Dengue Risk Zone Index (DRZI) for Mapping Dengue Risk Areas

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Abstract
Geographic Information System (GIS) techniques are used to develop the risk zone map of Dengue Fever (DF) / Dengue Haemorrhagic Fever (DHF) in Chachoengsao province, Thailand. The risk zonation index is derived using the Analytical Hierarchy Process (AHP). The medical database considered for the study was referenced to the geographical and meteorological data layers. Based on this analysis, potential areas were categorized as very high, high, moderately high, moderately low, low, and very low risk categories. The model used in this study provided valuable information to prepare DF/DHF risk zones for decision support to mitigate the epidemic. Factor weights used in AHP were evaluated and found to be acceptable as the consistency ratio (CR) was 0.031, which was < 0.1. Spatial modelling included a huge database about physical-environment, climatic, and demographic factors. Approximately 74.96% people lived in very high, high, and moderately high risk zones. The most at risk zone was shown to be Mueang Chachoengsao district with a population of 142,485 or 22.34% of total population. The results from AHP based DF/DHF risk zonation gave useful information on different levels of disease risk areas. The methodology is general and can be applied in other application fields, such as disease outbreak during natural disasters.

1. Introduction

Dengue is an arboviral disease which includes four serotypes of *Flavivirus*, Dengue-1, Dengue-2, Dengue-3, and Dengue-4 (DEN-1, DEN-2, DEN-3, and DEN-4) transmitted by mosquitoes, mainly *Aedes Aegypti* (Gubler and Kuno, 1999, Rotela et al., 2007 and Thammapalo et al., 2008). Dengue Fever (DF) is primarily a disease found in older children and adults. It is characterized by the sudden onset of fever and a variety of nonspecific signs and symptoms, including frontal headache, retro-orbital pain, body aches, nausea and vomiting, joint pains, weakness, and rash. Dengue Hemorrhagic Fever (DHF) is primarily a disease found in children under the age of 15 years, although it may also occur in adults. It is characterized by the sudden onset of fever, (which usually lasts for 2 to 7 days), and a variety of nonspecific signs and symptoms (Gubler, 1998). The first known cases of DHF occurred in Manila, Philippines in 1953-54, and within 20 years, the disease has taken epidemic dimension throughout Southeast Asia. By the mid1970s, DHF had become a leading cause of hospitalization and death among children in the region (WHO, 1997). In Asia, the DHF epidemic has expanded geographically from Southeast Asian countries towards the west i.e. Bangladesh, India, Sri Lanka, the Maldives, and Pakistan and also to the east in China (Gubler, 1998). In 1997, dengue viruses and *Aedes Aegypti* mosquitoes had a worldwide presence in the tropics. Over 2.5 billion people now live in areas where dengue fever is epidemic. DF/DHF poses a constant serious risk and continues to be a major public health threat in Thailand (Nakhapakorn and Jirakajohnkool, 2006). Thailand is located in the heart of the endemic areas of dengue (Kittayapong et al., 2008). The Bureau of Epidemiology, Thailand, has reported that there have been regular outbreaks in the past. Large numbers of cases were reported in 1987 when the incidence rate was as high as 325 cases per 100,000 of the population (based on the number of cases reported). The latest epidemic was in 1998 when the incidence rate went as high as 211 cases per 100,000 of the population. This was the second highest recorded incidence rate in the last 40 years of the history of DF/DHF outbreaks (Bureau of Epidemiology, 2002 and Promprou et al., 2006). Cases of DF/DHF in Thailand have gone up by 36% since the year 2008. The outbreak has killed 17 people in Thailand and affected more than 21,000 since the beginning of the year. The number infected by the virus, which is especially dangerous to children and the elderly, has risen by 36% from the same period in 2006.

