding containers [1][2][4][10][11] and [12]. Dengue transmission dynamics in urban or semi-urban areas that are at-risk areas is the result of various processes related to changes in the physical environment. Similarly, the dynamics of the spread of infectious diseases carried by other insects is a major public health problem [13][14][15][16][17] [18] and [19]. Therefore, a thorough understanding of landscape changes and Human-induced changes, rather than natural processes, is an important knowledge basis to determine guidelines for assessing the risk of dengue fever transmission and setting guidelines, methods, measures, and various activities to surveillance and control of disease-carrying mosquitoes more efficiently and sustainably. Knowledge and understanding of the relationship between *Aedes* mosquitoes and dengue, Chikungunya virus and Zika virus disease, and global warming is, therefore, an important basis for surveillance, prevention and control of disease effectively [20][21] and [22].

A literature review reveals that dengue remains a significant public health issue in Health Region 11, particularly in Phuket Province, where dengue cases have increased annually. Phuket, a tourist destination with a high population density and mobility, is particularly vulnerable to dengue outbreaks because there are many hotels, educational institutions, service establishments at all levels. [23] High in population migration, Phuket Province, therefore, has significant factors that may affect the dynamics of the spread of dengue fever as well as the disease prevention and control operations.

According to the assessment of the dengue fever situation mentioned above, it can be shown that Phuket Province is an area where there is a continuous outbreak of dengue fever and it is affected by environmental changes from the expansion of communities in urban areas. Therefore, it is in high risk of dengue fever. Therefore, this research aims to study the spatio-temporal distribution of dengue cases and analyze the impact of landscape changes on dengue transmission in various areas, using Geographic Information Systems (GIS) technology to create a spatial data-related database [24] linking data on the number of patients at the village level for analysis, followed by spatial interpolation analysis. Then, categorizing intervals using the natural breaks method to display spatial distribution. The goal is to develop models and strategies for managing vector-borne diseases and planning public health initiatives at provincial and regional levels for more sustainable development.

2. Material and Methods

2.1 Study Area

The research area is Phuket Province, which is at risk for dengue fever outbreaks. Cases of dengue fever are reported every year. Phuket is an island located in the southern part of Thailand, bordering the Andaman Sea. Its geographical coordinates are between 7 ° 45′ to 8 ° 15′ north latitude and 98 ° 15′ to 98 ° 40′ east longitude. Regarding the public health, Phuket is under the jurisdiction of the Office of Disease Prevention and Control 11, Nakhon Si Thammarat Province. According to Figure 1, the highest number of dengue fever cases is in Mueang Phuket District, followed by Thalang District and Kathu District, respectively. Over the past 11 years, the largest outbreak occurred in 2013, while the years with the fewest outbreaks were 2009 and 2011. However, understanding the outbreaks requires a more thorough analysis.

2.2 Data Used

The data used to analyze the distribution of dengue fever cases across Phuket Province is secondary data, using village-level patient data obtained from the National Disease Surveillance System (Report 506) of the Office of Disease Prevention and Control 11, Nakhon Si Thammarat Province, and the Phuket Provincial Public Health Office for over 11 years, from 2007 to 2017.

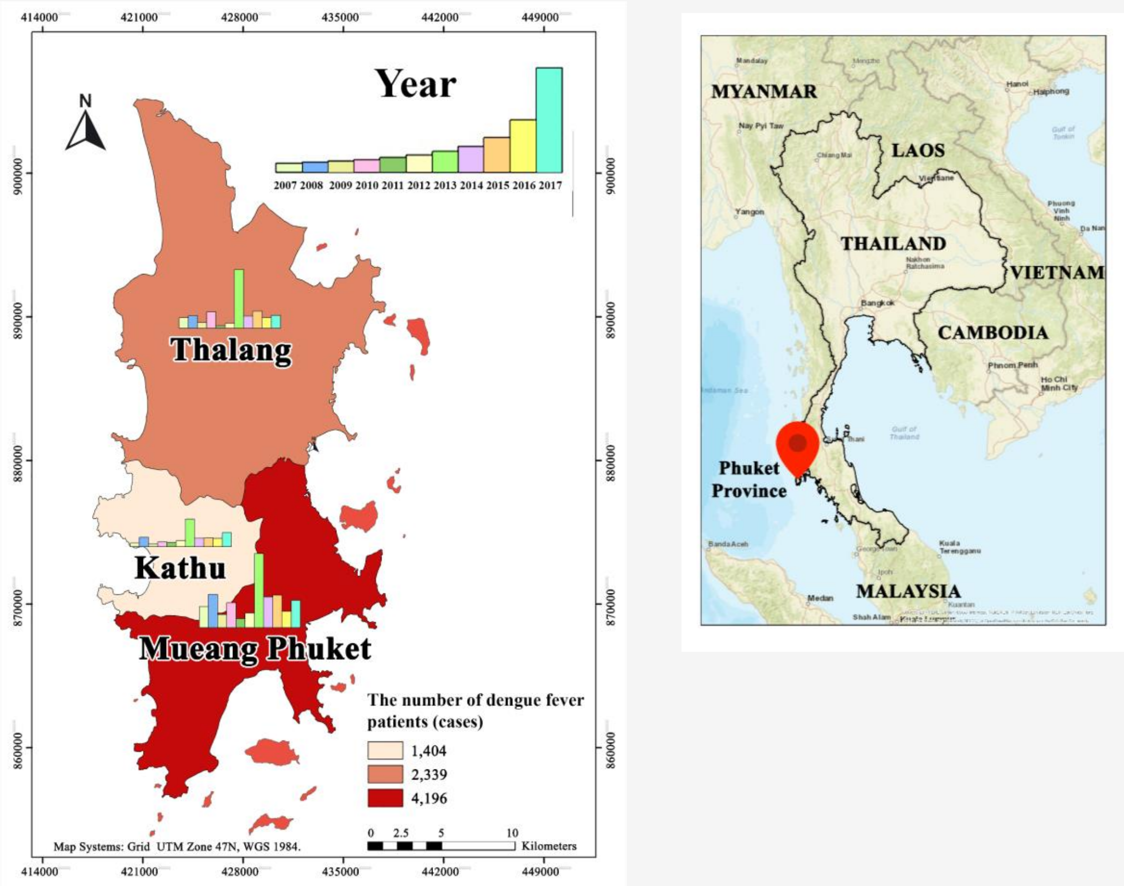


Figure 1: The number of dengue fever cases by district and year in Phuket province, from 2007 to 2017

The overall epidemiological variables include: 1) demographic variables such as gender, age, marital status, and occupation; 2) spatial variables such as village, sub-district, and district where dengue fever occurred; 3) temporal variables such as the date of illness onset. This secondary data was used to analyze the epidemiological situation of dengue fever in each study area of the province and to analyze the spatial relationship between the incidence of dengue fever and various spatial factors, including linking this secondary data with the classification and analysis of land use characteristics from satellite imagery. Primary data was used to identify the sources of dengue outbreaks by surveying households in various communities across each district. The survey covered six communities, distributed across all districts. Data included information on the study area, landscape, geographical conditions, and ecological environment. Household information comprised the physical environment, types and categories of water containers, and entomological data on mosquito larvae. These primary data were collected during the larval habitat survey in households over different seasons, divided into three periods: late rainy season (October - November 2017), dry season (February - March 2018), and rainy season (May - June 2018). Data collection across these three seasons was conducted by a multidisciplinary team, including the team leader, entomologists, field officers surveying houses and the environment and village health volunteers.

