ASSESSMENT OF CHIKUNGUNYA FEVER (CHIKF) RISK AREAS IN THE SOUTH OF THAILAND BASED ON ENVIRONMENTAL, SOCIO-ECONOMIC AND EPIDEMIOLOGICAL DATA

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Abstract. The south of Thailand is a popular touristic destination and, at the same time, a very high-risk area for a Chikungunya fever (CHIKF) outbreak due to the tropical environment. Therefore, it is essential to monitor and potentially prevent the CHIKF disease outbreak in this area. This research aims to apply synergistically the Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) techniques to evaluate CHIKF risk spatially in the south of Thailand. Five criteria related to the risk of CHIKF disease were selected following the most influential factors: CHIKF patient density data, the number of population density, the household number data, land use/land cover and rainfall data. The importance weight of each criterion was calculated; the consistency ratio (CR) that gives less than 0.1 was considered acceptable. The higher the essential weight of a given factor, the more influence it will have on the final decision. CHIKF risk area in 14 provinces in the south of Thailand was reclassified into five categories (very high, high, moderate, low and very low). The CHIKF risk area map was found to be in agreement with the CHIKF patient number data recorded in the last 10 years. The results can support the government's disease control departments and the Provincial Public Health Office to devise strategies and plans for controlling potential outbreaks efficiently.
Keywords: *analytic hierarchy process, outbreak, geographic information system, multiple criteria decision making, criteria*

Introduction

Chikungunya fever (CHIKF) is a serious disease that has become a major public health concern worldwide. The Chikungunya virus (CHIKV) belongs to the genus Alphavirus and the family *Togaviridae* (Tuanudom et al., 2017; Ramachandran et al., 2012). The CHIKV spreads to people by the bite of infected Aedes mosquitoes (Kaslow and Evans, 1997). The symptoms of infection are fever and joint pain including muscle pain, headache, nausea, fatigue or eruption. In the present time, there is no vaccine or medicine against the CHIKV infection, nevertheless, practices to prevent mosquito bites such as wearing neutral-coloured (beige, light grey) clothing and long pants and sleeves, usage of mosquito repellent exist. Outbreaks of CHIKF have occurred in many parts around the world including Europe, Africa and Asia (Garcia et al., 2020). Since the late 1950s, outbreaks of CHIKF have been reported in several Asian countries. In Thailand, CHIKV was found in 1958 (Hammon et al., 1960) and from 1960 to 2000 the disease was reported in several other Asian countries (Cambodia, India, Vietnam Sri Lanka, Philippines, Myanmar and Indonesia) (Chastel,

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1963; Sarkar et al., 1964; Dai and Thoas, 1967; Marchette et al., 1978; Slemons et al., 1984). Since October 2018 large outbreaks of CHIKF in Thailand were reported in the southern part of the country (Tuite et al., 2019). *Ae. Albopictus*, commonly named the Asian tiger mosquito, is found in Asia, Africa, America, Australia and Europe (Akiner et al., 2016; Delatte et al., 2010). As the main occupation of inhabitants of the south of Thailand relates to agriculture (rubber trees, fruit and oil palm farms), and the rainy season lasts for 6-8 months per year, there is, therefore, a high risk of CHIKV infection through the bite of infected Asian tiger mosquitoes. The Department of Disease Control, Thailand (2021) have released the data of reported cases of CHIKF in Thailand between 2011-2021. It is evident that many southern provinces had more than 100 cases of CHIKF. Therefore, it is important to address the role and spatial association between CHIKV and risk areas. Moreover, the southern part of Thailand is a touristic region receiving visitors from other parts of Thailand and abroad such as Europe, Singapore, Malaysia etc., and the number of tourists increases every year (Ministry of Tourism and Sports, 2019). The tourists have a high risk in getting exposed to CHIKF as the local weather and environmental conditions are suitable for the CHIKF. Hence, it is very essential to study the hazard and the factors influencing the CHIKF spread in the south of Thailand in order to establish management practices to prevent and control the disease in the risky regions. The application of spatial analyst Geographic Information System (GIS) tool has been proven a powerful tool for performing spatial analysis of managed data. Currently, GIS technique is applied for investigating and monitoring epidemiological surveillance in the tropical countries (Richardson et al., 2013). Therefore, the combination of Multiple Criteria Decision Making (MCDM) and GIS has advanced the multi-criteria decision by integrating geospatial data (Malczewski, 1999). The Analytic Hierarchy Process (AHP), developed by Saaty (1977) is one of the best tools to frame a decision problem based on a set of priorities, namely weightages (Saaty, 1990).