The DF/DHF incidence situation in 2007 was more serious than last year because of the early arrival of the rainy season, which brought forward the hatching period of the dengue mosquito. In 2008, rising temperatures, longer rainy seasons and increased urbanization have led to an explosion of dengue cases in Thailand in what health officials are calling a near-crisis situation. Temperatures higher than 20°C are the most favourable for *Aedes Aegypti* mosquitoes (WHO, 1997). At least 14,000 people were diagnosed with DF/DHF in the year 2008 alone and most since April, when the rains started early. DF/DHF is a tropical, mosquito-borne viral disease found mostly in urban areas (The media report, 2008). In 2007, Chachoengsao province in Thailand alone reported an alarming number of 792 DF/DHF cases. Geographic Information Systems (GIS) and Remotely Sensed data were used to evaluate and model the relationships between climatic and environmental factors with the incidences of dengue (Nakhapakorn and Tripathi, 2005). Dengue, a vector-borne viral disease, generally emerges in certain seasons; therefore, the climate seems to be an important factor. Another important factor could be the physical setting of the locations where these diseases frequently occur. Spatial analysis involving the use of GIS for health has been adopted by several workers and is becoming one of the accepted phenomenon (Gesler, 1986, Mayer, 1986, Twigg, 1990, Marshal, 1991, Scholden, and de Lepper, 1991, Walter, 1993 and Nakhapakorn and Tripathi, 2005). The integration of an Analytical Hierarchy Process (AHP) method in GIS for solving spatial planning problems has received considerable attention among multidisciplinary planners. The ability of GIS to integrate with AHP has been demonstrated in several studies related to natural and environmental management (Pawattana and Tripathi, 2008). Multi-criteria decision-making (MCDM) techniques can be used to make the process more explicit, rational and efficient. For multi-criteria evaluation, AHP is used to determine the weights of each individual criterion. Determination of weights in AHP depends on the pair-wise rank matrix which is developed based on the experts' opinion (Tseng et al., 2008). Systematic decision-making process helps the decision maker to summarize and judge all information effectively, define the right question and find out the optimum and the most appropriate solution. An AHP method was applied to derive the weights of parameters because of its simple hierarchical structure, sound mathematical basis, widespread usage, and its ability to measure inconsistencies in judgments (Thirumalaivasan et al., 2003). The potential of GIS for disease mapping, site suitability and risk zonation studies has been proven by several authors when it is integrated with AHP (Vansarochana et al., 2008). Nakhapakorn and Tripathi (2005) performed a study to explore the influence of physical-environmental factors on dengue incidence in Sukhothai province, Thailand using the Information Value (IV) method which shows that a built up area has the maximum influence on the incidence of dengue compared to other landcover or landuse classes. Rakotomanana et al., (2007) carried out a study using the multi-criteria evaluation method of weighted linear combination technique with GIS to determine risk zones from the malaria epidemic in the Central highlands of Madagascar. El Morjani Zel et al., (2007) used the pair-wise comparison method developed by integrating AHP and GIS based methods to develop the first volume of the Atlas which looks at the spatial distribution of 5 natural hazards (flood, landslide, wind speed, heat, and seismic hazards). Brent et al., (2007) used AHP method to establish and optimise health case waste management (HCWM) systems. Rinner et al., (2006) adopted a map-based, interactive AHP implementation, which provides a link between a well-understood decision support methods and exploratory geographic visualization. The goal of this paper is to develop a model for DF/DHF risk zonation in Chachoengsao province, Thailand using AHP and GIS. The essential parameters adopted were the location of DF/DHF affected villages, rainfall (1999-2007), micro-land use, elevation, and population density. In this study, temperature data was not selected because the province of Chachoengsao does not have enough thermal variations. An AHP method was applied to derive the weights of parameters using pairwise comparison, sound mathematical basis, widespread usage, and its ability to measure inconsistency in judgments (Thirumalaivasan et al., 2003).

2. Study Area: Chachoengsao Province, Thailand

As shown in Table 1, Chachoengsao province, located in central Thailand, is the second top most provinces in Thailand with a morbidity rate of 39.68 per 100,000. (Ministry of Public Health, Thailand, 2007). Therefore, it is selected as the study area (Figure1). It has also reported high incidence rates for last several years. The province has an approximate population of about 637,665. The province consists of 11 districts, which are Mueang Chachoengsao, Bang Khla, Bang Nam Prieo, Bang Pakong, Ban Pho, Khlong Khuean, Phanom Sarakham, Plaeng Yao, Ratchasan, Sanam Chai Khet, and Tha Takiap. The province is 80 km from the eastern part of Bangkok and covers an area of

5,093.94 km^2 with geographical location between 13° 10' 48"N to 13° 38' 24"N and 100° 50' 24"E to 101° 8' 24"E (Projection system: WGS84 UTM Zone 47 North: 700000E to 831000E, 1460000N to 1544000N). The average temperature is around 34°C in the summer season, 16°C in the cold season and 26°C in the rainy season. In all, the average temperature in Chachoengsao province was between 26.63°C to 29.98°C in during 1999-2007 (Thai Meteorological Department).