The survey of mosquito larval habitats covered a total of 740 households, with the number of houses surveyed in study areas 1, 2, 3, 4, 5 and 6 being 120, 123, 121, 121, 126 and 129 respectively. Each house was geotagged and the types, categories and number of water containers either inside or outside the house were recorded, noting whether mosquito larvae were present or not. A household survey form was used for data recording. The steps for collecting data on mosquito larval habitats and larval samples included 1) surveying mosquito larval habitats in households in the study area of Phuket Province, 2) sampling mosquito larvae, and 3) identifying mosquito larva species under a stereo microscope (Figure 2).

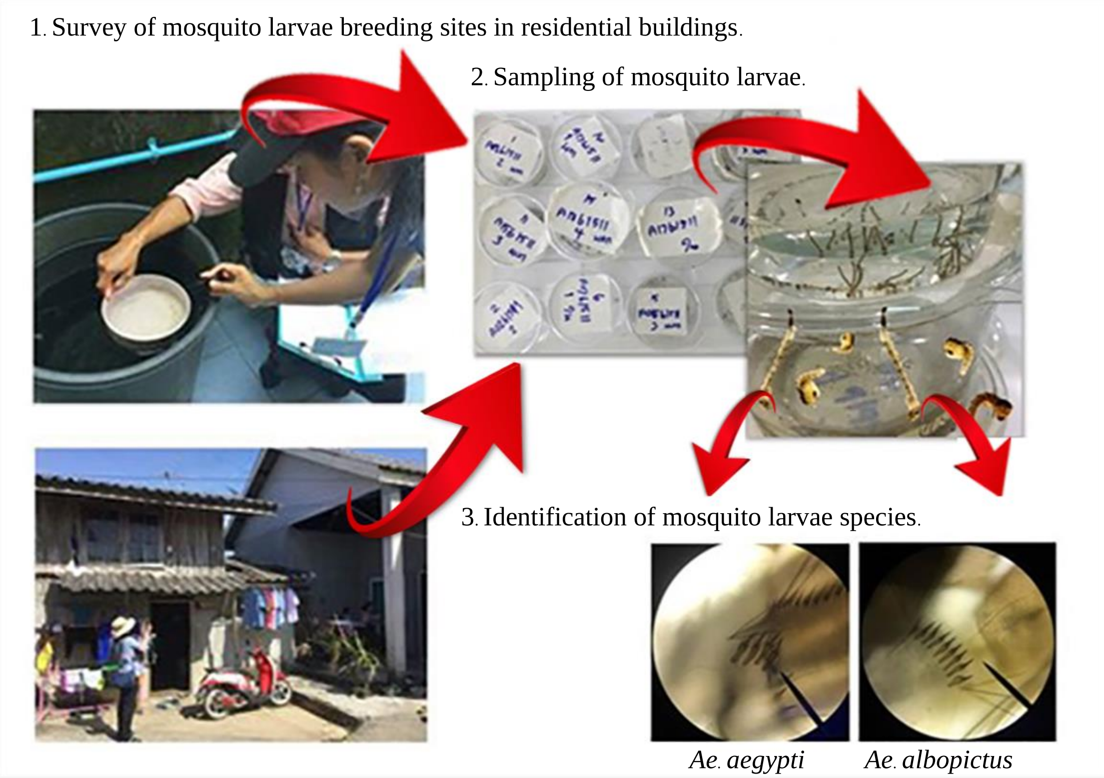


Figure 2: Steps for collecting data on mosquito larval habitats and mosquito larval samples

2.3 Spatial Analysis

The unit of analysis can be divided into three levels 1) Provincial level using data from all villages 2) Community survey sites with six locations and 3) Household and water container level to analyze mosquito larval indices. Details are as follows:

1) Provincial Level Analysis: data on the number of patients were aggregated for all 95 villages in Phuket Province, and the number of patients per 100,000 populations was used to create a geographic information systems (GIS) database of village-level patient data over 11 years, from 2007 to 2017. This data was then linked to the 8-digit village code in the GIS database, followed by spatial interpolation. The results are displayed as annual maps of dengue fever incidence, showing the distribution patterns of patients across Phuket Province.

2) Community Level Analysis: six community survey sites were randomly sampled, namely site 1: old town community, Mueang Phuket District, site 2: Baan Thai Mai community, Mueang Phuket District, site 3: Baan Nanai community, Kathu District, site 4: Baan Nok Lay community, Kathu District, site 5: Baan Bang Tao Nok community, Thalang District, and site 6: Baan Bang Ma Lao community, Thalang District. A 500-meter buffer zone was created around each site to analyze surrounding land use.

3) Household and Water Container Level Analysis: Field survey data of households and water containers were used to examine the spatial relationship between mosquito larval indices and surrounding land use characteristics, along with explaining the spatial significance of the House Index (HI) and Container Index (CI) across the three seasons.

The household level refers to the units used in the survey for *Aedes aegypti* and *Aedes albopictus* larval habitats in each study area. This includes the number of surveyed households with mosquito larval habitats, serving as a basis to identify *Aedes*-infested households and *Aedes*-infested containers inside and outside the house. Entomological indices used to assess mosquito breeding sites include the prevalence of surveyed households with water containers containing mosquito larvae (House Index, HI) and the prevalence of water containers inside and outside the house with mosquito larvae (Container Index, CI). The analysis of household infestation, which involves breeding sites for mosquito larvae, is conducted by calculating the Household Index (HI), where HI equals the number of surveyed households found to have containers with mosquito larvae inside the house or in the surrounding area divided by the total number of surveyed households with containers inside or outside the house, multiplied by 100. Statistical significance testing (P-value < 0.05) is performed to determine differences between the proportions (%) of households surveyed with containers inside or outside the house that have mosquito larvae, those with containers but no mosquito larvae, and those with no containers found both inside and outside the house, using the Chi-square test.

Similarly, the analysis of container infestation, which involves breeding sites for mosquito larvae, is conducted by calculating the Container Index (CI), where CI equals the number of containers found inside or outside the house with mosquito larvae divided by the total number of containers found inside or outside the house, multiplied by 100.

3. Results

3.1 Spatial-temporal Distribution Pattern of Dengue Fever

Considering the number of dengue fever cases in Phuket Province from 2007 to 2017, there were fluctuations. In 2007, there were 496 cases, which increased to 784 cases in 2008. The number then decreased and increased slightly in the following years until 2013 when there was a significant increase to 2,264 cases. The trend started to decline, and by 2017 there were 776 cases (Figure 3). In 2013, there was a significant outbreak, especially during the rainy season. This was caused by the presence of numerous stagnant water containers in general communities, which the public neglected to eliminate as mosquito breeding grounds. Over the 11-year period, the highest cumulative number of cases was in Mueang Phuket District with 4,196 cases, accounting for 52.85% of the total cases in the province. Thalang District followed with 2,339 cases, accounting for 29.46%, and Kathu District had the fewest cases with 1,404 accounting for 17.68%.

