Analyzing Spatial Clustering and Hotspots Detection of HIV/AIDS Prevalence using GIS Technology

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Abstract
HIV/AIDS is one such epidemic that poses serious challenges and threatens the overall human welfare. This paper examines the spatial variation of HIV/AIDS prevalence rates in Phayao province, Thailand from 2006 to 2010. It uses spatial autocorrelation analysis (SAA) techniques to provide insight into the patterns, in terms of their geographical distributions and hotspot identification. The overriding objective is to determine if there is a significant spatial clustering of HIV/AIDS. In addition, local indicators of spatial association (LISA) and kernel density (KD) estimation were used to detect HIV/AIDS hotspots using data at village level. The hotspot maps showed spatial trend patterns of HIV/AIDS diffusion. Villages in the northern part revealed higher incidence. Furthermore, the spatial patterns during the years 2007 and 2010 were found to represent spatially clustered patterns, both at global and local scales.

1. Introduction

Thailand has the highest adult HIV/AIDS prevalence in the South East Asia region. Successful efforts throughout the past two decades have reduced the number of annual new HIV/AIDS infections from 143,000 in 1991 to 10,853 in 2010 (National AIDS Prevention and Alleviation Committee, 2010). The objective of this study was to analyze the epidemic patterns of HIV/AIDS in Phayao province, Northern Thailand, in terms of their geographical distributions and hotspot identification. The methodology and the results could be useful for public health officers to develop a system to spread awareness, monitoring, and preventing HIV/AIDS. Acquired immune deficiency syndrome (AIDS) is an infectious disease caused by the human immunodeficiency virus (HIV). There are two variants of the HIV virus, HIV-1 and HIV-2, both of which ultimately cause AIDS. AIDS is one of the most devastating worldwide public health problems in recent history. AIDS was first recognized in the United States 1981 in homosexual men. Today is seen in both homosexual and heterosexual men and women. AIDS is the advanced form of infection with HIV virus. This virus may not cause recognizable symptoms for a long period after the initial exposure (latent period). As of early 2009, no vaccine was available to prevent HIV infection. Until such a vaccine is developed, all forms of HIV/AIDS therapy are focused on improving the quality and length of life for people who are infected by slowing or halting the replication of the virus and treating or preventing infections and cancers that often develop in people with AIDS (WHO/UNAIDS/UNICEF, 2010). In Thailand, by the year 2007 approximately 610,000 cases of those living with HIV/AIDS had been reported. In 2008, the Division of Epidemiology, Ministry of Public Health Thailand reported 8,331 new cases or an incidence of 13.18 per 100,000 population (Department of Epidemiology, MOPH Thailand, 2008). The Northern region of Thailand has the highest seroprevalence of HIV/AIDS (Apidechkul, 2011). The HIV/AIDS prevalence was 16.50 per 100,000 population in the north, with Phayao province has seen the highest HIV/AIDS levels than anywhere in Thailand (UNAIDS, 2000). For HIV transmission in Phayao, the