3. Methodology

The main objective of the study is to develop a model based on the Analytical Hierarchy Process (AHP) and the multi-criteria approach. A flow chart of the methodology for modeling dengue risk zones is shown in Figure 2.

Criteria and indicators were evaluated by applying GIS techniques on remote sensing data, coupled with the physical-environment, climate, and demographic factors, in association with DF/DHF incidence locations.

3.1 Factors Considered in DF/DHF Modeling

Earlier researchers have used several factors to analyze the influence of DF/DHF incidence like; physical-environmental, land cover types (agricultural, forest, urban, and water bodies), location of DF/DHF affected villages, climate factors (Nakhapakorn and Tripathi, 2005), and population data (Tran, 2005). Satellite images, environmental and epidemiological data were also frequently used (Rotela et al., 2007). In this research following factors were considered (Figure 3):

Table 1: Provinces showing top ten morbidity rate of DF/DHF incidence in year 2007

Rank	Province	Morbidity rate (per 100,000 populations)
1.	Ranong	55.63
2.	*Chachoengsao*	*39.68*
3.	Saraburi	32.78
4.	Phetburi	31.78
5.	Prachinburi	30.15
6.	Ratchaburi	27.51
7.	Rayong	23.93
8.	Bangkok	23.42
9.	Nakhonphatom	23.12
10.	Lopburi	22.87

