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PATTERN OF LEPTOSPIROSIS INCIDENCE IN THAILAND: A SPATIOTEMPORAL ANALYSIS

Surapon Yimsamran¹ and Songkot Dasananda^{2*}

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Abstract

Human leptospirosis is endemic in many provinces of Thailand, especially in its northeast region. At present, little is known about the spatial and temporal patterns of the disease. The current research applied geoinformatic technology and spatial statistics to analyze the leptospirosis incidence data in Thailand during 2003-2009. Exploratory spatial data analysis was done to demonstrate the geographical distribution of the disease. Kulldorff's scan statistic was used to detect significant spatial clusters, temporal clusters and spatiotemporal clusters of leptospirosis in Thailand's provinces. The results revealed that leptospirosis occurred more in the northeast region than in the others. Seven significant spatial clusters and 11 spatiotemporal clusters were detected during the study period. The most likely spatial cluster and the most likely spatiotemporal cluster were located in the northeast region. There was a significant temporal cluster identified during the high peak of leptospirosis in 2009. This study suggests that the northeast region of Thailand is an important area of leptospirosis transmission which requires closer surveillance.

Keywords: Leptospirosis, spatiotemporal cluster, geoinformatics, scan statistics

Introduction

Leptospirosis is a zoonotic bacterial disease that affects vertebrate animals including humans. Transmission of leptospirosis can occur world-wide, except in the areas with enduring snow or ice and desert, but is more common in the tropics than in temperate regions (Levett, 2001), and in either urban or rural environments of both industrialized and developing countries (Bharti *et al.*, 2003). Many kinds of wild, domestic and farm animals can be infected by this organism but the most powerful reservoirs belong to the rodent group (Michel *et al.*, 2002).

The causal agent of leptospirosis is a spiral-shaped aerobic spirochete bacterium of the genus *Leptospira* in the family Leptospiraceae, order Spirochateales. The size of this organism is 6-20 µm long and 0.1 µm in diameter with 18 or more coils per cell. The coils tend to stain poorly with common laboratory stains and are best visualized by dark field microscopy, silver stain or fluorescent microscopy. Before 1989, the genus *Leptospira* was divided into 2 species, *Leptospira interrogans* and *Leptospira biflexa* (Levett, 2001). The species *L. interrogans*

¹ Faculty of Tropical Medicine, Mahidol University, Bangkok 10400, Thailand. E-mail: tmsys@mahidol.ac.th

² School of Remote Sensing, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand. E-mail: songkot@sut.ac.th Tel.: 0-4422-4379; Fax: 0-4422-4316

* Corresponding author

comprises all pathogenic strains while *L. biflexa* contains the non-pathogenic strains. Recently, taxonomic studies based on DNA hybridization divided the genus *Leptospira* into 20 species (Bharti *et al.*, 2003). The species that causes illness to man is *L. interrogans*. More than 200 serovars of *L. interrogans* have been identified. *Leptospira* can survive in mud, moist soil, and water for months under the suitable environment. The incubation period of leptospirosis is as short as a few days to as long as 30 days with the average of 15 days (Ministry of Public Health, Thailand, 2009). Infected animals carry the *Leptospira* bacteria in their kidneys and shed the organisms in their urine. Animals infected with the pathogens may or may not have symptoms. Asymptomatic or sub-clinical infection in humans is possible and common in endemic areas (Tangkanakul *et al.*, 2000). Water, food, or soil contaminated with urine from the infected animals can be the sources of infections to humans and other susceptible animals. The most common reservoir hosts are rodents and domestic animals. Human infections may happen by swallowing contaminated foods and water as well as through the eyes, nose, or broken skin contact with the contaminated environments. It can be an occupational hazard for many people who work with soil, water, and animals, e.g., agriculturists (especially paddy rice farmers), aquaculture workers, veterinarians, sewer workers, livestock farm workers, soldiers, or patrol policemen.