AHP has been applied in Earth Observation synergistically with GIS which is named spatial-AHP (Siddiqui et al., 1996). The capacity of GIS to combine with the AHP technique has been demonstrated in several studies. For example, Ali and Ahmad (2019) applied AHP and GIS to determine a mosquito-borne diseases in Kolkata Municipal Corporation mapping in the Golestan National Park. Ten factors were selected to determine their weight through a pairwise comparison matrix. The results showed that water bodies is a main factor for mosquito-borne diseases. Ahmad et al. (2017) used a Multi-Criteria Approach to study Malaria epidemic for vulnerability zones. Socio-economic, epidemiological and environmental criteria were considered. 59.1% of the study area is vulnerable from high to very high risk of malaria event. Mollalo and Khodabandehloo (2016) used AHP and fuzzy AHP decision-making methods to determine the Zoonotic cutaneous leishmaniasis (ZCL) risk zones in northeastern Iran. They proved that AHP and FAHP techniques are powerful and useful to analyze high risk areas of ZCL. Chaiphongpachara et al. (2017) found that 9% of the total dengue hemorrhagic fever (DHF) areas were in the very high-risk areas, 23.89% in the high-risk areas, 13.14% in the moderate risk areas and 53.97% in the low-risk areas in Samut Songkhram province. Bohra and Andrianasolo (2001) applied GIS in modelling the Dengue risk based on sociocultural data in Rajasthan, India. In this case 5 classes of risk were classified from very low to very high, with 94.5% of validated samples being acceptably classified. Ai-leen and Song (2000) monitored Dengue in Singapore using GIS technique. The previous

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studies proposed several main causes of disease outbreak such as socio-economic, epidemiological and environmental factors. The essential environmental criteria set for CHIKF risk area maps were in the order of importance. The most important factor was deemed the CHIKF patient number data and the second and third important factors were the number of population density and the household number data respectively. Land use/land cover and rainfall factors were considered as the fourth and fifth criteria in order of importance.

The main goal of the current study is to develop a map-based system indicating CHIKF risk areas in the south of Thailand. The five factors introduced (CHIKF patient number data, the number of population density, the household number data, land use/land cover and rainfall) are considered and combined using GIS and AHP techniques to categorize fire risk zones and derive a final risk map.

Materials and methods

Study area

The south of Thailand comprises of 14 provinces which are located between Andaman sea and the gulf of Thailand (*Fig. 1*) covering a total area of 71,506 km^2. Its climate is characterized as a tropical monsoon with 2 alternating seasons, notably the rainy season which lasts from May to December and the dry season lasting from February to April. The average temperature is 27.9 °C, the maximum average temperature is approximately 24.8 °C and the minimum average temperature is around 40.3 °C. The mean rainfall is approximately 2,066.7 mm. The topography of the region is lowlands and the north part of the provinces is high land and mountainous (Thai Meteorological Department, 2019).