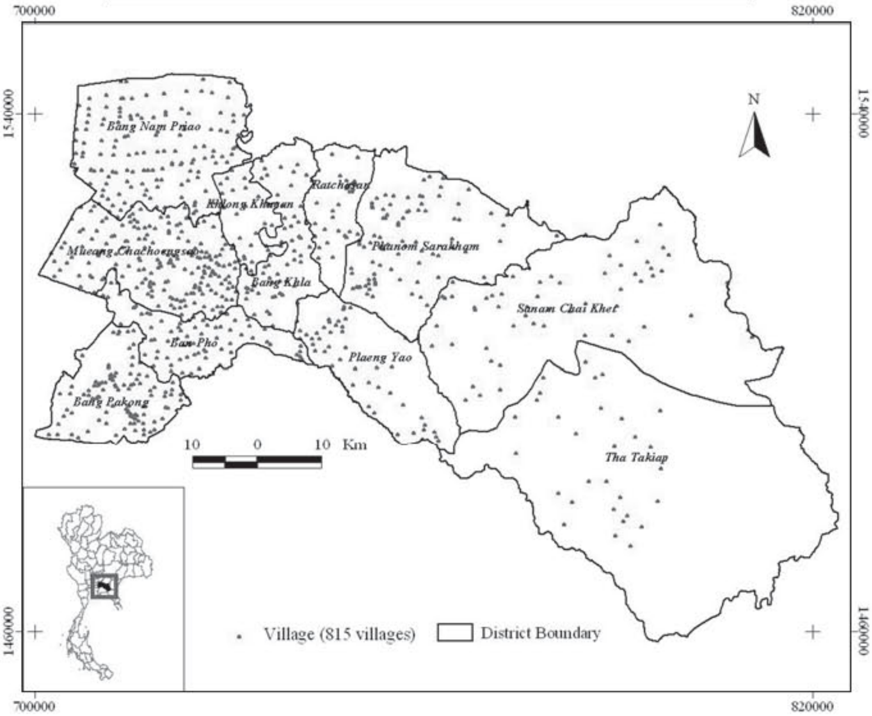

Figure 1: Chachoengsao province, Thailand

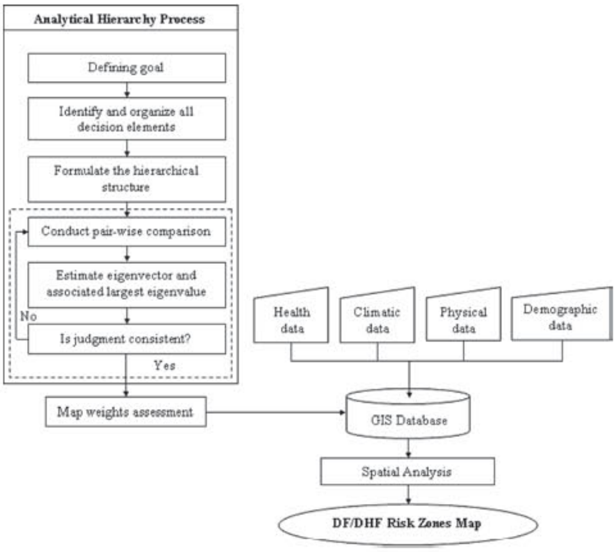

Figure 2: Flowchart for the DF/DHF risk zonation

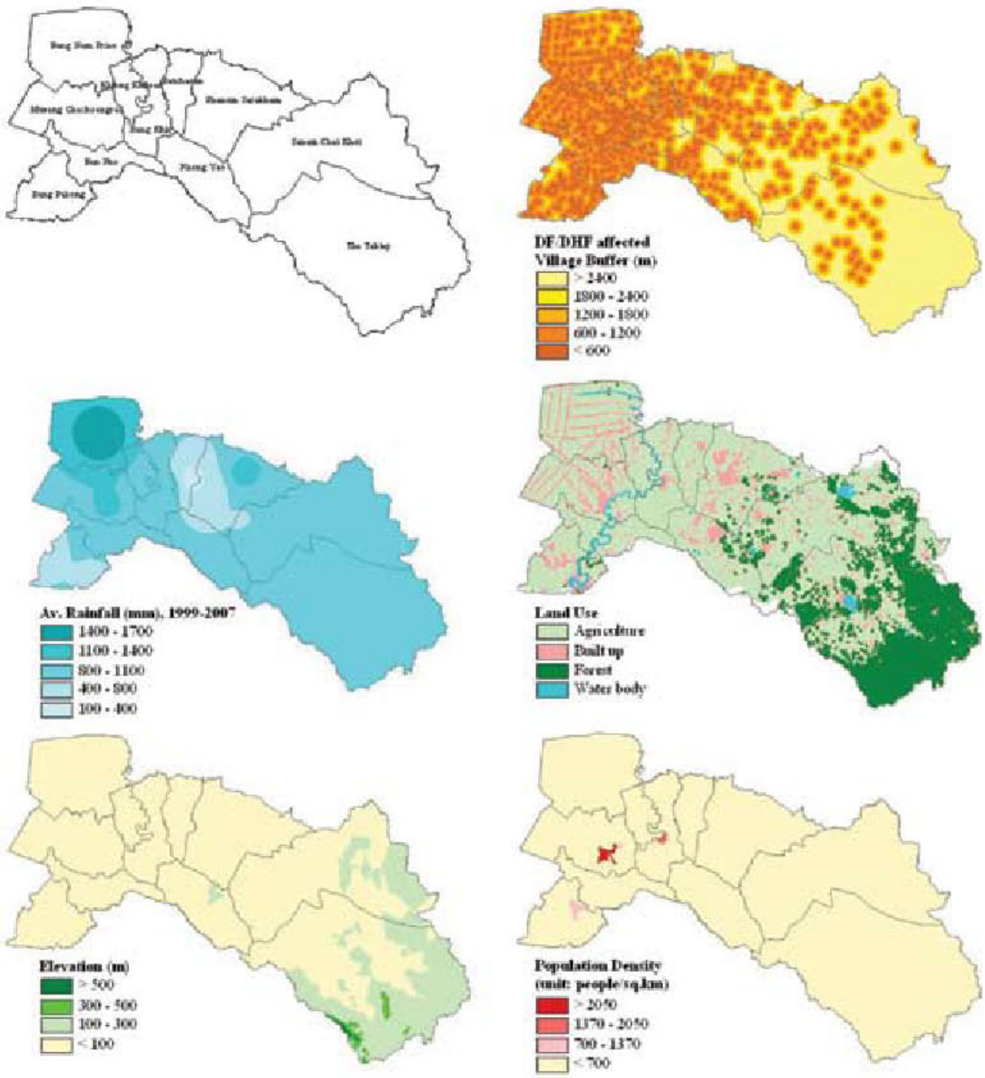

Figure 3: Factors considered in the DF/DHF analysis

Location of DF/DHF Affected Villages: The location data was collected from the Chachoengsao Provincial Public Health Office. The village-wise case data for DF/DHF was obtained from 1999 to 2007. Buffers of specific sizes were created from affected villages to identify the geographic environmental conditions such as land use, water bodies, surrounding villages affected by DF/DHF. The buffer distance was considered keeping two factors in mind: flight distance covered during the life span, and average distance travelled per day by the *Aedes Aegypti* mosquito (Nakhapakorn and Tripathi, 2005). The average lifespan of the female is about 8-15 days and the female mosquito can fly about an average of 30-50 m per day. This indicates that in general, the female mosquito would move about a 240 to 600 m range in their lifetime (Bohra, 2001). The adults of peri-domestic strains of *Aedes Albopictus* are both *zoophilic* and feed outdoors during the day. Their longevity is comparable with that of *Aedes Aegypti*, or a little longer. The active maximum dispersal range of *Aedes Albopictus* females appears to be 400-600 m (Gubler and Kuno, 1999). These buffer zones were combined in one group corresponding to the distance, with respect to life span and average distance travelled per day by the *Aedes Aegypti* mosquito. Therefore, buffer zones of 600 m intervals in five categories were created, which covered 815 villages.

Rainfall: Average annual rainfall data from 1999 to 2007 was collected from the Department of Meteorology, Thailand. The climate office has reported that it has observed that dengue incidence outbreaks coincide with El Nino years. El Nino events in Thailand are related with high temperature and low rainfall. Thailand experiences rain from May to September and the remaining part of the year remains mostly dry. Seasonal fluctuations of dengue were driven by rainfall increases from May to November (Jury, 2008). The average monthly humidity during 1999-2007 was found to be 72.68%.

Land Use: Land use layers for 2007 were collected from the Land Development Department (LDD) of Thailand. LANDSAT 5 Thematic Mapper (TM) data obtained in January 2007 to map land use for Chachoengsao province was employed to develop it. The land use was classified into many types of crops, forest, rice field, urban/village areas, water bodies and so forth. These were grouped into agricultural, forest, built up, and water body areas.