Outbreaks often occur after heavy rainfall during floods (Gubler *et al.*, 2001). Many reported outbreaks of human leptospirosis usually occurred by exposure to contaminated water. Leptospirosis is closely related to climate, especially rainfall (Kupek *et al.*, 2000; Maciel *et al.*, 2008). Surface water is the most important vehicle for transmission of the infection agent, *leptospira* bacteria, to man. Heavy rains produce an expansion of flooded lands, and flooding can amplify the spread of leptospirosis. *Leptospira* can comfortably survive in a water and muddy soil environment especially in paddy rice fields. A typical feature of paddy fields is that the rice needs to grow in flooded soils for a period of

time after rice transplanting. This period plays an important role in the contamination and transmission of *leptospira* bacteria to farmers or those who are exposed to such contaminated environments. Sasaki *et al.* (1993) conducted clinic-hospital-based leptospirosis surveillance in the islands of Hawaii. Factors that were associated most strongly with the development of leptospirosis were household use of rain-water catchments systems (p-value = 0.003), the presence of skin cuts during the incubation period (p-value = 0.008), contact with cattle or the urine of cattle (p-value = 0.05 and 0.03, respectively), and the handling of animal tissues (p-value = 0.005).

The study of risk factors for leptospirosis during an outbreak in India conducted by Sugunan *et al.* (2009) revealed that the presence of cattle in the house, drinking stream water, contact with garbage, walking barefoot, and standing in water while working were significantly associated with leptospirosis. They found that the stratified analysis showed a dose response relationship between the number of cattle in the house and the risk of leptospirosis infection, and also suggested that cattle could be a source of infection. So far we know a lot about the risk factors of leptospirosis from a vast number of epidemiologic studies. The well-documented risk factors are: age, gender, occupation, and some environmental factors (Sundharagiati *et al.*, 1966; Sasaki *et al.*, 1993; Levett, 2001). The prevalence rates of leptospirosis usually increase with the age of the population. A higher age causes a higher chance of exposure. Susceptibilities to infection among males and females are not different, but males get infected more than females because males seem to experience more risk activities. Agriculturists, especially paddy rice farmers, are at high risk of indirect contact with animal urines in soil and water. Livestock farmers and abattoir workers are at high risk of direct contact with animal urines. If the animal urines are positive for *Leptospira*, those workers will get infected undoubtedly.

Since leptospirosis is said to be the most widespread in the world, clinical cases are

regularly reported from almost all continents except Antarctica. Leptospirosis is most common in tropical countries. Even though it is not common in the United States, it has been reported from all regions of the country. In the United Kingdom and other European countries, the most common causes of leptospirosis were water-associated and cattle-associated (Arunagiri, 2009).

Southeast Asia is an endemic area of leptospirosis. Human cases of leptospirosis have been reported throughout the region (Riccardo and Bayugo, 2008). All countries in this region have suffered from leptospirosis. Thailand has been experiencing the highest incidence of leptospirosis in Southeast Asia. It is considered as an important public health problem and is also a notifiable disease in Thailand (Tangkanakul *et al.*, 2005). It was re-emerging in 1997 with the annual incidence rate increased by approximately 6 times from the baseline (from 0.6 per 100000 in 1996 to 3.8 per 100000 in 1997). The incidence continued to increase and reached its highest peak in the year 2000 in which 14285 Thai people (23.1 per 100000) were infected. After 2000, the incidence rate showed a decreasing trend until 2005, and it slightly increased from 2006 to 2009. Leptospirosis occurred in every province of Thailand but 90% of the cases were reported in the northeast region (Tangkanakul *et al.*, 2005). A survey of leptospirosis among rodent reservoirs conducted by Wangroongsarb *et al.* (2002) showed that the rodents in the northeastern provinces had a more positive rate than in other regions of Thailand. The temporal variations of leptospirosis in Thailand include a peak incidence in August to September in association with the rainy season. This pattern is often seen in the Indian sub-continent and southern provinces of China (Sehgal, 2006). Leptospirosis still remains a public health problem in Thailand, especially in the northeast region.

The applications of geoinformatic technology in epidemiological study can help in better understanding the distribution of a particular disease. Information on the locations of disease clusters and the variation of disease frequency over space and time are very important for the

formulation of preventive strategies (Nobre and Carvalho, 1996; Ostfeld *et al.*, 2005). Allocation of the proper prevention and control measures to the right places and time can effectively lessen transmission of the disease as well. Recently, there has been increasing utilization of GIS technology, remote sensing data, and spatial statistical methods in epidemiological studies of many infectious diseases including malaria, dengue hemorrhagic fever, viral encephalitis, and so on (Cline, 1970; Bailey, 2001; Rushton, 2003; Odoi *et al.*, 2004; Goujon-Bellec *et al.*, 2011; Liu *et al.*, 2011, Makita *et al.*, 2011). The successful detection and control of diseases needs to take into account the spatial pattern of disease occurrence and any related risk factors (Pfeiffer *et al.*, 2008). The epidemiologic pattern of leptospirosis has varied from place to place. Many researches have been carried out to gain knowledge about the spatial distribution and related factors of many communicable diseases using geoinformatic technology. Among such studies, very few have studied leptospirosis. The study by Tassinari *et al.* (2008) was performed using scan statistics to detect clusters of urban leptospirosis cases in Rio de Janeiro, Brazil between 1997 and 2002. Six space-time clusters were identified and the cluster cases events were significantly associated with heavy rainfall.