From Table 1, it can be observed that the number of dengue fever patients is the highest in the 10-20 age group, accounting for 28% of the total cumulative patients. The next highest age group is between 20 and 30 years old, comprising 25% of the total. The youngest age group, up to 10 years old, accounts for 18% of the total patients (Figure 4). When categorized by gender, male patients represent 55%, while female patients represent 45% of the total. Regarding marital status, single individuals account for the highest percentage at 75%, followed by married individuals at 24%. Other statuses such as divorced, widowed, and unknown have significantly lower proportions, at 0.4%, 0.3%, and 0.1% respectively. In terms of ethnicity, the majority of patients are Thai, comprising 93%, followed by Burmese at 3%, and others at approximately 2.7%. Regarding occupation, 36% of the patients are laborers or artisans, followed by 29% who are students. Other statuses and unknown status have equal proportions of 11%. In 2010, there was a significant outbreak among government officials and homemakers, while in 2013, there was a significant outbreak among artisans and students.

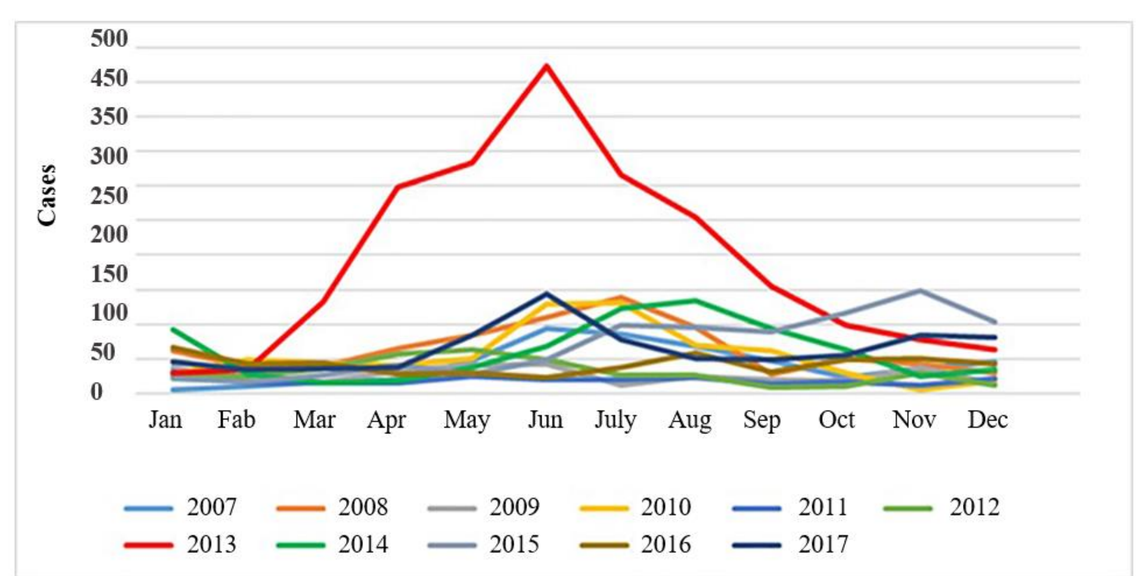


Figure 3: The number of dengue fever patients per month in Phuket province, from 2007 to 2017

Table 1: The number of dengue fever patients classified by age group, gender, marital status, occupation, and month, categorized by district in Phuket province, from 2007 to 2017

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Age	**Cases**										
0 - 10	139	163	71	110	42	57	432	116	116	84	145
> 10 to 20	186	276	89	216	60	116	633	179	225	119	193
> 20 to 30	100	179	78	168	57	98	554	194	234	149	219
> 30 to 40	45	98	42	92	39	62	342	132	147	97	130
> 40 to 50	11	46	23	46	17	22	170	52	60	34	51
> 50 to 60	10	17	5	17	6	6	87	32	25	20	24
> 60 to 70	4	4	3	3	3	2	33	16	8	3	13
> 70 to 80	1	1	0	2	1	1	11	6	7	4	3
> 80 to 90	0	0	0	0	0	1	2	2	1	0	0
Gender	**Cases**										
Male	271	444	159	323	146	210	1,257	386	486	250	436
Female	225	340	152	331	79	155	1,007	344	347	251	340
District	**Cases**										
Mueang	295	471	187	354	127	205	1,042	435	460	230	390
Kathu	50	132	40	68	63	87	390	123	128	120	203
Thalang	151	181	84	232	35	73	832	172	245	151	183
Status	**Cases**										
Single	403	621	237	475	166	271	1707	516	605	361	598
Married	93	158	74	176	56	91	530	208	221	133	166
Divorced	0	2	0	1	1	2	8	5	3	1	3
Widowed	0	1	0	2	1	0	2	0	1	1	1
Other	0	2	0	0	1	1	17	1	3	5	8
Occupation	**Cases**										
Agriculture	2	0	0	4	2	2	15	5	4	3	3
Government official	2	4	0	147	5	2	22	6	18	68	12
Laborer	150	325	125	157	90	156	854	273	323	156	262
Merchant	11	16	6	17	9	12	42	24	22	7	24
Housework	15	24	13	144	3	12	45	21	32	41	26
Student	267	310	100	96	63	105	604	163	220	116	239
Military/Police	1	0	1	1	0	0	2	1	0	1	1
Fishing	1	2	0	1	1	0	3	1	0	0	0
Teacher	3	2	2	19	0	1	1	0	3	1	4
Other	7	33	14	44	33	24	289	142	124	60	134
Unknown	37	66	50	19	18	49	381	94	86	48	59
Clergy	0	0	0	1	1	12	4	0	0	0	2
Healthcare personnel	0	2	0	4	0	0	2	0	1	0	0
Month	**Cases**										
January	5	61	38	28	31	25	29	92	22	67	46
February	10	39	16	49	15	25	35	28	16	42	34
March	16	39	17	44	15	36	132	15	26	44	36
April	20	65	33	41	15	56	298	18	40	28	38
May	47	84	40	50	24	63	333	37	28	29	84
June	94	110	42	129	19	48	474	68	49	23	143
July	85	139	12	130	20	26	315	122	98	37	77
August	68	95	25	69	23	26	254	134	95	58	50
September	47	28	19	61	14	9	155	94	89	31	48
October	23	51	18	29	17	10	99	63	117	49	55
November	36	43	38	6	11	29	77	25	149	51	84
December	45	30	13	18	21	12	63	34	104	42	81
Total	**496**	**784**	**311**	**654**	**225**	**365**	**2,264**	**730**	**833**	**501**	**776**