first AIDS case was reported in 1989. After that the number of symptomatic HIV/AIDS cases increased rapidly and reached the peak during 1995-1997 (on an average 1700 cases per year). Six years later, there were still over 1,000 cases every year. Then it showed continuous reduction, from around 400 cases per year in 2008-2009 to 300 and 100 in 2010 and 2011 respectively. Up to September 2011, the total number of symptomatic HIV/AIDS cases reported in Phayao is 17,246 cases (Male 10,755 cases, female 6,491 cases, and died 7,631 cases). The proportion of symptomatic HIV/AIDS cases of male to female revolved from 4:1 in 1989 to 1.8:1 in 2011. The three highest incidence rates in 2011 was 0.39, 0.35 and 0.34 (per 1,000 population) in Chun, Dok Khamtai, and Mae Chai districts and the three highest number of commutative cases are 3,773, 3,711, 2,511 found in Chiang Kham, Mueang, and Dok Khamtai districts. The highest infected rate found to be in age group of 30-34 years old and 35-39 years old (0.62 and 0.54 per 1,000). The highest age group died was 25-39 years old (0.08 per 1,000). Still, Phayao is ranked the 1st (March 31, 2011) highest incidence in the country (Phayao Provincial Health Office - PPHO, 2012). GIS is potentially powerful resource for community health for a many reasons including their ability to integrate data from various sources to produce new information, and their inherent visualization (mapping) functions, which can promote creative problem solving and sound decisions with lasting, position impacts on people's live (Buckeridge, 2002 and Maged and Kamel, 2004). Through multivariate spatial statistical modeling of disease processes, GIS enables the evaluation of potentially true disease outbreaks and a more effective allocation of sparse remedial resources towards their containment and prevention (Croner et al., 1996). Spatial autocorrelation is an assessment of the correlation of a variable with reference to its spatial location and it deals with the attributes and the locations of the spatial feature (Nakhapakorn and Jirakajohnkool, 2006 and Xiao-Ni, 2011). There are two popular indices for measuring spatial autocorrelation applicable to a point distribution: Geary's C Ratio and Moran's I Index. Both indices measure spatial autocorrelation for interval and ratio attribute data (David and Wong, 2005 and Olalekan, 2009). Although the disciplines of spatial analysis and GIS have developed quite independent of each other, together not only do these techniques provide insight into the HIV epidemic but can also aid in mapping risk areas, by identifying causal factors driving HIV transmission in the country as well as aid in decision making and surveillance (Robinson, 2004). The local indicators of spatial association (LISA) statistics can also be used to identify influential locations in spatial association analysis (Ching-Lan, 2011). The goal of this article is to identify spatial patterns of HIV/AIDS based on a hypothesis, which also revealed previously unsuspected patterns leading to the formulation of additional theories. The spatial analyses were used to investigate spatial patterns of HIV/AIDS. In addition, the LISA was used to indicate the level of spatial autocorrelation that enabled the location of hotspot zonations of HIV/AIDS in Phayao from 2006 to 2010.

