# GRID AND CENSUS: A GEOGRAPHIC SAMPLING STRATEGY FOR STUDYING DENGUE VECTOR BREEDING SITES IN URBAN AREA

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**Abstract:** Dengue haemorrhagic fever (DHF) is mainly an urban disease that has been associated with sudden epidemics in tropical regions. Dengue vector surveillance is an important methodology to take the control and prevention action. This paper aims to develop a geographic sampling strategy for vector breeding sites surveillance and ecologic studies by using combination of Grid Cells from high-resolution satellite imagery and Block Cells from census tract data. Spatial sampling methods and spatial multi criteria evaluation were integrated to determine the best location of breeding sites for entomological surveillance in an urban area. Urban structure and ecological characteristics, factors of dengue breeding sites include population density, building and tree cover density, DHF incidence density and rainfall density, were collected and processed using geospatial tools. This approach could improve the efficiency and accuracy of dengue vector surveillance which could be used for evaluating urban sites and randomly selecting locations for accurate entomological surveys.

## INTRODUCTION

Dengue haemorrhagic fever (DHF) is mosquito-transmitted disease of human caused by dengue viruses, with *Aedes aegypti* the main vector (WHO, 2009). Currently DHF is a major global health problem, particularly in rapidly expanding urban and semi-urban areas in tropical and subtropical regions. The interplay of vector biology, climate change, international travel, human ecology and behavior gives the disease its complex epidemiology (WHO, 2010). The DHF vector breeding sites are often found in water-filled artificial containers such as discarded tires filled with rainwater, flower pots, buckets, old oil drums, and water storage containers (Focks and Chadee,1997, Gubler, 1997) and shows a close association with humans mostly in urban and semi-urban environments with high human population density, building density, tree cover and low vegetation coverage (Eisele et al., 2003, Troyo et al., 2009, Arboleda et al., 2011). Besides, the *Aedes aegypti* breeding site, bionomics and population density are influenced by climatic factors such as temperature and rainfall (Shekhar and Huat, 1992, Biswas, 1993, Thammapalo, 2005). Dengue vector surveillance is an important methodology to take the control and prevention action, served by effective tool (WHO, 2010).

Geospatial tools, as Geographical Information Systems (GIS), Global Positioning System (GPS), and Remote Sensing (RS) offer powerful tools for describing, illustrating, explaining, and predicting epidemiological phenomena of vector-borne diseases, which can be used to develop or improve surveillance, prevention, and control strategies (Rogers and Randolph 2003, Rinaldi et al., 2006, Eisen and Eisen, 2011). A geographic sampling strategy differs from non-spatial sampling methods because a sample is selected based on geographic locations and/or their associated characteristics (Kumar, 2007), this method could be used to evaluate urban areas and randomly select sections aimed at obtaining data on mosquito larval habitats (Troyo et al., 2009, Fuller, 2010). This paper aims to develop a geographic sampling strategy for vector breeding sites surveillance and ecologic studies in urban map scale by using combination of Grid Cells from high-resolution satellite imagery and Block Cells from census tract data. Spatial Multi Criteria Evaluation was used to determine the best location of breeding sites.

## METHODS AND EQUATION

### Study Site

Hat Yai City municipality is located at 7°0′6″N, 100°27′24″E on the east coast of Thailand approximately 1,000 km south of Bangkok. The municipality cover 21 km$^2$ 56,042 households with population of 157,682 in 2011.The municipality is divided into 338 EA Block (Enumeration Area) each with Approximately 166 houses (buildings) and population of 468. Hat Yai is the largest city of Songkhla Province, the largest metropolitan area in the South, and third largest metropolitan area of the country. The Office of Disease Prevention and Control 12 Songkhla reported dengue incidence in Hat Yai City municipality is one of the highest in southern urban area (see Figure 1).