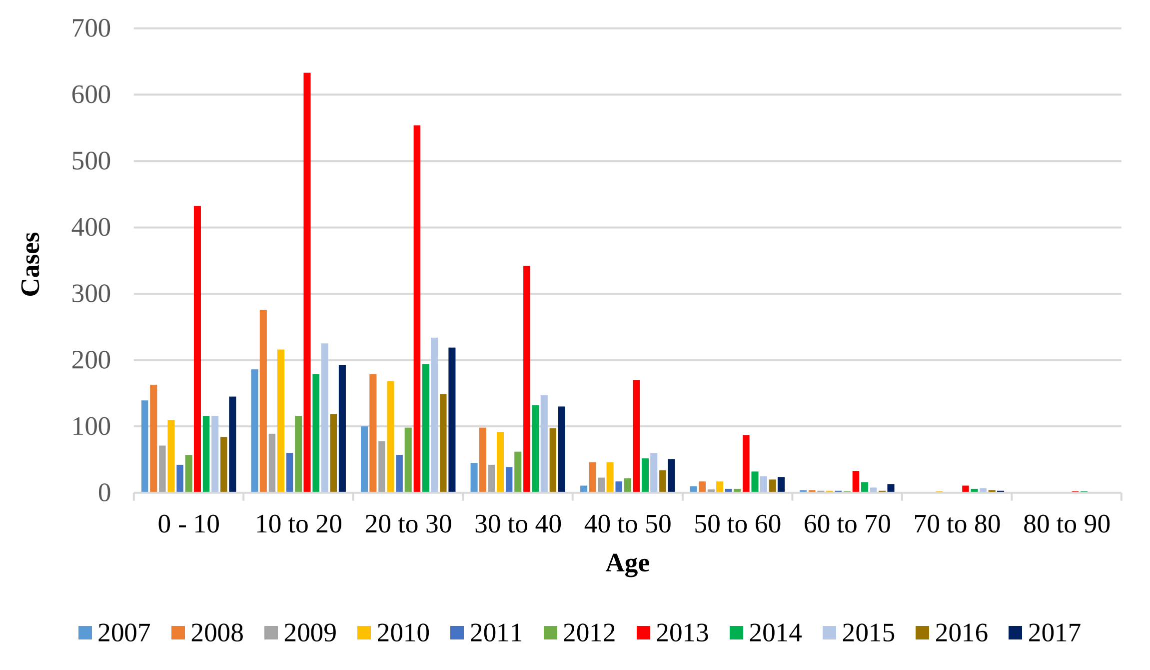


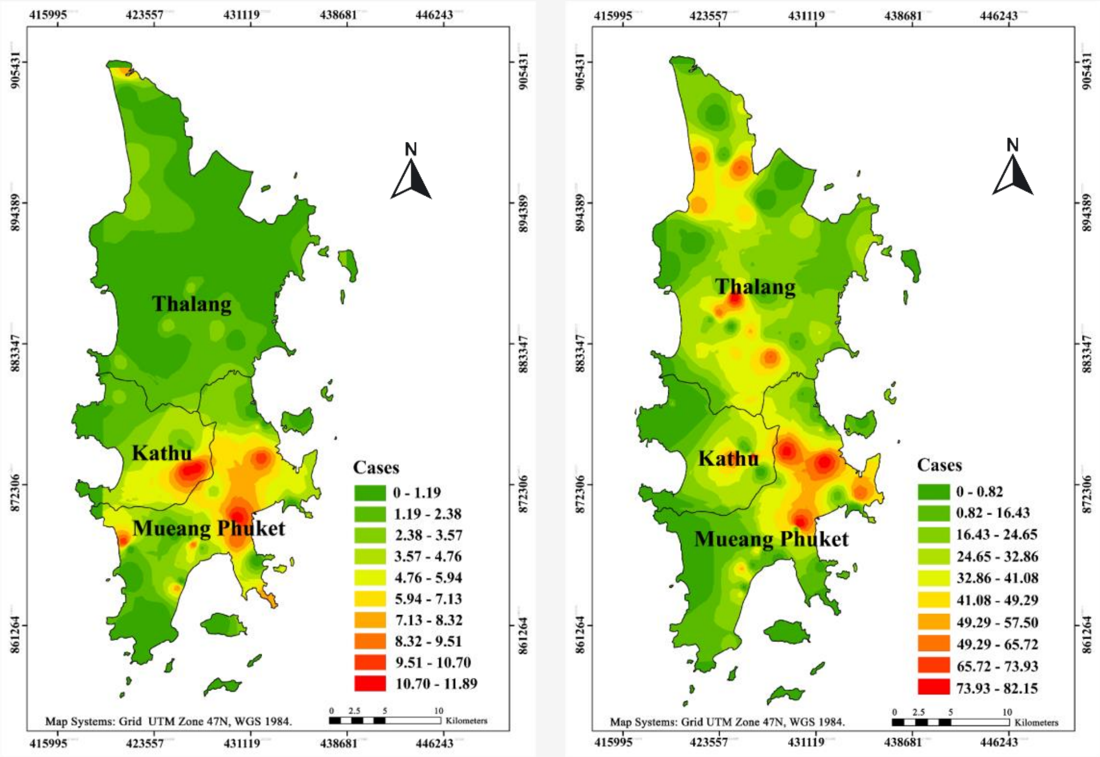
Figure 4: The number of dengue fever patients classified by age group in Phuket province, from 2007 to 2017

Overall, throughout the 11-year period, the highest number of patients was observed in June, accounting for 15.1%, which is during the rainy season, and decreased in July, August, and September, being 13.3%, 11.3%, and 7.4% respectively. Then, the percentage of patients slightly increased and decreased slightly in November, with percentages of 6.9% and 5.8% respectively. At the beginning of the year, January had a percentage of 5.5%, and from February to May, the percentage of cumulative patients gradually increased, from 3.8% to 5.2%, 8.2%, and 10.3% respectively. In summary, dengue fever tends to occur mostly at the end of the hot season to the beginning of the rainy season, with the lowest numbers during the winter season.

3.2 Spatial Distribution

In terms of spatial distribution, it is evident that the highest concentration of dengue fever patients is clustered in the eastern and southeastern regions of Phuket province, particularly in Wichit Sub-district, 346 cases. Specifically, the highest numbers are found in Na Bon Nai village with 292 cases and Bo Rae village with 54 cases. When analyzing the annual incidence patterns of dengue fever patients, it is observed that in 2007, there was a high incidence in Mueang Phuket District, particularly in Na Bon Nai village, Wichit Sub-district with 28 cases, followed by Tha Ruea Mai village, Rasada Sub-district with 20 cases, and Koo Koo village, Rasada Sub-district, with 18 cases. Similarly, in 2008, there was a similar spatial pattern to year 2007 when the highest number of patients was found in Mueang Phuket District, particularly in Na Bon Tai village, Wichit Sub-district with 46 cases, Bo Rae village, Wichit Sub-district, with 30 cases, and Thung Ka Pha Niang Taek village, Rasada Sub-district, with 26 cases. However, in Kathu and Thalang districts, there were fewer cases.

In 2009, besides Koo Koo Sub-district, Mueang Phuket District, there was an emergence of outbreaks in new areas in Thung Ka Pha Niang Taek village, Rasada Sub-district, Mueang Phuket District with 10 cases, and in Ka Ron village, Ka Ron Sub-district, Mueang Phuket District with 11 cases. Additionally, outside Mueang Phuket District, there were 8 cases found in Liphon Tai village, Sri Sunthorn Sub-district, Thalang District. In 2010, the cases increased in the Thalang District, particularly in Cherng Thale village in Cherng Thale Sub-district, Takhian village in Thepkrasattri Sub-district, and Tha Ruea village, Si Sunthon Sub-district respectively in descending order. In 2011, there were very few cases (Figure 5(a)), with the dengue fever cases concentrated in the Mueang District and Kathu District. The cases were found in Na Bon Tai village, Wichit Sub-district, Mueang Phuket District, totaling 12 cases. In 2012, clusters were found similar to 2011, but spread out in the lower areas of Phuket Province in Thung Thong Sub-district, and Kathu Sub-district.