The current research aims to use geoinformatic technology together with spatial statistics to demonstrate leptospirosis distribution patterns and identify the significant spatial clusters, temporal clusters, and spatiotemporal clusters of human leptospirosis incidence at the provincial level in Thailand between 2003 and 2009.

Material and Method

Study Area

Thailand is composed of 76 provinces with a total area of 513115 square kilometers and has been divided into 6 geographic regions: northern (9 provinces), central (22 provinces), northeastern (20 provinces), eastern (7 provinces), and western (5 provinces), and

southern (14 provinces) (The Royal Institute, 2007).

Data

The leptospirosis data were the cases reported to the surveillance system of the Ministry of Public Health of Thailand. All cases that were included in the reports were diagnosed based on specific clinical and laboratory criteria, which then could be classified into 2 types, i.e., suspected cases and confirmed cases. A suspected case referred to a case that was compatible with the clinical criteria and a screening laboratory diagnosis. A confirmed case referred to a suspected case that had a confirmatory laboratory result (Ministry of Public Health, Thailand, 2010). All records of leptospirosis cases in Thailand from 2003 to 2009 were used in the analyses. The data were aggregated into each province relating to the resident locations of the cases. Topographic maps (series L7018) at a scale of 1:50000 pertaining to all provinces of Thailand and prepared by the Royal Thai Survey Department were used as a base map.

Exploratory Spatial Data Analysis (ESDA)

The monthly incidence rates from 2003 to 2009 were calculated for each province of Thailand. The incidence rate is the number of new cases per population in a given time period. It is calculated by the division of the number of cases by the number of the population in a particular province. To avoid the problem of variance instability, the incidence rates were then smoothed prior to making the maps of the geographical distribution of leptospirosis. The Spatial Empirical Bayesian (SEB) method was used to smooth the incidence rates before performing the visualization. This smoothing procedure required a spatial weight file to be specified. This weight file was used to impose a neighborhood structure on the data to assess the extent of similarity between the provinces and values. The queen contiguity weighting method was used. Therefore, provinces that either share a border or vertex with a particular province were categorized as neighbors.

GeoDaTM v.0.9.5-i, released on August 3, 2004 (Anselin, 2004), was used to calculate the SEB smoothed incidence rates at the provincial level. Maps of these smoothed incidence rates were created. ESRI[®] ArcGISTM 9.0 was used for making maps that visualized the variations of leptospirosis incidence in both space and time. The 5-category choropleth map was used as the mapping method for these raw and smoothed incidence rates.

Furthermore, the “excess risk” was calculated for each province and each year during 2003-2009. The excess risk is the ratio of the observed rate to the overall rate computed for all the data. The overall rate is calculated as the proportion of the total sum of all cases over the total sum of all the populations (Anselin, 2005). The excess risk of each province can be calculated using the equation below:

$$ER_i = IR_i / IR_t \quad (1)$$

The term ER_i denotes the excess risk of a province i , IR_i refers to the incidence rate of province i , and IR_t refers to the incidence rate of all provinces. The provinces with excess risks greater than 1 are those which have higher risks than the overall average. In contrast, provinces with excess risks less than 1 are those which have lower risks than the overall average.

Analysis for Leptospirosis Clusters

Analyses for spatial cluster were performed to determine the significant local clusters using spatial scan statistics. Furthermore, temporal clusters and spatiotemporal clusters were evaluated using temporal scan and space-time scan statistics, respectively. SaTScanTM software was used to carry out these analyses. This software was developed under the joint auspices of (i) Martin Kulldorff, (ii) the National Cancer Institute, and (iii) Farzad Mostashari at the New York City Department of Health and Mental Hygiene. In this study, version 7.0 released on August 14, 2006 (Kulldorff and Information Management Services Inc., 2006) was used. This software can be freely downloaded at <http://www.satscan.org/>. This

method imposes a circular scanning window on the map and lets the center of the circle move over the study area so that at each position the window includes different sets of neighboring administrative areas (Kulldorff, 1997; Kulldorff *et al.*, 1998). For each circle centroid, the radius varies continuously from zero to a user-defined maximum. The test statistic adopted is the likelihood ratio, which is maximized over all the windows to identify the most likely clusters.