2. Materials and Methods

2.1 Study Area Phayao Province, Thailand

Phayao, a province in the northern part of Thailand (Figure 1), has the first highest HIV/AIDS morbidity rate in Thailand in 2010, therefore Phayao was selected as the study area because of the high number of cases.

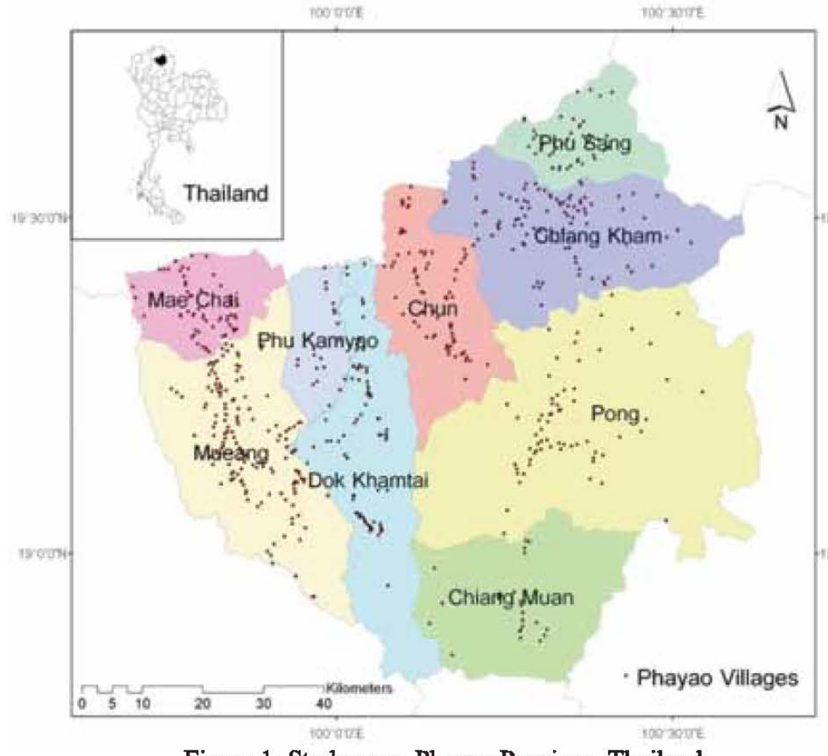


Figure 1: Study area: Phayao Province, Thailand

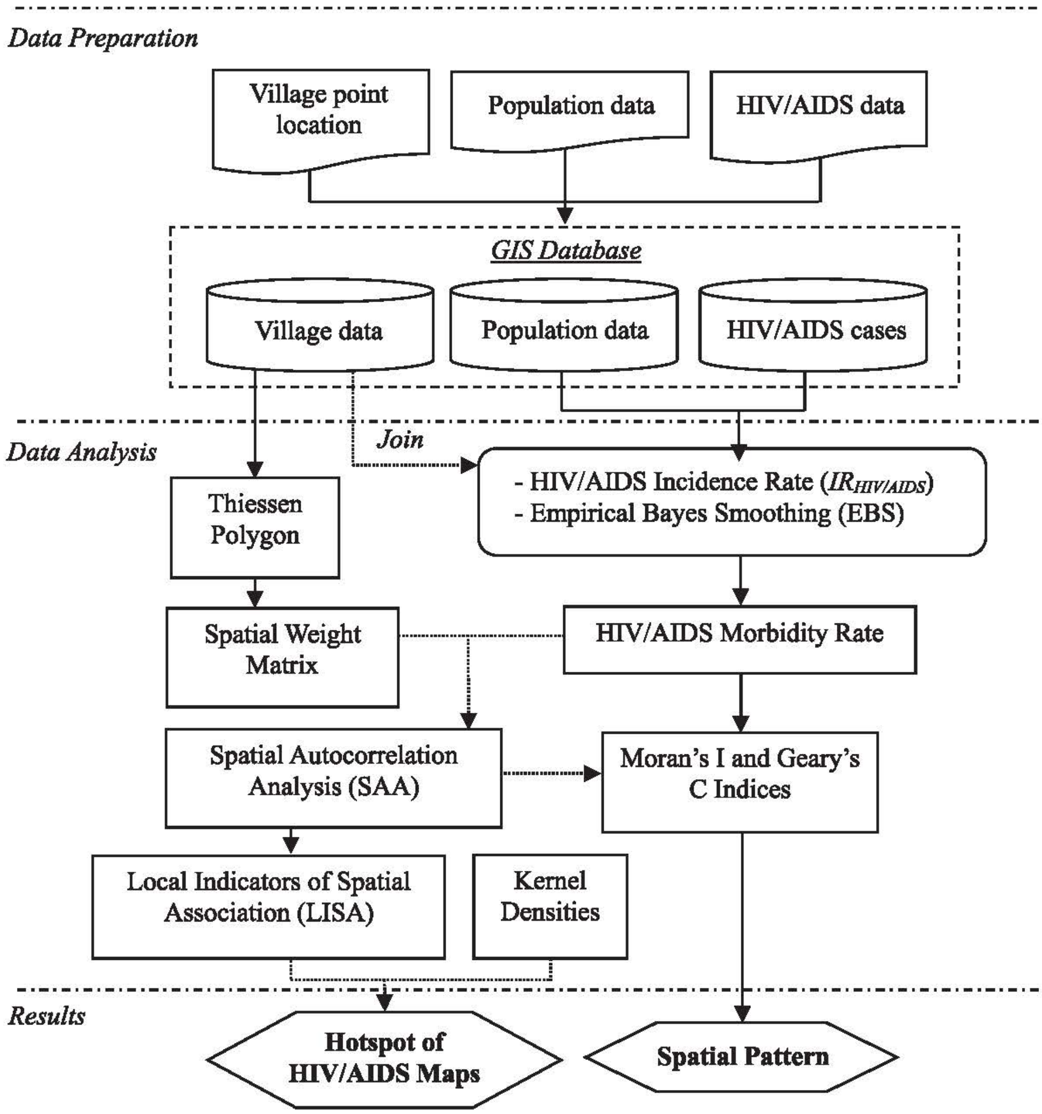


Figure 2: Flowchart of methodology

Phayao province comprises 9 districts, 68 sub-districts, and 766 villages. The province covers an area of 6,335 square kilometers with geographical location between 18 degrees 44 minutes north to 19 degrees 44 minutes north and 99 degrees 40 minutes east to 100 degrees 40 minutes east. The province has a population of about 469,000 people (Department of Province Administrator, 2010). It is mostly covered with forested mountain, with an approximate elevation of 380 meters about mean sea level. Methodology is summarized in the flowchart shown in Figure 2.

2.2 Data Preparation

Data about patients with HIV/AIDS cases and the population at village level were obtained from the Phayao Provincial Public Health Office (PPPHO), Thailand. The study of spatial patterns of HIV/AIDS covers the 766 villages for the years 2006 through 2010. Data represented only the patients and were filled in the official form by the PPPHO. The form provided data for each patient's address, age, gender, and the dates of the symptoms. For village data, locations of each village of Phayao province were collected from the Department of Provincial Administrative (DPA), Thailand. Village point locations were confirmed for accuracy by overlaying on high-resolution QuickBird satellite images.

2.3 Data Analysis

2.3.1 HIV/AIDS Affected Villages

Data from all the HIV/AIDS cases were geocoded using village location from the address of the patient e.g. 56010401,…,n (56 = province code, 01 = district code, 04 = sub-district code, and 01 = village code). Initial assessment for geographical accuracy at the village level revealed sufficient information to study the spatial pattern of the disease, and allowed us to use the patient address as the location of the infection (Jeefoo