Elevation: The province of Chachoengsao is having varied topography. Elevation was considered to reflect its influence in risk zonation. Elevation data was collected from the Royal Thai Survey Department of Thailand.

Population Density: The population data for 2007 was collected from the Department of Administration, Thailand. Muaeng Chachoengsao, Bang Khla and Bang Pakong districts respectively reported highest population density.

3.2 The Analytic Hierarchy Process (AHP)

The AHP was based on;

Decomposition: A complex problem is decomposed into a hierarchy of interrelated decision elements. A hierarchical structure is established to interrelate and chain all decision elements of the hierarchy from the top level down (Pawattana and Tripathi 2008). The global objective (DF/DHF risk zones) was placed at the top of the hierarchical structure. The lower level of the hierarchical structure consisted of more detailed elements, which interrelated to the criteria in the next higher level. The hierarchical structure of the decision tree is presented in Figure 4.

Prioritization: After the hierarchical structure is established, the relative importance of all decision elements is captured and revealed through pair-wise comparison. This method involves pair-wise comparisons to create a ratio matrix. Pair-wise comparisons of the main and sub-criteria within the same hierarchical level are established. The numerical scales as proposed by Saaty ranging from 1 to 9 were used in the pair-wise comparison matrices (Saaty, 1980).

Synthesis: To identify DF/DHF risk zonation, a weighted linear combination (WLC) method, which is one of the most often used techniques for tracking spatial multi-attribute decision-making (MADM), is used (Malczewski, 1999). The method of WLC is used to assess the weightings for factors, and to map the risks in the various zones (Rakotomanana et al., 2007). It is based on the concept of a weighted average. The relative weights are assigned to each attribute. The weights of the main-criteria are multiplied by the weights of sub-criteria within the same hierarchical level and summing of the products over all attributes to obtain total scores (R_i) by the following formula:

$$R_i = \sum_k w_k r_{ik}$$

Equation 1

Where, w_k and r_{ik} are vectors of priorities of the main and sub-criteria, respectively.