Since the number of leptospirosis cases in each province is Poisson-distributed according to a known underlying population at risk, the Poisson-based model for the scan statistics was selected to analyze the significant clusters. Outputs of these analyses were transferred to GIS software to make the maps.

Results

Spatial and Temporal Distribution of Leptospirosis

During 2003-2009, a total number of 27860 cases of leptospirosis were reported to the surveillance system. Sixty-eight percent (19063 cases) were in the northeast region, whereas the rest 15%, 11%, and 6% were from the north, south and central regions, respectively. The incidence of leptospirosis in the whole of Thailand ranged from 4.6 to 8.5 per 100000 of the population (Table 1).

Figure 1 shows the annual incidence rates of leptospirosis in each region. It reveals that the incidence rates in the central and north

regions appeared to be less varied throughout the study period, whilst incidence rates in the south region were gradually increasing year by year from 2003 to 2009. The fluctuation pattern of incidences in the northeast region was quite different from the others. The line graph of the incidences of the northeast region was U-shaped distributed. High incidence rates were observed at the beginning (2003) and at the end (2009) of the study period with the rates of 17.7 and 17.5 per 100000 population, respectively. The map in Figure 2 shows the comparison of the leptospirosis incidence rate distribution by region from 2003 to 2009.

Monthly fluctuation of the leptospirosis incidence rates in Thailand during 2003 and 2009 are shown in Figure 3. It illustrates that the highest leptospirosis incidences occurred during the late rainy season of each year varying around August to October.

The raw annual incidence rate and SEB smoothed incidence rate by province were

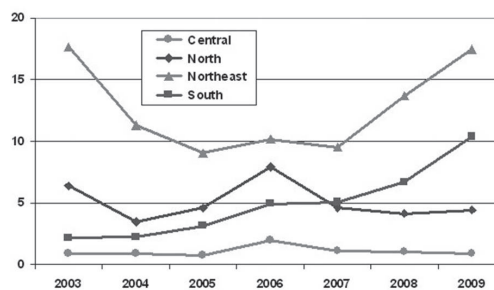


Figure 1. Annual incidence rates of leptospirosis by region, 2003-2009

Table 1. Annual cases and incidence rates (per 100000 population) of leptospirosis by regions, 2003-2009

Year	Central		North		Northeast		South		Total	
	Cases	Rate	Cases	Rate	Cases	Rate	Cases	Rate	Cases	Rate
2003	180	0.87	773	6.38	3829	17.70	180	2.13	4962	7.88
2004	175	0.85	416	3.48	2421	11.28	187	2.21	3199	5.12
2005	145	0.71	540	4.55	1920	9.02	263	3.10	2868	4.61
2006	406	1.95	936	7.87	2177	10.20	422	4.93	3941	6.29
2007	222	1.06	546	4.59	2038	9.53	435	5.06	3241	5.16
2008	213	1.00	491	4.13	2926	13.66	580	6.67	4210	6.66
2009	219	0.88	522	4.40	3774	17.50	924	10.35	5439	8.47
Overall	1560	-	4224	-	19085	-	2991	-	27860	-

calculated and mapped in Figures 4 and 5, respectively. Those maps illustrate few differences between the raw rates and SEB smoothed rates due to the instability of variances. The interpretation and comparison of leptospirosis incidence between provinces using raw rates might be done with bias. Using the smoothed rates instead of the raw rates is more efficient and less biased. However, both kinds of rates showed similar patterns in that leptospirosis incidence rates in the northeast provinces were higher in than other regions in every year. The incidence rates of many provinces of the northeast region and some provinces in the north region were higher than in the central region and the upper part of the south region. Similar patterns were observed in every year throughout the study period.