(a) (b)

Figure 5: The number of patients with dengue fever: (a) 2011 and (b) 2013

In 2013 was the year where the largest number of patients were found (Figure 5(b)). They were found widely distributed in all 3 districts, besides Mueang District. Cases were found in Naban Tai village, Wichit Sub-district, Mueang District, Tha Kien village, Thep Krasattri Sub-district, Thalang District, and Koo Koo village, Rasada Sub-district, Mueang District, with 83, 70, and 65 cases respectively. In 2014, there was a decrease in the number of patients, with concentrations almost everywhere in Mueang Phuket District, especially in Na Bon Nai village and Bo Rae village in Wichit Sub-district, and Koo Koo village, Rasada Sub-district, with 27, 24, and 22 cases respectively. In 2015, it was found concentrated in the Mueang District, Nabon Tai village, Wichit Sub-district with 43 cases, Koh Sire village, Ratsada Sub-district with 23 cases, and Thung Kha Pha Niang Taek village, Ratsada Sub-district with 22 cases. In 2016 and 2017, similar distributions of patients were found in Mueang Phuket District. In 2016, they were mostly found in Na Bon Tai village, Wichit Subdistrict with 17 cases, and Ko Sire village, Ratsada Sub-district with 17 cases. In 2017, many patients were found in Na Bon Tai village, Wichit Sub-district with 36 cases, and Karon village, Karon Sub-district with 36 cases. When considering the incidence of dengue fever patients at the village level per hundred thousand populations, it is found that over the 11-year period, there are two patterns of distribution 1) Clear clustering in two locations, namely the Seaside village in Cherng Talay Sub-district, Thalang District, and the Takhian village in Thep Krasattri Sub-district, Thalang District, observed in the years 2007-2008, 2010, 2013-2014, and 2016-2017. Particularly notable is the year 2013, which saw the highest incidence, with clear outbreaks in these two villages, and 2) Clear clustering in one location, found in the Seaside village in Cherng Talay Sub-district, Thalang District, especially evident in 2009 with the least spread (see Figure 6).

Therefore, special attention should be paid to surveillance in these specific villages to prevent the spread of dengue fever. From the previous study of the whole Phuket province, we have now conducted community-level research through field surveys of residential buildings and water container inspections, using the Household Index (HI) and Container Index (CI) at six survey locations. Regarding, site 1 and 6, there is a notable difference in land use surrounding the survey sites, with site 1 being a commercial area and site 6 being an agricultural and forest community. Additionally, other sites have interesting analysis results as follows (Figure 7).

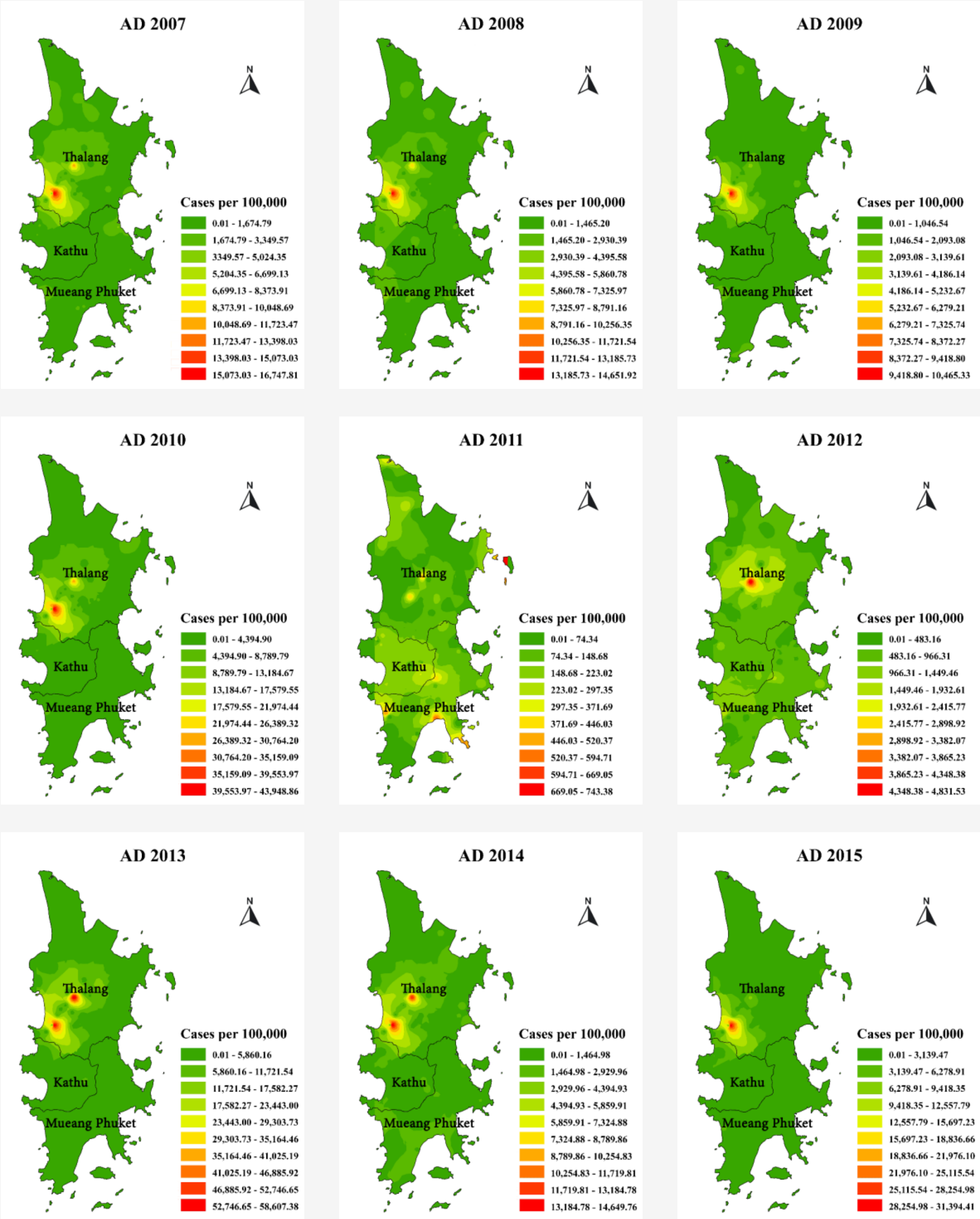


Figure 6: The occurrences of dengue fever cases per hundred thousand populations, for the years 2007 – 2017 (continue next page)