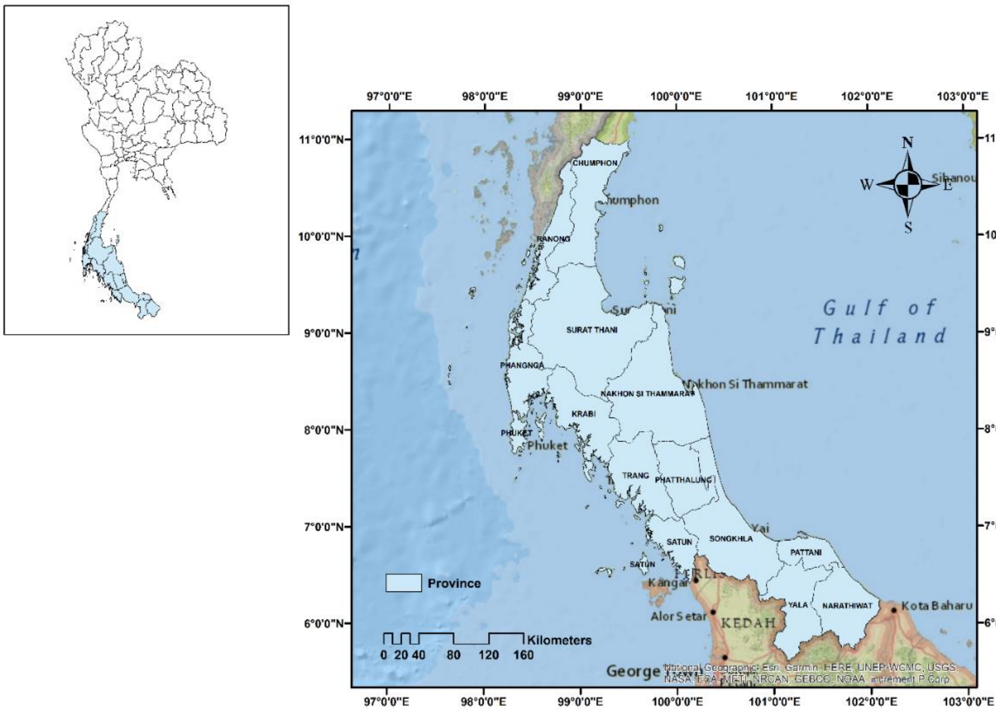

Figure 1. *Study area in the south of Thailand*

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Chikungunya risk factors

Five factors were selected as representative of environmental, socio-economic and epidemiological parameters, which, in sequence of importance based on various research findings, are CHIKF patient number data, population density, the household number data, land use/land cover and rainfall data (Stolerman et al., 2019; Wahid, 2019; Delatte et al., 2010).

Rainfall

The main climatic factor considered to affect Chikungunya transmission is the humidity, which is directly associated to rainfall. As humidity provides suitable conditions for mosquito growth, rainfall impacts mosquito population density. The rainfall data (2019-2021) from the provinces of South Thailand were estimated by the climate data management system (CDMS) method by the Thai Meteorological Department. The average annual rainfall (mm) from 25 stations found in the study area were calculated and used. The kriging interpolation method was selected to build the average annual rainfall map. Then, the rainfall map was classified in five categories (very low, low, moderate, high and very high) as depicted in *Figure 2* (Chaiphongpachara, 2017).

Land use/Land cover (LU/LC)

LU/LC data is an important parameter in support of Chikungunya transmission. Crop cultivation, dense forest, built up and water body areas were considered as possible risk factors for CHIKF outbreak. Falling leaves from plants produce litter with high moisture which provides suitable environment for the mosquito habitats. The LULC data in 2019 were provided by the Land Development Department, Thailand. The LULC map was classified based on satellite imagery from THEOS and Landsat 8 OLI and with ground data. THEOS and Landsat 8 OLI images were selected from 2017-2019. A reclassification was implemented based on five categorical classes. The weight value was set based on the previous scientific findings (Jeefoo and Tripathi, 2011) and is described in *Table 1* and *Figure 2*.

Household density

The number of households considered as a weighted factor in CHIKF outbreak due to the fact that high household density areas provide vital insights into the epidemiology of CHIKF potential risk. Household density was calculated by the number of household in each province per km^2 area in 2020. The household data were collected from the Official statistics registration systems, The Bureau of Registration Administration (BORA), Thailand. As Choropleth map provides an intuitive display for the spatial distribution of density data, household density data was calculated using Choropleth technique in this study (*Fig. 2*) (Prabphala, 2008).

Population density

Population density is one of the most essential socio-economic factors concerning increasing CHIKF risk. Population data in 2020 were retrieved from Department of Provincial Administration, Thailand. Population density was calculated by population

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number in each province per km^2 area. Subsequently, we used Choropleth map to classify 5 classes ranging from very low to very high (*Fig. 2*) (Somard et al., 2017).