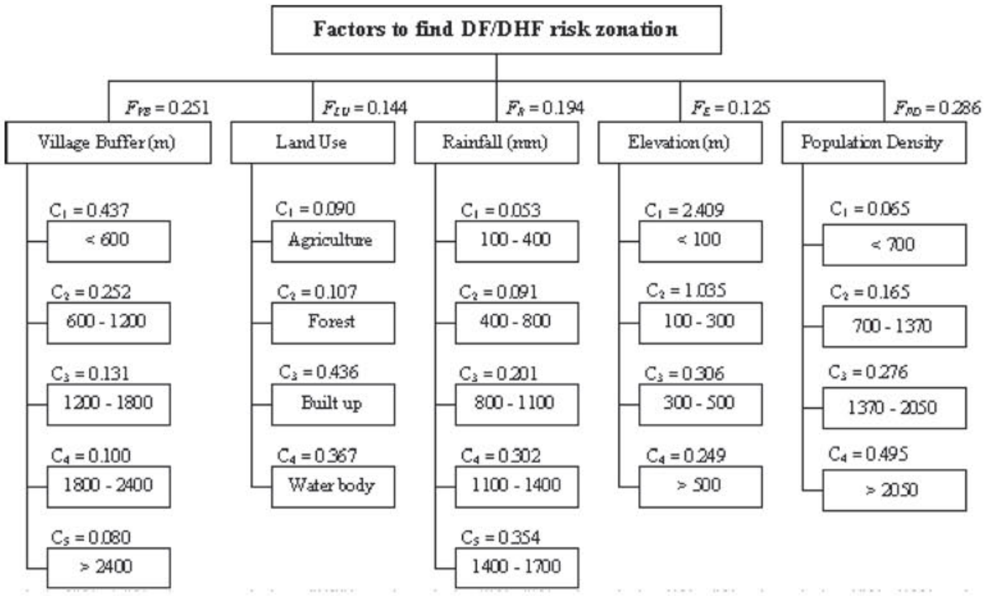

Figure 4: Decision tree for determining the main and sub-criteria for DF/DHF risk zonation

Table 2: Pair-wise comparison elements and weights of main criteria[a]

	Village buffering	Rainfall	Land use	Elevation	Population Density	Weights	Normalized weights
VB	1	1	2	2	1	0.251	2.00
R	1	1	1	2	1/2	0.194	1.54
LU	1/2	1	1	1/2	1/2	0.144	1.15
E	1/2	1/2	2	1	1/2	0.125	1.00
PD	1	2	2	2	1	0.287	2.29

[a]*CI = 0.034, CR = 0.031,* $\lambda_{max} = 5.137$

Table 3: Pair-wise comparison elements and weights of location of DF/DHF affected villages (village buffer)

	<600	600-1200	1200-1800	1800-2400	>2400	Weight	Normalized weight
< 600	1	2	3	4	6	0.437	5.50
600 - 1200	1/2	1	2	3	3	0.252	3.17
1200 - 1800	1/3	1/2	1	1	2	0.131	1.65
1800 - 2400	1/4	1/3	1	1	1	0.100	1.26
> 2400	1/6	1/3	1/2	1	1	0.080	1.00

CI = 0.012, CR = 0.011

4. Results and Discussions

4.1 Model Development: Analytical Hierarchy Process

AHP follows an approach of pair-wise comparison, provides a way for calibrating a numerical scale, particularly in new areas where measurements and quantitative comparisons do not exit (Saaty, 1980 and Brent et al., 2007). The pair-wise comparison matrices for all criteria along with weights are calculated. The pair-wise comparison elements were decided in consultation with experts and field knowledge. The advised scores for each element in Saaty's scale of importance were applied in the matrix. The consistency ratio is less than 0.1 which shows the calculated values are in acceptable range. The pair-wise comparison for the main criteria, sub-criteria and weights are depicted in Table 2 (for main criteria) and Table 3 to Table 7 (for sub-criteria), along with the values of consistency index (CI), consistency ratio (CR) and Eigen (λ_{max}) values. The values of CI and CR of the main criteria were 0.034 and 0.031, respectively. The value of CR for the sub-criteria of location of DF/DHF affected villages (village buffer), rainfall, land use, elevation, and population density were 0.011, 0.015, 0.012, 0.026, and 0.008, in that order. All the weights are acceptable. To calculate the Dengue Risk Zonation Index (DRZI) map the normalized weights of the main criteria were multiplied with the normalized weights of the sub-criteria, each generating output layer using Equation 2, which is a modified form of Equation 1. These multiple layers were merged to a single layer using union operation thus generating DRZI (Dengue Risk Zone Index) layer:

$$DRZI = \Sigma\left(F_{VB}C_i + F_R C_i + F_{LU}C_i + F_E C_i + F_{PD}C_i\right)/\Sigma W_i$$