et al., 2011). Mapping incidence is the first step in spatial analysis of a disease, but mapping, as always with any ratio, need to be made carefully. Villages with a small number of inhabitants are more variable than villages with high numbers of inhabitants, and ratios may also reflect this difference in statistical variability (Ashley et al., 2011). While a small population density occurs generally in large areas, mapping reinforces this difference and may give a false view of observed reality. To overcome this problem, an empirical Bayes smoothing (EBS) method based on the idea of pooling information across villages was developed (Jeefoo, 2012). Essentially, rates were smoothed and thus stabilized by borrowing strength from other spatial units (Anselin, 2005). The HIV/AIDS incidence rate ($IR_{HIV/AIDS}$) per year were adjusted by EBS function and converted to the HIV/AIDS morbidity rate by multiplying by 1000 (Jeefoo et al., 2011). Boxplot was used to represent the spread of the HIV/AIDS morbidity rate in Phayao province. It displays the difference between the annual HIV/AIDS morbidity rate in the period from 2006 to 2010 without making any assumptions about the underlying statistical distribution. The spacing between the different parts of the box helps indicate the degree of dispersion (spread) and skew in the data, and identifies outliers or abnormal data (Chaikaew et al., 2009).

2.3.2 Spatial pattern analysis

Spatial autocorrelation analysis (SAA) was applied to detect spatial patterns of HIV/AIDS in Phayao province (Kristen, 2011). The village locations and the annualized HIV/AIDS morbidity rate at each of these villages were used in the analyses. Spatial autocorrelation analysis (SAA) was used to measure and test how villages were clustered/dispersed in space with respect to their HIV/AIDS morbidity rate. To evaluate autocorrelation in HIV/AIDS spatial distribution, Moran's I and Geary's C indices were used by setting the significance level as 0.01 and the indices were evaluated by simulation (999 permutation tests) (Anselin et al., 2006). All these global indices measure the spatial patterns of HIV/AIDS. The interpretation of the indices values are presented in Table 1.