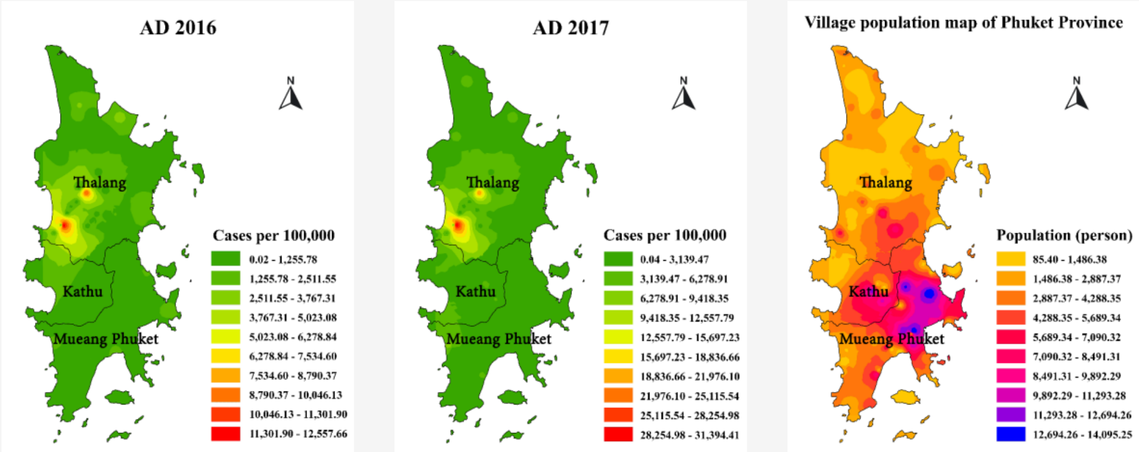


Figure 6: The occurrences of dengue fever cases per hundred thousand populations, for the years 2007 – 2017 (continue from previous page)

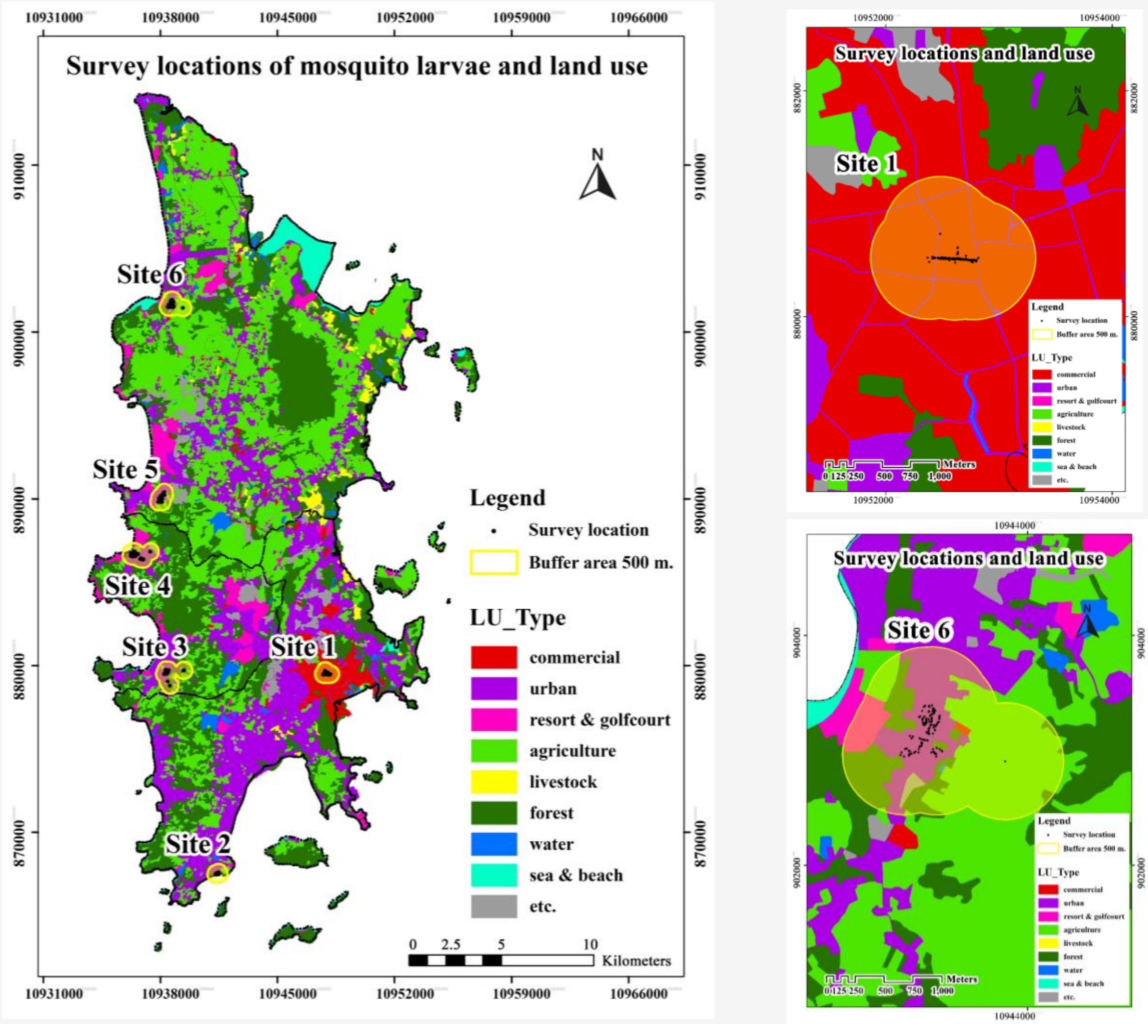


Figure 7: The positions of surveyed mosquito breeding sites overlaid with land use characteristics in Phuket province. Survey Site 1 represents a commercial area, while Site 6 represents an agricultural and forest community

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Table 2: The relationship between surveyed mosquito breeding sites and land use characteristics within a 500-meter buffer zone

Site	Study Area	Land Use (sq.m.) and Percentage (%) Value							
		C	**U**	**R**	**A**	**F**	**W**	**S**	**Etc.**
1	Commercial Area (Old Town Community, Mueang Phuket District)	1,330,095 94.96%	70,601 5.04%	-	-	-	-	-	-
2	Slum Community (Baan Thai Mai, Mueang Phuket District)	-	512,635 70.89%	-	151,168 20.91%	55,941 7.74%	-	3,367 0.47%	-
3	Rural Community, Forest, and Agriculture (Baan Na Nai, Kathu District)	-	1,380,495 50.24%	-	574,495 20.91%	738,840 26.89%	5,655 0.21%	-	48,265 1.76%
4	Urban Community, Tourism, and Forest (Baan Nok Lay, Kathu District)	-	1,512,824 68.36%	133,414 6.03%	176,834 7.99%	155,372 7.02%	-	51,851 2.34%	182,567 8.25%
5	Urban Community, Agriculture, and Forest (Baan Bang Tao Nok, Thalang District)	-	1,074,086 65.07%	-	296,510 17.96%	177,185 10.73%	6,841 0.41%	-	96,063 5.82%
6	Agricultural and Forest Community (Baan Bang Ma Lao, Thalang District)	8,289 0.40%	572,659 27.96%	113,569 5.54%	956,021 46.67%	372,522 18.19%	2,553 0.12%	-	22,811 1.11%

C = Commercial, U = Urban, R = Resort & golf course, A = Agriculture, F = Forest, W = Water, S = Sea & beach, Etc. = Others.

From Table 2, the relationship between the surveyed positions of mosquito breeding sites and land use characteristics within a 500-meter radius, where the approximate distance that mosquitoes can fly is considered. Regarding each surveyed area, field surveys were conducted to collect data on both containers and mosquito breeding sites. Then it is calculated to find a relationship with the surrounding environment. The environmental and landscape characteristics of the community that were surveyed were as follows:

Site 1 is an old town community in Phuket City. Primarily, it is a commercial area and the origin of Phuket City. It consists of urban and built-up land, including residential areas, commercial areas, and private/governmental office areas (Figure 8).

Site 2 is the community of Ban Thai Mai Village in Mueang Phuket District. It is a slum-type urban community. Houses in residential areas are very dense and clustered together. The environmental sanitation system is not very clean.