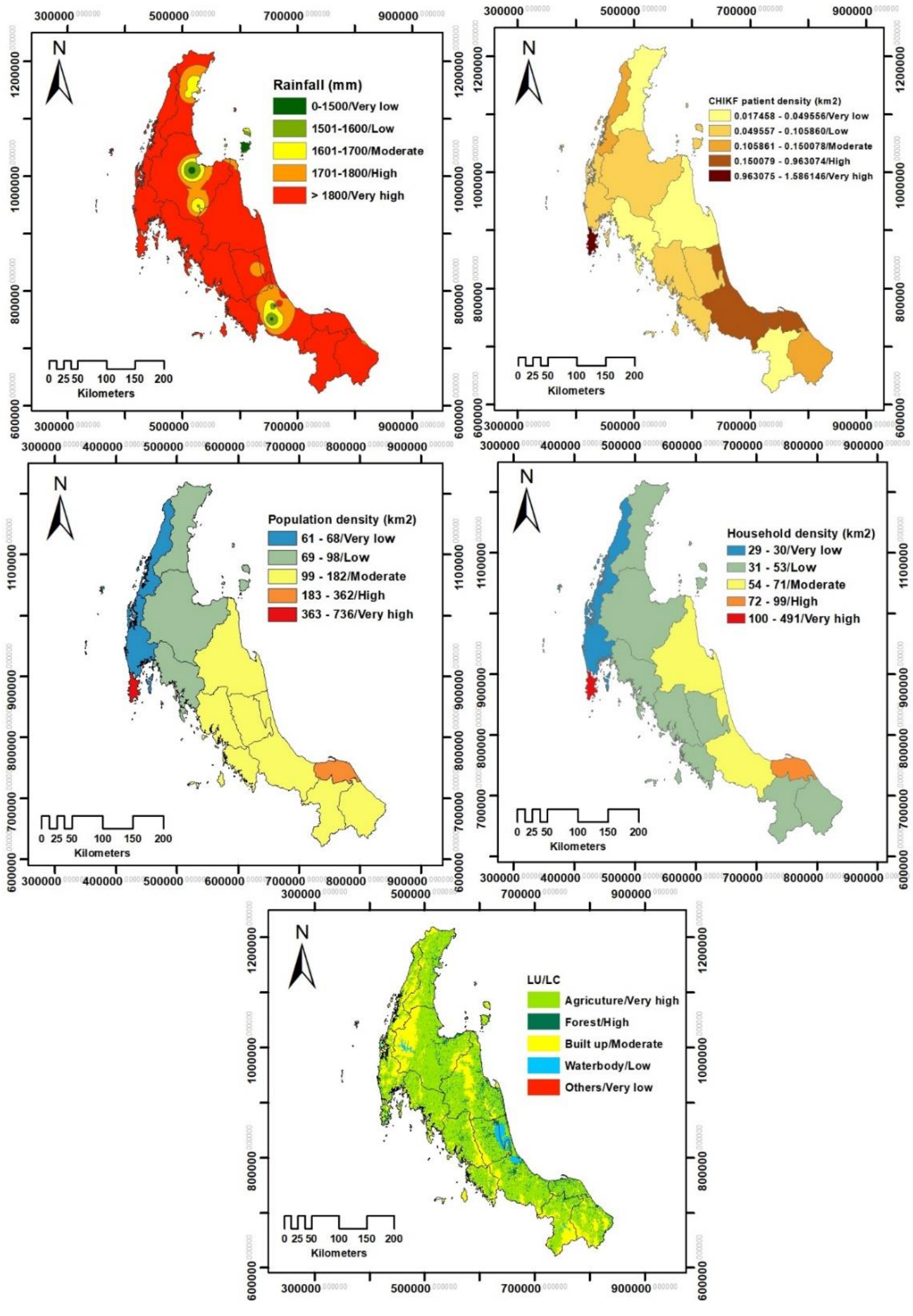

Figure 2. *The individual input layers of (a) rainfall (mm), (b) CHIKF patient density (km^2), (c) population density (km^2), (d) household density (km^2) and (e) LU/LC classification*

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Table 1. *Factors, rank and weight for the environmental, socio-economic and epidemiological criteria*

Criteria/factor	Class	Range	Weight	Reference
Rainfall (mm)	>1801 1701-1800 1601-1700 1501-1600 0-1500	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low)	0.07	Chaiphongpachara (2017)
Land use/Land cover	Agriculture Forest Built up Waterbody Others	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low)	0.11	Jeefoo and Tripathi (2011)
Household density (household number/km^2)	100-491 72-99 54-71 31-53 29-30	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low)	0.20	Prabphala (2008)
Population density (population number/km^2)	363-736 183-362 99-182 69-98 61-68	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low)	0.25	Somard et al. (2017)
CHIKF patient density (CHIKF case/km^2)	0.963075 - 1.586146 0.150079 - 0.963074 0.105861 - 0.150078 0.049557 - 0.105860 0.017458 - 0.049556	5 (Very high) 4 (High) 3 (Moderate) 2 (Low) 1 (Very low)	0.36	Somard et al. (2017)

CHIKF patient number data

CHIKF patient number data is the most important factor for analyzing the disease outbreak risk assessment and has been assigned the highest weight value in this multi-criteria model. The data of the DHF patient number in each province from 2019 to 2021 were derived from the Bureau of Epidemiology, Department of Disease Control, MoPH, Thailand. The intensity of CHIKF patient data in each province was calculated by patient number per km^2 area. For risk area, the intensity of CHIKF patient data in each area was grouped into 5 risk area classes (*Fig. 2*) (Somard et al., 2017).