2.3.3 Hotspot detection

Hotspot is defined as a condition indicating some form of clustering in a spatial distribution (Osei and Duker, 2008). Hotspot detection can be useful, even if the global pattern is not clustered. Moreover, clusters of cases that occur randomly can also have an influence on the spread of an infectious disease. This section describes the methods for detecting hotspots of HIV/AIDS by considering both the location of the villages and HIV/AIDS morbidity rate. Previous spatial analyses evaluated only global patterns. Local indicators of spatial association (LISA) can be used to determine locations of clusters or hotspots. The LISA method was carried out in order to find the HIV/AIDS case hotspot patterns (clustered/dispersed/random) at the local level. In this study, local Moran's I value was used to examine the local level of spatial autocorrelation in order to identify villages where values of the HIV/AIDS morbidity rate were both extreme and geographically homogeneous (Jepsen et al., 2009) (the variability of the local indices are evaluated by simulation and the spatial pattern of the villages does not influence the results). This led to identification of so-called HIV/AIDS hotspots, where the value of the index was extremely pronounced across localities, as well as those of spatial outliers.

Table 1: Numeric Scales of Moran's I and Geary's C ratio

Spatial Patterns	**Moran's I**	**Geary's C**
Clustered pattern in which adjacent or nearby points show similar characteristics	$I > E(I)$	$0 < C < 1$
Random pattern in which points do not show particular patterns of similarity	$I \sim = E(I)$	$C \sim = 1$
Dispersed pattern in which adjacent or nearby points show different characteristics	$I < E(I)$	$1 < C < 2$

$E(I) = \sim (1) / (n - 1)$, with n denoting the number of points in the distribution

Firstly, the standardized values of HIV/AIDS morbidity rate were calculated using the spatial weight matrix that defined a local neighborhood around each geographic unit and 999 permutation tests by setting the significance level as 0.01. Secondly, a Moran scatterplot was produced with a spatial lag of HIV/AIDS morbidity rate on the vertical axis and a standardized HIV/AIDS morbidity rate on the horizontal axis. Once a significance level was set values could also be plotted on a map to display the specific locations of hotspots: locations with high values with similar neighbours (high-high) and potential outliers (Getis and Ord, 1992). The last, to compare hotspot locations with HIV/AIDS disease spatial distribution, kernel density (KD) interpolation was used to create a continuous surface representing the density of HIV/AIDS morbidity rate across the study area (Osei and Duker, 2008).

2.3.4 Software

Various software's, namely GeoDa, SpaceStat (www.biomedware.com), ArcGIS (www.esri.com), and SPSS, were used in this study.

3. Results

3.1 HIV/AIDS Affected Villages

The annual HIV/AIDS morbidity rate in the years of 2006 through 2010 can be generated with parallel boxplots (Figure 3). The boxplots of every year shows a positive skewed distribution of annual HIV/AIDS morbidity rate. The largest distribution rate was found in 2010 and the rate of distribution in 2008 and 2009 appear to have smaller variability than the other years.

3.2 Spatial Pattern Analysis

Table 2 gives the global spatial autocorrelation analysis for annualized morbidity rate of villages in Phayao from 2006 through 2010 showed that the Moran's I (0.02, 0.03, 0.04 and 0.06) and Geary's C (0.90, 0.95, 0.97 and 0.99) values were significant (significance < 0.01) for each year, implying that distribution of the affected villages with HIV/AIDS was somewhat spatially auto correlated (low clustered) though the overall tendencies were not so strong. The global spatial autocorrelation analysis with Moran's I and Geary's C indices showed that the spatial distribution of HIV/AIDS morbidity rate was clustered, for all years (2006-2010) (Table 1).