An excess risk map was produced to assist those who want to know by how many times the risk of there being a leptospirosis case in each province increased as compared with the overall average risk calculated from the data for the whole of Thailand. These maps are shown in Figure 6. Provinces with an excess risk of

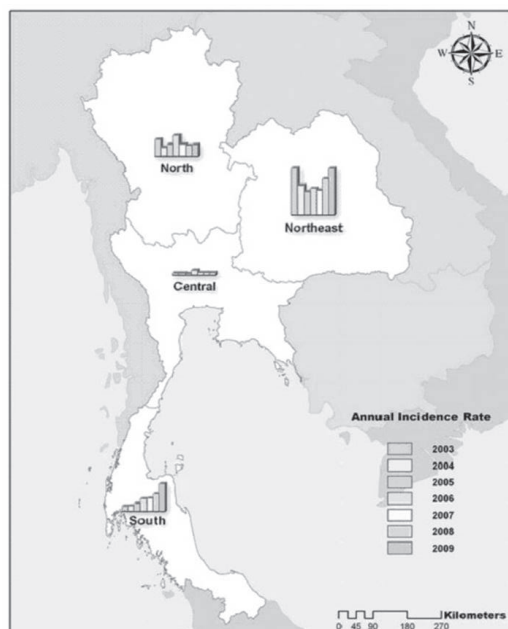


Figure 2. Distribution of leptospirosis incidence rates by region, 2003-2009

greater than 1 were those with higher risks than the overall risk. On the other hand, provinces with an excess risk of less than 1 were the lower risk provinces. For every year, the higher risks were observed in most of the northeastern provinces and some northern provinces. Two provinces in southern Thailand, Ranong and Phang Nga, had a high risk almost every year.

Purely Spatial Clusters

Seven significant purely spatial clusters of leptospirosis were detected by purely spatial analysis. Figure 7 demonstrates the distribution of these spatial clusters. The most likely cluster was in 4 provinces of the northeast region, i.e., Buriram, Surin, Sisaket, and Roi Et. The second and the third clusters were also in the northeast region while the clusters numbers 4 to number 7 were in other regions.

Table 2 shows details of each significant spatial cluster. It details the number of province(s) in each cluster, as well as the number of the population, numbers of observed and expected cases, relative risk, and p-values. The relative risk showed by how many times the observed incidence rate was higher than the expected rate in each cluster. There were 8154 leptospirosis cases out of a population of 5678662 in the first cluster. The relative risk of this cluster was 4.18. This means that the incidence rate in this cluster was 4.18 times more than expected.

Purely Temporal Cluster

There was 1 significant purely temporal cluster of leptospirosis that occurred during July