Analytic hierarchy process (AHP)

We applied the AHP, which was developed by Saaty (1977), to estimate the weight or importance of each individual CHIKF risk factor. A qualitative hierarchy of importance among the five parameters is established by classifying the parameters with a pairwise comparison. The importance of each parameter was defined from the literature review as shown in *Table 1.* The values of each factor were classified into five levels (very low, low, moderate, high and very high). The weights for each factor were calculated by dividing the sum of each row with the total number of factor (*Table 1*). The consistency index (CI) and the consistency ratio (CR) were calculated based on the *Equations 1* and *2,* respectively.

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$$CI = \frac{\lambda_{max} - n}{n-1} \quad \text{(Eq.1)}$$

where λ_{max} is the maximum Eigen value of the comparison matrix, *n* is the dimension of comparison matrix.

$$CR = \frac{CI}{RI} \quad \text{(Eq.2)}$$

where *RI* is the Random Consistency Index and if $CR \leq 0.10$ is considered acceptable.

In this research, CI is 0.04 and RI is 1.12; thus, CR is 0.03 which is less than 0.10. Then the weights calculated are considered acceptable.

The final CHIKF risk map was derived based on the linear combination of five criteria with the weights for each factor from the AHP as *Equation 3*.

$$\text{CHIKF risk} = 0.07 \times \text{Rainfall} + 0.11 \times \text{LULC} + 0.20 \times \text{Household density} + 0.25 \times \text{Population density} + 0.36 \times \text{CHIKF patient data} \quad \text{(Eq.3)}$$

Results

The CHIKF risk map was generated based on five factors related to rainfall, LULC, household density, population density and CHIKF patient data. The spatial layer of each factor was reclassified into five risk classes, namely very high, high, moderate, low and very low as presented in *Figure 2*.

Moreover, the percentage and zone of the CHIKF risk map were calculated (*Table 2*). The study area, which covers an area of approximately 71,506.10 km^2, was categorized as 0.79% of very high class (562.77 km^2), 13.23% of high class (9,458.89 km^2), 61.59% of moderate class (44,039.27 km^2), 24.39% of low class (17,439.26 km^2) and 0.01% of very low class (5.91 km^2) as presented in *Table 2*. The final CHIKF risk map in the south of Thailand is presented in *Figure 3*. It indicated that very high- and high-risk areas were found in association with environmental, socio-economic and epidemiological parameters. Phuket province is classified as very high CHIKF risk area and Songkhla and Pattani provinces are classified as high CHIKF risk area. The main reason is the highest of CHIKF cases density reported in Phuket, Songkhla and Pattani provinces. Furthermore, the very high- or high-risk areas were calculated where the household density was greater than 72 households/km^2, population density was more than 183 persons/km^2 and CHIKF patient density was higher than 0.2 cases/km^2. Also, agriculture and forest areas of land use and land cover layer were considered as high and very high risk and the quantity of rainfall (mm) was more than 1,701 mm (*Fig. 2*). On the other hand, Krabi, Phangnga and Chumphon provinces were indicated in low CHIKF risk area. Environmental factors such as rainfall (mm) was lower than 1600 mm and waterbody and others (other miscellaneous lands) were considered low and very low classes. For epidemiological parameters, CHIKF patient density (km^2) was less than 0.05 case/km^2. Moreover, the household density was lower than 53 households/km^2, the population density was less than 98 persons/km^2 in case of socio-economic factors. Ranong, Surat Thani, Nakorn Si Thammarat, Trang, Phattalung, Satun, Yala and Narathiwat provinces were classified as moderate CHIKF risk areas. The factors were analyzed for moderate class; the quantity of rainfall (mm) factor was the value between 1601-1700 mm; the built-up area was considered for this

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level; the household density areas were displayed between 54-71 household number/km^2; the population density areas were presented between 99-182 population number/km^2 and CHIKF patient density areas were showed between 0.11 - 0.15 CHIKF case/km^2. The Bureau of Epidemiology, Department of Disease Control, Ministry of Public Health, Thailand reported the number of Chikungunya patient cases per province for 14 provinces in the south of Thailand between 2011 and 2021 (*Fig. 4*). (The Department of Disease Control, Thailand (2021). It was found that Songkhla province had the highest CHIKF patient cases (4,250 cases) while Nakorn Si Thammarat province indicated the lowest CHIKF patient cases (174 cases). *Figure 5* indicates that the number of CHIKF disease patients is in strong correlation with the CHIKF disease risk assessment map. For example, Phuket, Songkhla and Pattani provinces have high CHIKF diseased patients which relate to very high and high class CHIKF disease risk assessment map while Chumphon, Phangnga and Krabi provinces identified as low class which related to low CHIKF diseased patients.