Site 3 is Ban Na Nai Community in Kathu District. It appears to be a forest and agricultural area. Houses are clustered together in some spots. and there is a distribution of buildings in low-density residential communities.

Site 4 is Ban Nok Lay community in Kathu District, characterized as an urban area, resort area, agricultural areas, forests and sea areas, sandy beaches, and buildings are not densely located. There is a clustering at some points.

Site 5 is the community of Bang Thao Nok community in Thalang District. It is a mixed area comprising urban communities, forest zones, and agricultural areas. Additionally, it is a lightly packed tourist community, with some areas densely packed with residences occupied by employees working in the tourism business.

Site 6 is the community of Bang Malao in Thalang District (Figure 9). It is primarily an agricultural and forested area. The community consists of scattered residential buildings, interspersed with water bodies and structures.

From the data of the HI index (Table 3), it was found that during the end of rainy season, only *Aedes aegypti* were found at sites 1, 2 and 3, while both *Aedes aegypti* and *Aedes albopictus* were found at sites 4, 5 and 6. In the summer and rainy seasons, the data were quite obvious. In sites 1-5, only *Aedes aegypti* were found while in site 6 we found both *Aedes aegypti* and *Aedes albopictus* because site 1 and site 6 there is differences in land use surrounding the survey area. Site 1 is predominantly urban, a commercial area while Site 6 is characterized as an agricultural and forest community.

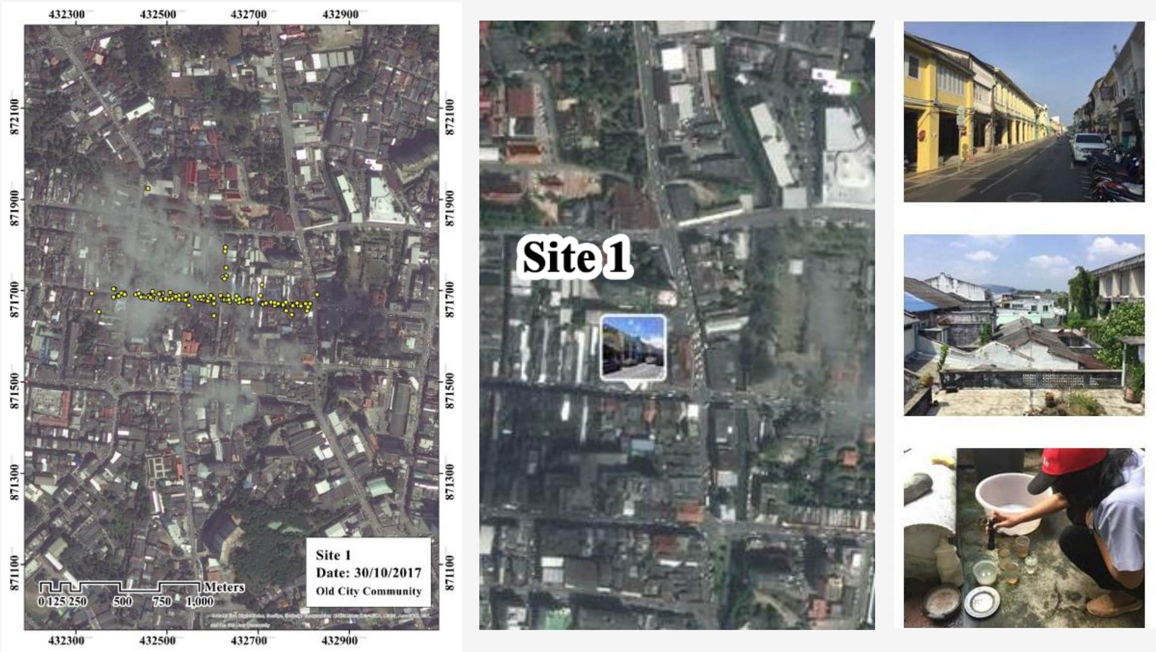


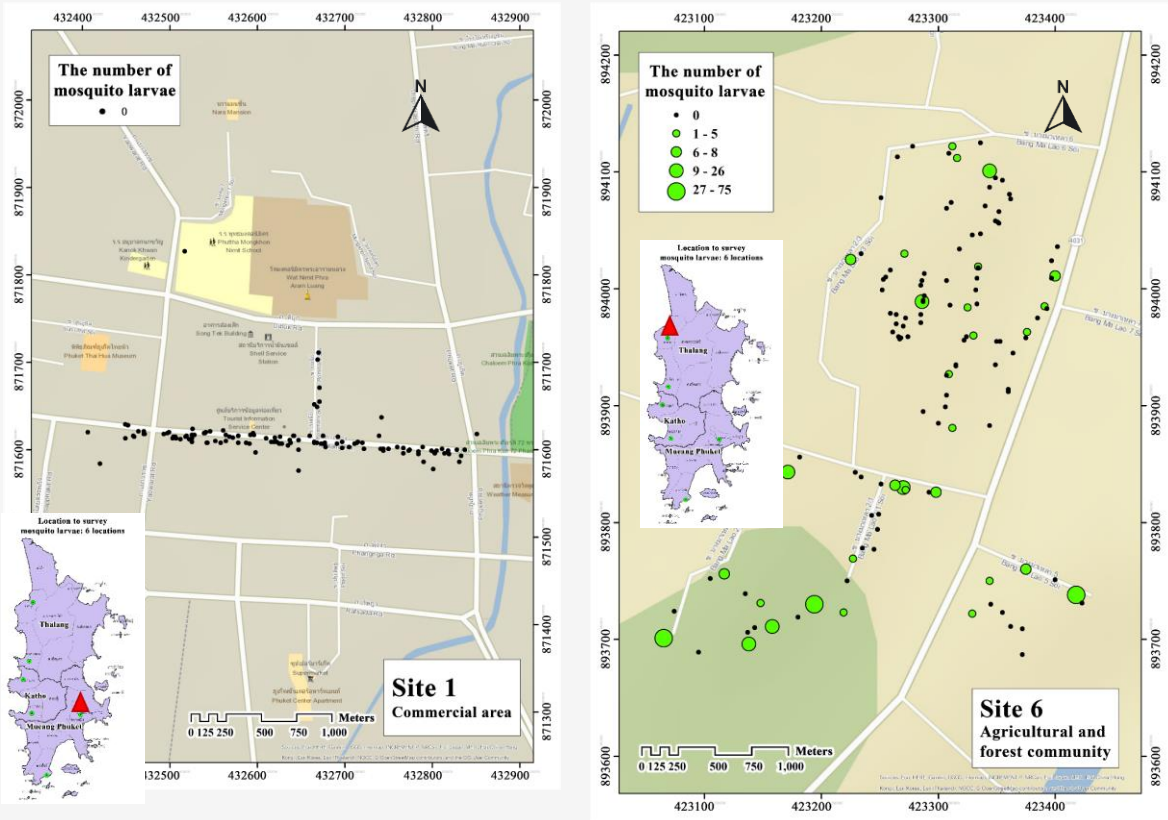
Figure 8: The environmental conditions and landscape, as well as the sampling of mosquito larval indices in Site 1, which is the commercial zone, an old town community, located in Talat Yai sub-district, Mueang district, Phuket province