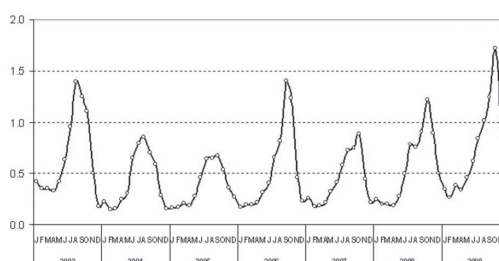


Figure 3. Monthly incidence rates of leptospirosis in Thailand, 2003-2009

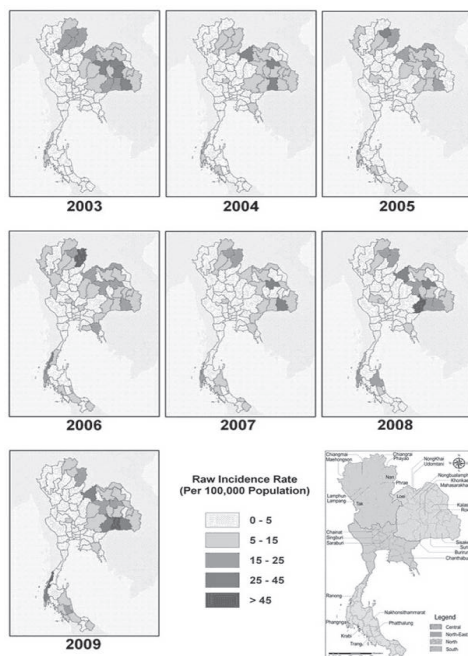


Figure 4. Raw incidence rates of leptospirosis by province, 2003-2009

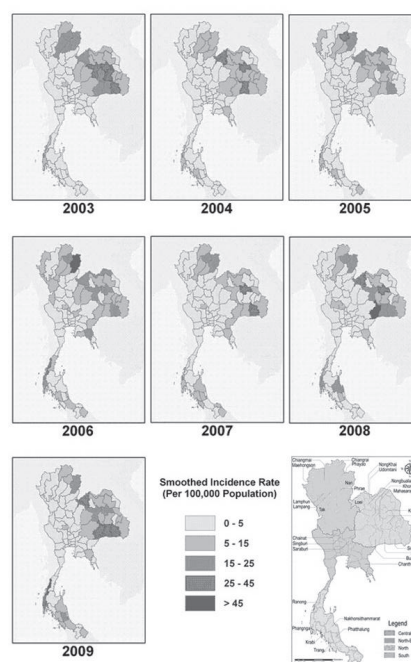


Figure 5. Smoothed incidence rates of leptospirosis by province, 2003-2009

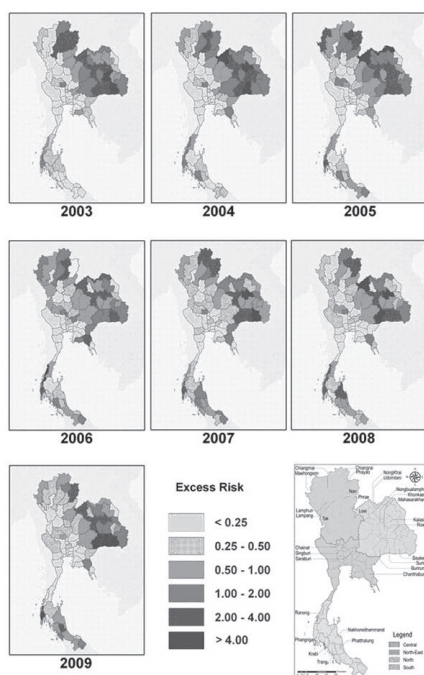


Figure 6. Excess risks of leptospirosis by province, 2003-2009

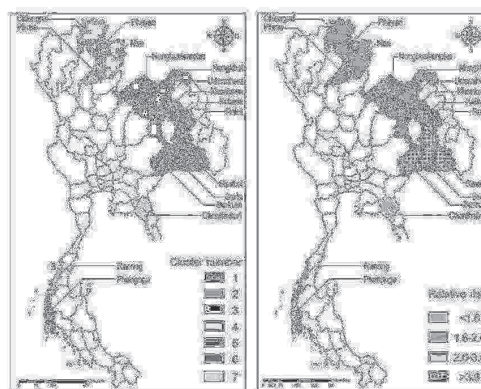


Figure 7. Significant spatial clusters and their relative risks during 2003-2009

to November 2009. The details are shown in Table 3 and Figure 8 and revealed that there were 3649 cases observed in this temporal cluster while the expectation was only 1678 cases. The incidence rate was 2.35 times higher than the expected rate.

Spatiotemporal Cluster

There were 11 spatiotemporal clusters that significantly occurred in Thailand during 2003-2009 (Figure 9 and Table 4). Three of them (Clusters 1, 2, and 6 in Table 4) were in the northeast region with quite high relative risks of 13.3, 6.9, and 7.4, respectively. The first cluster is composed of 3 provinces in the northeast region, i.e., Buriram, Surin, and Sisaket and

occurred during July to November 2009. More than 1400 cases of leptospirosis were observed in this cluster, while the expected cases were calculated at only 115.3 cases. The second cluster in the northeast region comprised 4 provinces, i.e., Khon Kaen, Mahasarakham, Roi Et, and Kalasin and occurred between July and October 2003. The observed cases were 1019 cases and the expected cases were 133. Another cluster included Loei and Nong Bua Lamphu between July and October 2004. Even though the observed cases in this cluster were 187 cases, which were very few when compared with the former clusters, and the expected cases in this area were only 29.5, there was a relative risk high

Table 2. Detailed characteristics of purely spatial clusters

Cluster no.	Number of provinces	Population	Observed cases	Expected cases	Relative risk	P-value
1	4	5678662	8154	2512.12	4.18	<0.001
2	1	979213	1969	433.18	4.82	<0.001
3	6	5302374	5098	2345.66	2.44	<0.001
4	4	2667056	2321	1179.85	2.01	<0.001
5	1	243915	299	107.90	2.79	<0.001
6	1	176263	341	77.97	4.42	<0.001
7	1	503482	337	222.73	1.52	<0.001

Table 3. Detailed characteristics of purely temporal cluster

Cluster no.	Time period	Cases per 100000 pop.	Observed cases	Expected cases	Relative risk	P-value
1	Jul–Nov 2009	13.7	3649	1677.93	2.35	<0.001

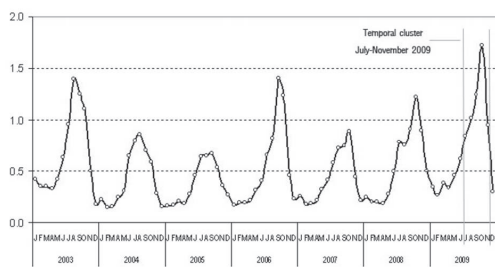


Figure 8. Temporal distribution of leptospirosis incidence rates in Thailand during 2003-2009 with a significant temporal cluster