Equation 2

Where F is factor weight of village buffer (VB), rainfall (R), land use (LU), elevation (E), and population density (PD). C_i is class weight of sub-criteria. The value of DRZI has no quantitative meaning other than to describe in relative significance. The equal interval method was used to define the risk zones. The detailed distribution of the classes is given in Figure 4 and Table 8. On the basis of weights assigned to the criteria in Table 2 and analysis performed, it can be concluded that the significant factors were; population density, location of DF/DHF affected village, rainfall, land cover types, and elevation respectively. The highest DF/DHF incidence was found in areas with population density greater than 2050 per km^2 e.g. Mueang Chachoengsao (Table 7). The high levels of DF/DHF cases were found in the buffer zone of 600 m around an affected village (Table 3). Regarding climatic factor (rainfall data), it can be established that the area with rainfall between 1400 to 1700 mm has the highest risk. Similarly, the area with rainfall between 100 to 400 mm has lower risk (Table 4). Analysis of land cover types has shown that the built up areas show the highest risk. Besides these, the rest of the risk influences were found in water bodies, forest and agriculture areas respectively (Table 5). Elevation maps were developed for 11 districts. The highest DF/DHF risk was found in areas with less than 100 m elevation (Table 6). From the DF/DHF risk zones map (Figure5), it is found that the Mueang Chachoengsao district is classified under a very high DF/DHF zone. Whereas, most of the district of the province falls into a low risk zone. Table 8 shows the summarized results from the study. Moderate high/low risk zone classes consist of 790 villages with an area of 1239.21 km^2, which is 71.06% of the whole province in terms of affected DF/DHF. Very high and high risk zones consist of 11 villages with an area of 27.17 km^2, which is 38.73% of the whole province in terms of DF/DHF. It was noted that the majority of the urban area fall under this category. Similarly low and very low risk zone classes consisted of 14 villages, which is 0.22% of the whole province in terms of affected DF/DHF. Accuracy was determined by calculating the intensity of cases in the areas falling in the predicted influence of DF/DHF. The results obtained are summarised in Table 8.

Table 4: Pair-wise comparison elements and weights of rainfall

	100-400	400-800	800-1100	1100-1400	1400-1700	Weight	Normalized weight
100-400	1	1/2	1/3	1/6	1/7	0.053	1.00
400-800	2	1	1/2	1/4	1/4	0.091	1.73
800-1100	3	2	1	1	1/2	0.201	3.81
1100-1400	6	4	1	1	1	0.302	5.73
1400-1700	7	4	2	1	1	0.354	6.72

CI = 0.017, CR = 0.015

Table 5: Pair-wise comparison elements and weights of land cover types

	Agriculture	Forest	Built up	Water body	Weight	Normalized weight
Agriculture	1	1	1/6	1/4	0.090	1.00
Forest	1	1	1/4	1/3	0.107	1.18
Built up	6	4	1	1	0.436	4.86
Water body	4	3	1	1	0.367	4.07

CI = 0.01, CR = 0.012

Table 6: Pair-wise comparison elements and weights of elevation

	<100	100-300	300-500	>500	Weight	Normalized weight
< 100	1	3	7	9	2.409	9.67
100 - 300	1/3	1	3	6	1.035	4.15
300 - 500	1/7	1/3	1	1	0.306	2.23
> 500	1/9	1/6	1	1	0.249	1.00

CI = 0.023, CR = 0.026

Table 7: Pair-wise comparison elements and weights of population density

	<700	700-1370	1370-2050	2050-2720	Weight	Normalized weight
< 700	1	1/3	1/4	1/7	0.065	1.00
700 - 1370	3	1	1/2	1/3	0.165	2.55
1370 - 2050	4	2	1	1/2	0.276	4.27
> 2050	7	3	2	1	0.495	7.67