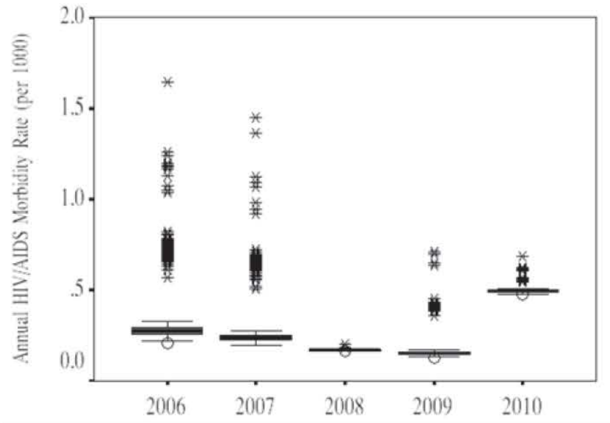
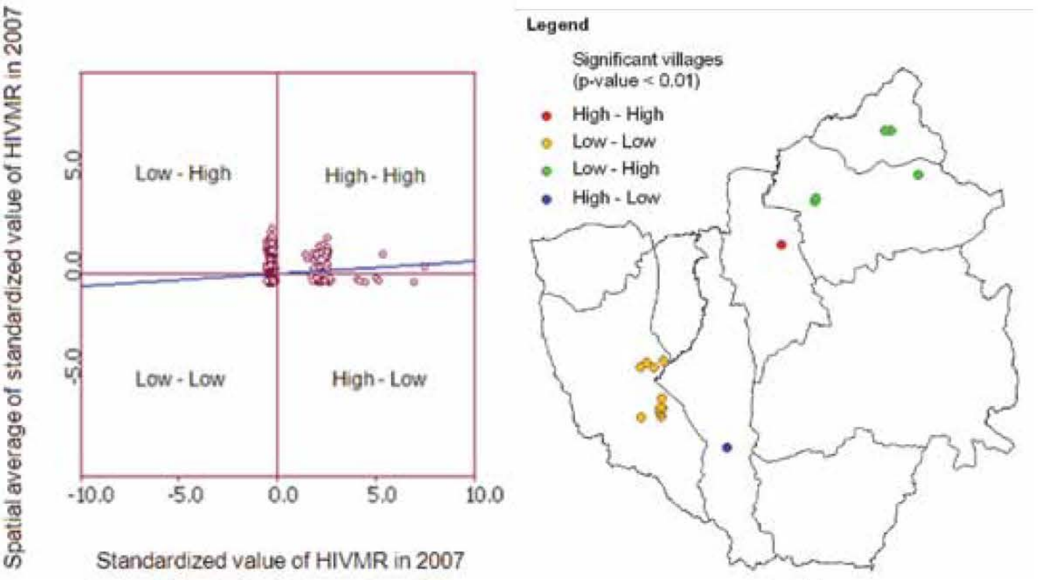


Figure 3: Parallel boxplots of annual HIV/AIDS morbidity rate

Table 2: Global indices of spatial autocorrelation

Year	Indices		Pattern
	Moran's I	Geary's C	
2006	0.04[g]	0.97[g]	Clustered
2007	0.06[g]	0.95[g]	Clustered
2008	0.03[g]	0.90[g]	Clustered
2009	0.02[g]	0.97[g]	Clustered
2010	0.03[g]	0.99[g]	Clustered



a) b)

Figure 4: Moran scatter plot matrix and LISA cluster (hotspot) maps of HIV/AIDS morbidity rate (HIVMR) for p-value < 0.01 for the year 2007