Table 3: The prevalence of residential buildings where mosquito larvae were found, categorized by the type of mosquito larvae and the season; the end of rainy season, summer and rainy

Site	End of rainy season				Summer				Rainy			
	HM	HM-aegypti	HM-albo pictus	HM-ae, al	HM	HM-aegypti	HM-albo pictus	HM-ae, al	HM	HM-aegypti	HM albopictus	HM-ae, al
1	45	45 (100%)	0	0	34	27 (79.4%)	0	7 (20.6%)	32	25 (79.4%)	0	7 (20.6%)
2	48	48 (100%)	0	0	54	48 (88.9%)	0	6 (11.1%)	80	79 (88.9%)	0	6 (11.1%)
3	23	23 (100%)	0	0	23	15 (65.2%)	0	8(34.8%)	37	37 (65.2%)	0	8 (34.8%)
4	43	29 (67.4%)	3 (7.0%)	11 (25.6%)	19	13 (68.4%)	0	6 (31.6%)	19	39 (68.4%)	0	6 (31.6%)
5	51	22 (43.1%)	5 (9.8%)	24 (47.1%)	37	34 (91.9%)	0	3 (8.1%)	62	48 (91.9%)	0	3 (8.1%)
6	61	25 (41.0%)	5 (8.2%)	31 (50.8%)	41	21 (51.2%)	1 (2.4)	19 (46.4%)	50	31 (51.2%)	1 (2.4%)	19 (46.4%)
Total	**263**	**178 (67.7%)**	**18 (6.8%)**	**67 (25.5%)**	**208**	**165 (79.0%)**	**1 (0.5)**	**42 20.5%)**	**208**	**165 (79.0%)**	**1 (0.5%)**	**42 (20.5%)**

*Tested with χ^2 test
HM = Number of houses where mosquito larvae were found
HM-aegypti = Number of houses where mosquito larvae were found (*Aedes aegypti*)
HM-albopictus = Number of houses where mosquito larvae were found (*Aedes albopictus*)
HM-ae, al = Number of houses where mosquito larvae were found (*Aedes aegypti* and *Aedes albopictus*)

Figure 9: The environmental conditions and landscape, along with the sampling of mosquito larval indices in Site 6, which is the agricultural and forest community of Bang Ma Lao, Sako sub-district, Thalang district, Phuket province



(a) (b)

Figure 10: The number of mosquito larvae found in containers placed outside houses during the end of rainy season (a) site 1 in commercial area, and (b) site 6 in agricultural and forest area

The survey results at the container level provided deeper insights. Analysis revealed that at site 1, which is a commercial and urban area, the proportion of containers with domestic mosquito larvae was significantly higher than those with larvae outside the containers, with a ratio of 76.7% to 23.3% during the end of rainy season. In the summer, the proportion was 96.7% to 3.3%, and during the rainy season, it was 75.6% to 24.4%. In comparison, Site 6 showed significant differences and contrasts with site 1. In site 6, the proportion of containers with mosquito larvae was lower than those with larvae outside the containers, with a clear disparity during the end of rainy season, with a ratio of 23.3% to 76.7%, and during the rainy season, with a ratio of 31.3% to 68.7%. Figure 10 compares the CI index between site 1 and site 6 during the end of rainy season. It was found that in the urban and commercial areas (site 1), *Aedes aegypti* were found in containers placed outside the houses, while *Aedes albopictus* were not found. In contrast, in the agricultural and forest community areas (site 6), *Aedes aegypti* and *Aedes albopictus* were found in containers placed outside the houses.

4. Discussion

The analysis revealed a significant outbreak of dengue fever cases during the rainy season, consistent with [1] and [2] due to increased breeding sites or water containers. Especially in 2013, the highest outbreak with the highest number of cases was detected in June. Similar outbreaks were also observed in 2007, 2009 and 2017. This correlates with the trend of dengue fever outbreaks in Thailand, which typically start increasing towards the end of April and peak between June and August, coinciding with the rainy season [25]. However, in Phuket dengue outbreaks can also occur during other seasons, such as in January 2011 and 2016, and November 2015. Additionally, outbreaks were observed in May 2012 during the summer, possibly due to earlier and heavier rainfall that year, leading to mosquito breeding.

Regarding, the spatial distribution, although the highest number of patients is shown in Mueang Phuket District every year, when considering the population per 100,000 people, it was found that the highest incidence of dengue fever cases appeared in Thalang District in 2 villages; Cherngtalay village and Takhian village. As for the spatial relationship of the *Aedes* mosquito larvae index during the post-rainy season, interesting information was found. The type of *Aedes* mosquitoes is clearly related to land use, especially in commercial areas that are urban areas where *Aedes albopictus* are not often found. However, in rural, semi-agricultural and forest areas, *Aedes aegypti* can be found, consistent with [3] where land use and land cover patterns affect the dynamics of the *Aedes* mosquito population and its spatial and temporal distribution [1][2][4][9][10][11] and [12].

However, the results detected both *Aedes aegypti* and *Aedes albopictus* mosquitoes at every survey site (Site 1-6) during the summer and rainy season. Therefore, when humans begin to expand their land, entering the natural forest area for agriculture, *Aedes albopictus* mosquitoes that used to breed only in the forest and agricultural areas changed their breeding to come closer to the community. The survey found *Aedes aegypti* and *Aedes albopictus* mosquitoes in residential communities, which may put people at risk of another epidemic; dengue fever, Chikungunya and Zika fever because in Thailand there are *Aedes* mosquitoes that are the main carriers of these disease (Chikungunya) [25]. Different and more dangerous outbreaks may also occur. *Aedes albopictus* mosquitoes do not only breed in community containers but they can also lay eggs in natural containers, including tree hollows, rock basins, and plant sheaths that support water [2][4][7][8][26][27] and [28]. The spread of *Aedes* mosquitoes may, therefore, not be controlled only by eliminating breeding grounds in residential communities. This statement points out that the transmission cycle of *Aedes aegypti* and *Aedes albopictus* mosquitoes is influenced by changes in land use. Changes in land use and land cover patterns inevitably result in transmission dynamics of insect-borne diseases such as malaria [4][12][20][29][30][31][32] and [33]. Deforestation and changes in Anthropogenic landscapes influence biological and physical environment changes in land systems, habitat changes and invasive species [34][35][36] and [37]. Therefore, disease prevention in public health units must be completely considered in planning along with urban development to achieve balance in health, society, economy and environment.

5. Conclusion

This research has investigated and clarified the dengue fever outbreak in Phuket province, using data from 2007 to 2017 to provide a comprehensive analysis. The findings reveal that the spatial distribution of dengue fever incidence per 100,000 people is highly concentrated in two villages in the Thalang district, necessitating special monitoring, particularly during the rainy season in June. The study also examines the spatial relationship of the *Aedes* mosquito larval index by classifying *Aedes aegypti* and *Aedes albopictus* and comparing them with land use around the community, as measured by the House Index (HI) and Container Index (CI).

The results show that *Aedes albopictus*, which can coexist with *Aedes aegypti*, contributes to an increased risk of dengue fever, Chikungunya, and Zika fever among people living near agricultural and forest areas. However, the research has limitations, as it considers land use types at a single point in time without accounting for changes in land use, which could be explored in future studies. Additionally, incorporating climate data in future research could enhance the spatial analysis, potentially yielding more insightful results.

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