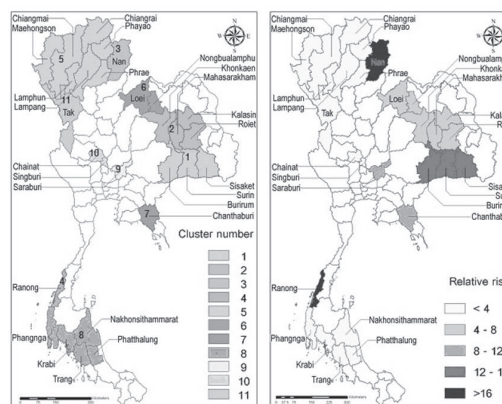


Figure 9. Significant spatiotemporal clusters and their relative risks during 2003-2009

enough to make it a significant cluster. The remaining clusters were scattered in other regions, i.e., 3 clusters in the north, 3 clusters in the central region, and 2 clusters in the south.

Cluster 3 (Nan) and cluster 4 (Ranong) were very high relative risks (56.5 and 37.5, respectively). The relative risks of the remaining 3 clusters (clusters 8, 10, and 11) were not so high but they were statistically significant. These results might draw the conclusion that flooding in the northeast region did not show an outstanding amplification of leptospirosis transmission, while flooding in other regions might trigger leptospirosis transmission.

Discussion

This research has demonstrated the use of geoinformatics and spatial statistics in the study of leptospirosis in Thailand. The general results of this study supported the evidence that leptospirosis is a burdensome disease of human health in Thailand just as in other countries in the tropics where there are the appropriate environmental conditions for the survival of infective agents. In some developed countries, unlike Thailand, leptospirosis is a disease of economical significance in animal husbandry (Levett, 2001) rather than a human illness.

Table 4. Detailed characteristics of spatiotemporal clusters

Cluster no.	Number of provinces	Time period	Population	Observed cases	Expected cases	Relative risk	P-value
1	3	Jul-Nov 2009	4366537	1462	115.37	13.32	<0.001
2	4	Jun-Oct 2003	4983818	1019	132.97	7.92	<0.001
3	1	Aug-Sep 2006	478716	282	5.04	56.48	<0.001
4	1	Jun-Nov 2009	176263	215	5.79	37.48	<0.001
5	7	Jul-Oct 2003	5265975	385	112.20	3.47	<0.001
6	2	Jul-Oct 2004	1114819	187	29.48	6.38	<0.001
7	1	Sep-Nov 2006	503482	85	7.89	10.81	<0.001
8	6	Jun-Nov 2009	3564546	266	114.89	2.33	<0.001
9	1	Oct 2009	612787	27	3.26	8.30	<0.001
10	2	Jul-Oct 2006	559418	39	11.85	3.29	<0.001
11	1	Jul-Oct 2006	522153	32	11.18	2.86	0.026

Table 5. Summary of flood events which occurred coinciding with some spatiotemporal clusters

Month-year	Affected region	Affected province
Aug-Sep 2006	North	Nan, Payao, Chiang Rai
Sep-Oct 2006	Central	Chai Nat, Sing Buri, Suphan Buri, Ang Thong
Sep-Oct 2006	North	Tak, Sukhothai
Jul 2009	South	Ranong, Satun, Trang, Phang Nga
Nov 2009	South	Nakhon Sri Thammarat, Trang, Phatthalung, Songkhla

The spatial patterns of leptospirosis by region (Figure 2) show that the northeast region was experiencing the highest incidence of leptospirosis throughout the study period. Monthly leptospirosis incidence rates in Thailand during 2003 to 2009 are shown in Figure 3 and reveal the obvious seasonal pattern with the peak between August and October in the late rainy season every year. The same temporal patterns were observed in other countries in Southeast Asia due to wide environmental contamination during the wet season (Riccardo and Bayugo, 2008).