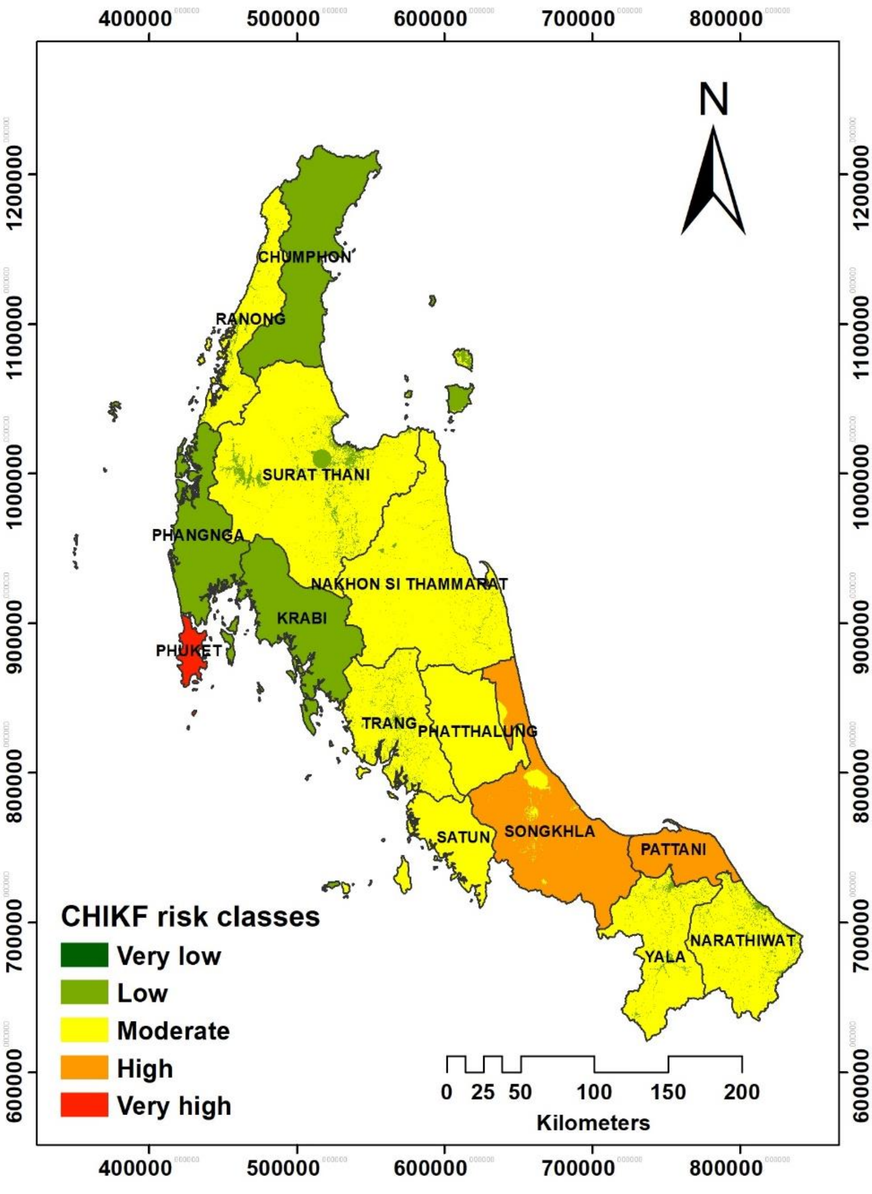

Figure 3. *The final CHIKF risk map*

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Table 2. *Percentage and area coverage of the CHIKF risk map*

CHIKF class	Area (km^2)	Area (%)
Very high	562.77	0.79
High	9,458.89	13.23
Moderate	44,039.27	61.59
Low	17,439.26	24.39
Very low	5.91	0.01
Total	71,506.10	100