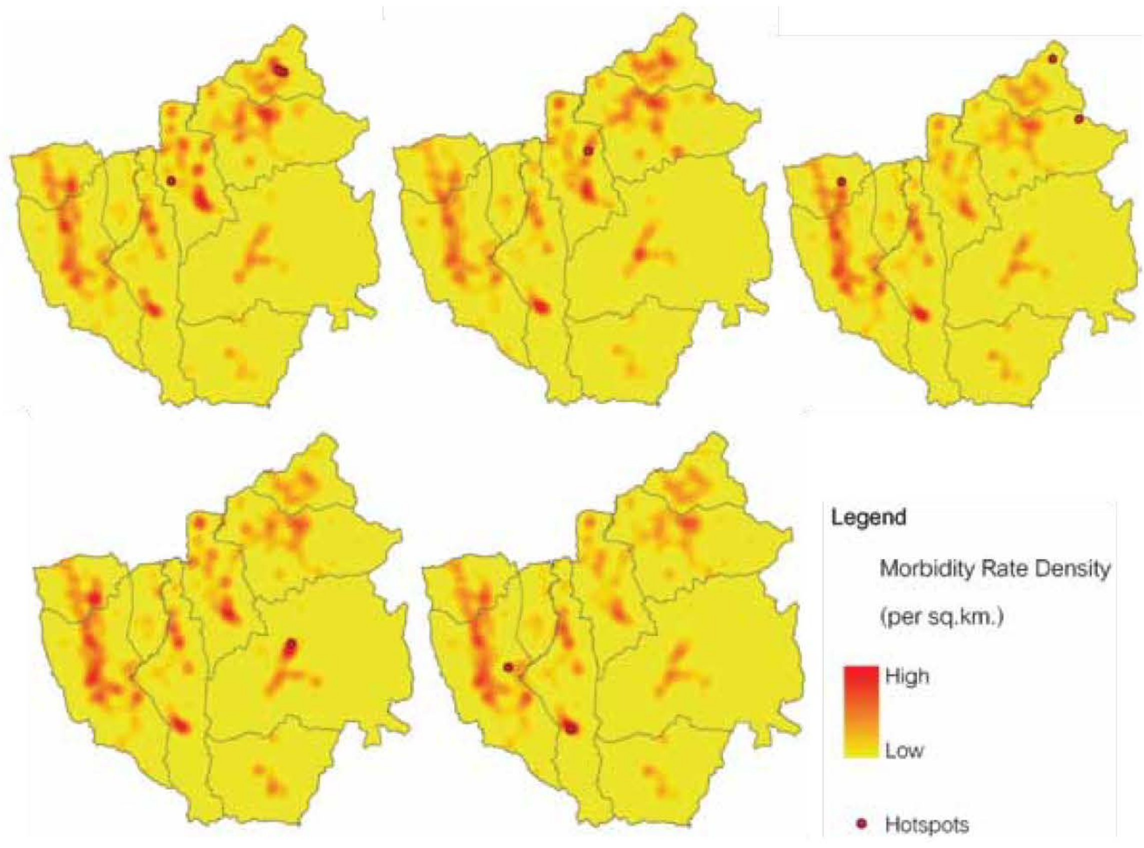


Figure 5: Hotspots of HIV/AIDS during 2006 to 2010

This information is a major finding to suggest Ministry of Public Health that HIV/AIDS is occurring in cluster and not spread uniformly or randomly throughout the province. The highest of Moran's I and Geary's C value were confirmed as 0.06 in 2007 and 0.99 in 2010 respectively. Global Moran's I and Geary's C indices measured the autocorrelation in the incidence villages with low HIV/AIDS morbidity rate or on cases, which were therefore less sensitive to clustering.

3.3 Hotspot Detection

The map in Figure 4 shows the locations with significant local Moran statistics and classifies those locations by type of association (LISA cluster map). The outputs from LISA represent the spatial autocorrelation of HIV/AIDS at the village level. The study only focused on the univariate spatial distribution and the location of any significant clusters or spatial outliers in the HIV/AIDS morbidity rate data. On the right hand panel of Figure 4 (b.), the sample LISA cluster map of HIV/AIDS morbidity rate in the year of 2007 is shown, depicting the locations of significant local Moran's I statistics, classified by type of spatial association as the red and yellow locations indicating spatial clusters (high surrounded by high, and low surrounded by low), the green and blue indicating spatial outliers (low surrounded by high, and high surrounded by low). There were some outstanding spatial clusters of HIV/AIDS morbidity rate coving specific areas in each year. The clustered villages with high HIV/AIDS morbidity rate (hotspot: red color point) were found to cover the conurbations in the north of Phayao, which is Chun district. The standardized values of HIV/AIDS morbidity rate in each village (a.) are displayed in spatial scatter plot to contrast observed value with their spatial average (spatial averaged adjacent values), and to detect outliers by obtaining the significant level as 0.01. The HIV/AIDS hotspots (high – high values) were illustrated by interpolating the values over the space by using Kernel Density (KD), as shown in Figure 5. These maps show clear spatial patterns of HIV/AIDS that were concentrated in north (Chun, Phu Sang, Mae Chai, and Chiang Kham districts) of the study area during 2006 to 2008 while in 2009 and 2010 they were mostly spread in the middle (Mueang, Dok Khamtai, and Pong districts) of Phayao. The highest density of clustering of hotspots occurred within the urban areas of Mueang Phayao district for the year 2010, Chun district in 2006-2007, Phu Sang district in 2006 and 2008, Mae Chai district in 2008, Chiang Kham districts in 2008, Dok Khamtai district in 2010, and Pong district in 2009.