CI = 0.007, CR = 0.008

Table 8: AHP-Intensity of DF/DHF incidence

Risk classes	DRZI levels	Affected DF/DHF area (km^2)	Number of cases	Case density (case*1000/ area (km^2))	Affected DF/DHF percentage (%)
Very high	43.08 – 49.80	8.13	4	492.00	22.17
High	36.36 – 43.08	19.04	7	367.65	16.56
Moderate high	29.64 – 36.36	413.46	330	798.14	35.96
Moderate low	22.92 – 29.64	825.75	460	557.07	25.10
Low	16.20 – 22.92	2924.45	14	4.79	0.22
Very low	9.48 – 16.20	903.11	0	0	0
Total		**5093.94**	**815**	**2219.65**	**100.00**

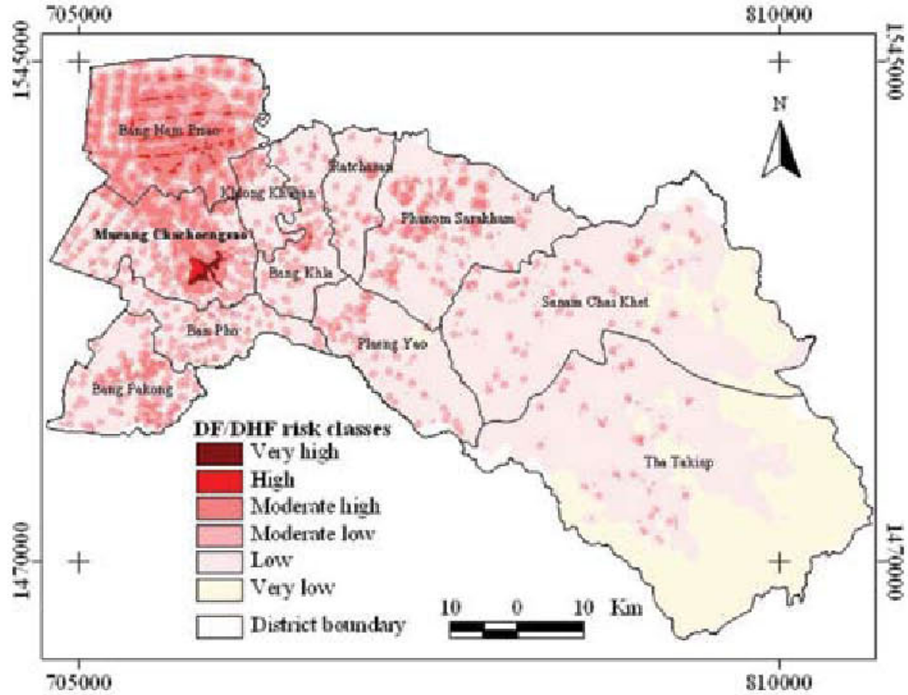

Figure 5: DF/DHF risks zone map of Chachoengsao Province, Thailand

For risk zones, the intensity of DF/DHF incidence (case*1000/area affected by DF/DHF) in each risk zone was calculated and grouped into six risk zone classes. The largest areas in terms of case density lie in a moderately high risk zone (Table 8). Similarly, the case density for a very low risk zone was the lowest i.e. 0 cases per km^2 which is the eastern part of the study area which has mountains and a low population. Approximately, 74.69% of the population lived in very high, high, and moderately high risk classes' level. Mueang Chachoengsao district lies in the very high risk zone and the districts comprises of 142,485 or 22.34% of total the population (Department of Administration, 2007).

5. Conclusions

In this study, AHP was applied in assessing the risk areas of DF/DHF. AHP has gained wide popularity and acceptance in GIS analysis for its robustness in the allocation of stable weights using pairwise comparison. The consistency ratio (CR) was 0.031, which was < 0.1 and found to be acceptable. These weights were later used in a weighted linear combination (WLC) method to develop Dengue Risk Zonation Index (DRZI) for Chachoengsao province. The main advantage of the AHP is its ability to rank choices in the order of their effectiveness in meeting conflicting objectives. Analysis of the physical-environment factors such as landcover types (agriculture, forest, built up, and water bodies) and elevation with the DF/DHF incidences helped in identifying the relationship between built up areas and risk zones. The water bodies offered the second level of high risk influence. Forest and agriculture areas have minor or no risk influence. Areas with an elevation less than 100 m have a high DF/DHF incidence, which is around 81% of the whole area. The Ministry of Public Health may use the dengue risk maps as a guide to plan and control the dengue outbreak and optimize the efforts. DRZI is empirical but the tools adopted are general and can be used to develop risk zonation indices for various other epidemics.

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