Recently, the issue of climate change and global warming has been raised for discussion in various forums worldwide. The changing climate may affect environmental conditions that lead to changes in leptospirosis transmissions in either positive or negative directions in different locations. The way this research was done can be used in the study of such changes. First of all, the ESDA should be obtained to discover the true distribution of the disease. This research used the smoothed rates for comparison of the incidence across the study area. The map of smoothed rates is presented in Figure 5 and can be used in the comparison of the extent of leptospirosis transmission among different provinces and different units of time. Moreover, the excess risk map in Figure 6 displays by how many times the risk for each province was more or less than the overall average risk in Thailand. From such maps, it is interesting to note that some provinces in the south region were at high risk but were surrounded by low-risk provinces. The high-risk provinces might have some specific factors that facilitated the transmission of leptospirosis. More detailed studies are required to explain such an occurrence. The result maps can be used for the initiation of further studies or further interventions. The results also showed the significant spatial clusters, temporal cluster, and spatiotemporal clusters at the provincial scale in Thailand. These gave us an idea about the heterogeneity of leptospirosis occurrence in Thailand provinces. Not all provinces had a similar transmission of leptospirosis during the

study period.

The core determinants of leptospirosis transmission are the availability of reservoir hosts (carrier animals), the suitability of the environment for survival of infective agent, and the interaction between man, animals, and the environment (Sehgal, 2006). The provinces that are included in the significant leptospirosis clusters identified from this study might be the areas with more exposure to these determinants than other provinces. A population which is exposed to the risk factors that are mentioned above would have more chances of getting infections. The areas with a presence of reservoir animals together with the suitable environment are the areas at risk for leptospirosis transmissions. Water and mud are the environmental conditions that facilitate the survival of *Leptospira* (Barcellos and Sabroza, 2001). In this study, the reports from the flooding database of The Hydro and Agro Informatics Institute (HAI) of Thailand (www.haii.or.th) were used for an additional explanation of the significant spatiotemporal clusters by comparing each individual cluster with the HAI flood incidence records. Five spatiotemporal clusters occurred at the same place in the period that followed a flood incidence recorded in the HAI database, while the remaining 6 clusters did not. The selected flood events which occurred and coincided with these spatiotemporal clusters are summarized in Table 5. This result was the same in as the study by Barcellos and Sabroza (2001) in which there is evidence that an outbreak of leptospirosis can occur widely after flooding.

In addition, the flooding database of the HAI documented that the well-known typhoon 'Sang San' which occurred in September 2006 devastated wide areas which included the provinces of Nan, Sing Buri, Chai Nat, and Tak. This might have contributed to the occurrence of 3 clusters in those provinces during that particular period of time. This finding also revealed that all of the 5 spatiotemporal clusters that occurred after flooding were in the central, north, and south regions only, whereas the 3 spatiotemporal clusters in the northeast region

did not coincide with flooding. It may be said that the clusters of leptospirosis in the northeast region could occur whether or not there is an incidence of flooding.

Conclusions

Although the etiology and epidemiology of leptospirosis have been understood for many years and such understanding has led to the development of helpful prevention and control measures, more knowledge on the spatial and temporal patterns of each specific and confined area is still required for use in launching the most appropriate measures to specific locations. This retrospective research attempted to identify leptospirosis clusters both spatially and temporally. More attention should be focussed on the northeast region because of its higher incidence than other regions. The results of this research clearly demonstrated the dense distribution in the northeast region. The output disease maps have facilitated knowledge on the geographical distribution of leptospirosis at the provincial level. Moreover, maps of significant clusters of the disease were produced. They indicated the areas of higher incidence and also provided valuable information on the spatial pattern and temporal change of the disease incidences. Such maps have clear advantages over the tables from classical analyses which did not consider the spatial aspects.

Cluster analysis using scan statistics can be used without the need of prior testing for global clustering. Scan statistics can also be effectively used to scan for purely spatial clusters, purely temporal clusters, or spatiotemporal clusters. The location of clusters can be ultimately obtained if the significant cluster was available. The study results reveal that there were 7 spatial clusters, 1 temporal cluster, and 11 spatiotemporal clusters which occurred in Thailand during 2003 to 2009. The output maps can show the disease hot spots and may be used to identify the prominent risk areas for leptospirosis infections. Consequently, they can help in highlighting the need for intervention or for further investigation.

This study initiated the use of the geoinformatic technique to study the spatiotemporal distribution of leptospirosis in Thailand. Further study should be carried out on this disease by using a smaller areal unit for data aggregation, i.e., district level or sub-district level, in order to get accurate results of more confined areas. This work was a retrospective study that utilized a lot of secondary data and some types of data which had already been collected. Information biases, therefore, can have easily arisen. These aspects should be considered in any further study. On the other hand if the data are analyzed prospectively soon after the cases were recorded, the analysis results can be effectively used in a near real-time disease warning system.

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