4. Discussion

Estimates of HIV/AIDS incidence rate ($IR_{HIV/AIDS}$) accounted for the variability in population distribution. Bayesian autoregressive smoothing models are often used in spatial epidemiology (Kathryn, 2012). The Bayesian smoothing technique addresses the issues of heterogeneity in the population at risk, and it is therefore recommended for use in explorative mapping of disease/incidence rates. The study showed that spatial distribution patterns of HIV/AIDS were significantly clustered, and corresponding HIV/AIDS hotspots were identified in Phayao, Northern Thailand. Kernel density estimation illustrated variation in the grouping of HIV/AIDS locations across the study area, and strongly confirmed the visible pattern on the point location map. From 2006 to 2010, we can see that hotspots migrated from urban areas to highland areas. The spatial distribution of HIV/AIDS is always correlated with socio-economic factors (Ezike-Dennis, 2007). Nevertheless, it would be helpful to investigate the underlying socio-economic causes of high incidence areas and hotspots identified in this study. However, there were some limitations in the study, firstly epidemiological data were unknown for some villages, which were either new or restructured and therefore did not figure in older data from other sources. Secondly, regarding the number of HIV/AIDS patients was classified by year and by village, but not by socio-demographic characteristic such as age and gender. Although these characteristics can be an important determinant for HIV/AIDS disease, they were not available in the epidemiological reports and were not included as a determinant in this study.

5. Conclusion

This study also demonstrated that the use of spatial autocorrelation, spatial statistics, cluster detection methods, and GIS can aid health planners in appropriately assessing and identifying spatial disparities in risk in populations so as to better guide evidence-based health planning decisions. The results showed that proposed methods and tools could be beneficial for public health officers to visualize and understand the distribution and trends of diffusion patterns of diseases and to prepare waning and awareness to the masses. This paper explored the spatial patterns of HIV/AIDS from 2006 to 2010 in Phayao and shows that the spatial distribution is clustered, which means areas of HIV/AIDS epidemic were densely clustered, and highlighted the spatial trends of the hotspots in the study area. These maps have shown clear spatial patterns of HIV/AIDS that were concentrated in north (Chun, Phu Sang, Mae Chai, and Chiang Kham districts) of the study area during 2006 to 2008 while in 2009 and 2010 they were mostly spread in the middle (Mueang, Dok Khamtai, and Pong districts) of Phayao. The highest density of clustering of hotspots occurred within the urban areas of Mueang Phayao district for the year 2010, Chun district in 2006-2007, Phu Sang district in 2006 and 2008, Mae Chai district in 2008, Chiang Kham districts in 2008, Dok Khamtai district in 2010, and Pong district in 2009. So, GIS can also be used as an effective tool to manage and monitor HIV/AIDS and related routine activities. The spatial modeling capabilities offered by GIS can help to understand the spatial variation in the incidence of disease, and its covariation with environmental factors with health care. An understanding of epidemiological principles and methods are required to structure studies and interpret results for proper socioeconomic development at various levels of the society. However, authorities adopted a more pragmatic approach of encouraging widespread condom use to prevent HIV transmission, rather than attempting to suppress commercial sex. There are very few developing countries in the world where public policy has been effective in preventing the spread of HIV/AIDS on a national scale. Thailand, where a massive program to control HIV has reduced visits to commercial sex workers by half, raised condom usage and achieved substantial reductions in new HIV infections, is an exception.

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