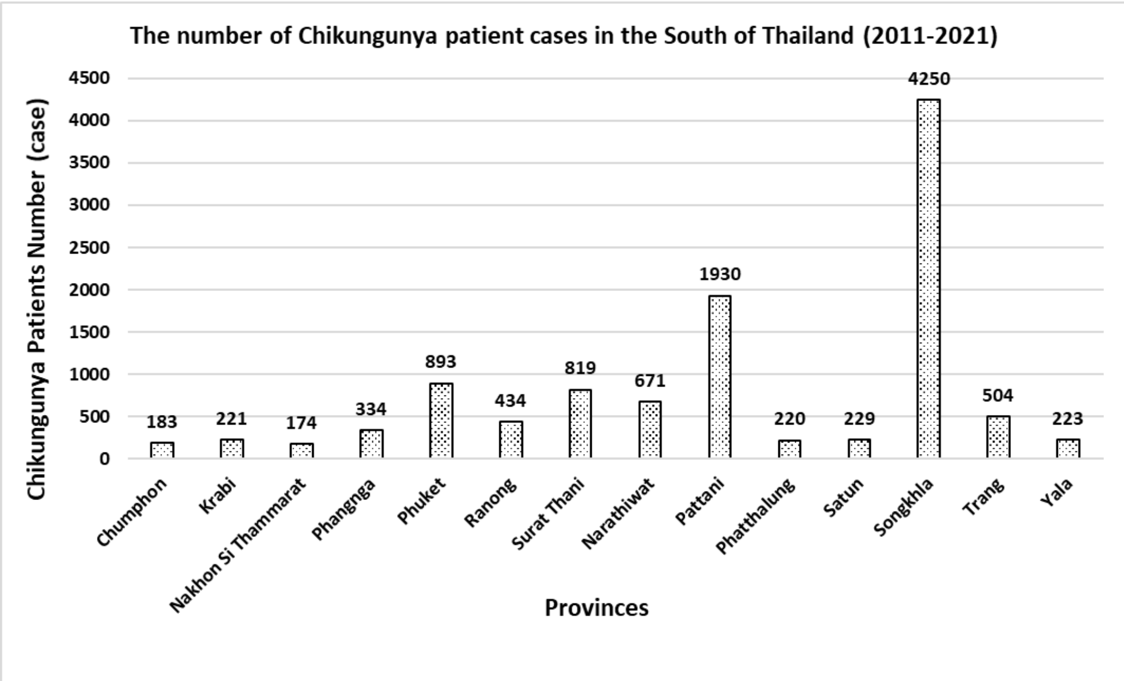

Figure 4. *The number of chikungunya patient cases per province for the 14 administrative provinces in the south of Thailand between 2011 and 2021 (The Department of Disease Control, Thailand (2021))*

Discussion

In this research, GIS and AHP techniques were selected to analyze five CHIKF-related parameters (namely rainfall, LU/LC, household data, population data and CHIKF patient data) and derive a CHIKF risk map covering 14 provinces in the south of Thailand. The results indicated that the Phuket province is assigned a very high CHIKF risk category and Songkhla and Pattani provinces are classified as high CHIKF risk class (*Fig. 3*). Interestingly, the same pattern occurs in the assessment of the CHIKF risk based on the number of Chikungunya patient cases in 14 provinces of the south of Thailand. Sonkghla, Pattani and Phuket province showed the top three highest cases in the south of Thailand which were 4,250, 1,930 and 893 cases, respectively (*Fig. 4*). Ranong, Surat Thani, Nakorn Si Thammarat, Trang, Phattalung, Satun, Yala and Narathiwat provinces were assigned a moderate CHIKF risk areas. Most of them related to the number of Chikungunya patient cases except Nakorn Si Thammarat province. Even though Nakorn Si Thammarat province showed the lowest cases for the

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last 10 years, household density (km^2) and population density (km^2) were classified in moderate groups. Moreover, the south of Thailand receives comparatively higher amounts of rainfall than other parts of Thailand during the rainy season and the inhabitants' main occupation is related to agriculture, therefore Nakorn Si Thammarat province was considered as moderate class based on all factors. Chumphon, Phangnga and Krabi provinces were classified as low CHIKF risk category which concerned on the number of Chikungunya patient cases and household density (km^2), population density (km^2) and CHIKF cases density were classified low and very low classes.

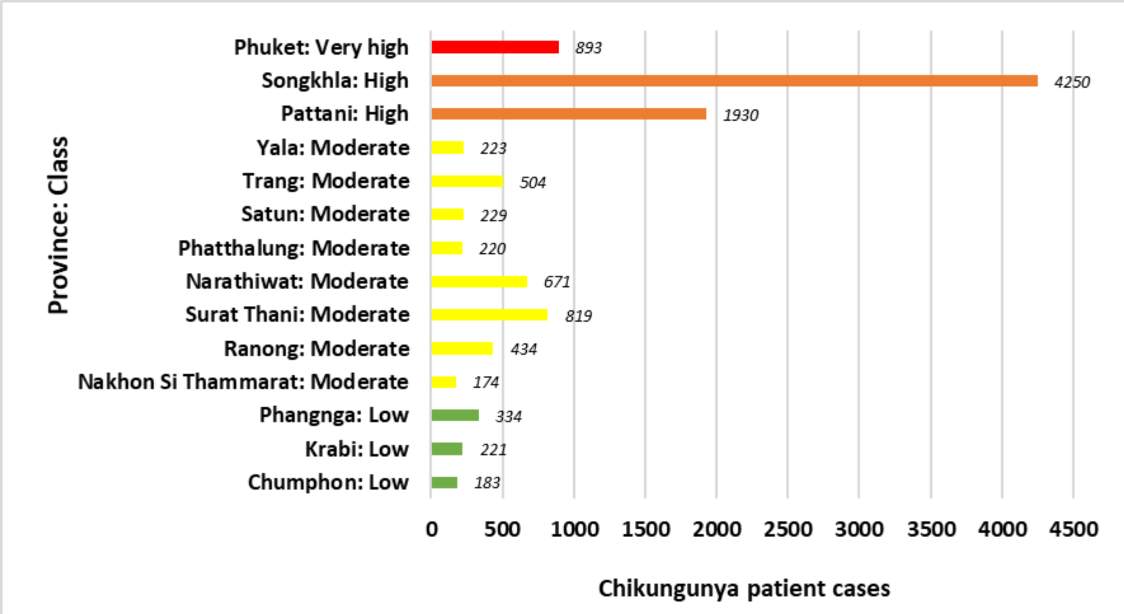

Figure 5. *Chikungunya patient cases with the disease risk assessment class in 14 provinces*

For the singular input layers, the rainfall data were selected for maintaining the solidity of the methodology in the spatial context. The rainfall data were derived by spatially interpolating the data from 25 Thai Meteorological stations covering 14 provinces in the south of Thailand. As the rainy season lasts for many months from May to December, the amount of rainfall is comparatively higher than other parts of Thailand. Therefore, very high and high classes were classified in the rainfall map for one of the criteria for analyzing CHIKF risk area. LU/LC layer is the fourth most important contributing factor in the overall CHIKF risk area. It is the very high and high risk category of the LU/LC class, mainly agriculture and forest. The three layers related to proximity to epidemiological parameters, CHIKF patient density (km^2), population density (km^2) and household density (km^2). We calculated data in each province related to each area per spatial unit and classified in 5 classes. The higher number of CHIKF patient, population and household have a higher chance of contracting the CHIKF disease. This study using the AHP technique to apply multiple variables to identify CHIKF risk area, which several studies have attempted with similar factors and using AHP tool for analyze the diseases from mosquitoes. Similar results were found by Ali and Ahmad (2018) who applied the AHP and GIS techniques to derive a Dengue risk map in West Bengal, India. Six criteria (population density, household density, water area, LU/LC, temperature and elevation) were selected in this study. The most

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important factors were the household and population data. Chaiphongpachara et al. (2017) used population density, household number data for most influential factors to map dengue hemorrhagic risk province in Samut Songkhram province. Last but not least, Dom et al. (2016) proved that GIS-based AHP has a strong ability to predict disease from a mosquito risk map in Subang Jaya, Malaysia. From previous studies and our results we reckon that AHP technique is a powerful tool to help the local government to make a plan for CHIKF disease preparedness and mitigation.

Conclusions

In this research, CHIKF risk was estimated based on the combined application of AHP and GIS techniques based on five individual input layers representative of environmental, socio-economic and epidemiological parameters. Five factors are the main important criteria, either directly or indirectly, related to the occurrence of CHIKF disease risk. The model indicated that the Phuket province has a very high CHIKF risk class while Chumphon, Phangnga and Krabi provinces are classified as low CHIKF risk class. The results are in agreement with the number of CHIKF patients. The AHP application presented that the method is useful and powerful for assessing the CHIKF risk in this specific area. The results can help the people and organizations to create decision making processes. It is envisaged that the AHP technique can be applied in vector-borne diseases such as dengue, malaria etc.

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Conflict of interests. The authors declare no conflict of interests.

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