**Figure 1** The study site: Hat Yai City municipality, Songkhla Province, Thailand.

**Data Collection and Mapping**

*Epidemiology Data*

The reported DHF cases (including Dengue Fever (DF) and Dengue Shock Syndrome (DSS)) in Hat Yai City municipality where occurring in the last 3 years (2009-2011) were used in this study. The data was obtained from the Hatyai Hospital and Bureau of Epidemiology, Department of Disease Control Ministry of Public Health with regard to the number of reported apparent and confirmed dengue cases diagnosis following WHO criteria (WHO, 2010). Because DHF cases geographic coordinates data are unavailable in epidemiological reports. The epidemiology data, 2,076 reported DHF cases, were geo-referenced according to Hat Yai City municipality area (spatial unit) with a 100 × 100 $m^2$ grid sizes by using “Generate Random Points” in Hawth's Analysis Tools for ArcGIS and epidemiological data, the DHF incidence rate per month (temporal unit) were used to create spatial weight for disease density estimation . Kernel density estimation, a realization method based on nearby event, was used to identify the pattern of spatial diffusion using the CrimeStat, GIS software program. Bandwidth or radius was defined value based on the average dispersal range of *Aedes aegypti* in urban area (100 m) (PAHO, 1994, Harrington et al., 2005; Russel et al., 2005, Troyo et al., 2009). The result, Kernel density grid map, showed the presence of significant spatial cluster of DHF incidence where occurring during 2009-2011 in Hat Yai City municipality as in Figure 2.

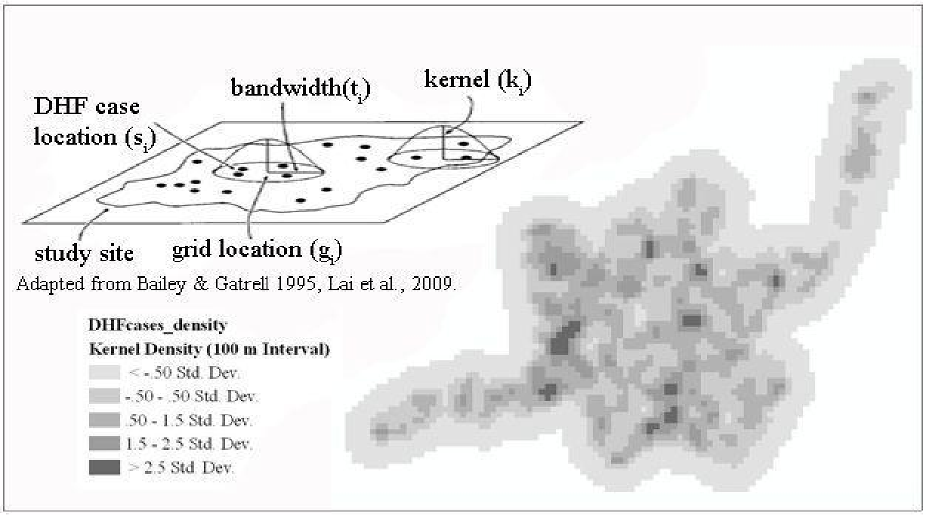


**Figure 2** Spatial pattern of DHF incidence or hot spots map from 2009-2011 in Hat Yai City municipal by using Kernel density estimation approach.

*Census Data*

The map of EA Block, the geographic area canvassed by one census representative, data on population and number of houses or buildings of Hat Yai City municipality were obtained from the population census survey conducted in

2010 by the National Statistics Office. Area-based thresholds of population characteristics derived from census data and DHF incidence rate per EA Blocks were used to DHF spatial autocorrelation analysis, measures the extent to which an disease occurrence in space is similar to or unlike occurrences in a neighboring areal unit by using GeoDa, GIS software program. The Moran's I statistic was used to evaluate autocorrelation in dengue spatial distribution and test how EA Blocks were clustered or dispersed in space with respect to their DHF incidence rate.

The LISA, Local indicators of spatial association, can be seen as the local equivalent of Moran's I in showing hot and cold spots as well as spatial outliers (Lai et al., 2009, Jeefoo et al, 2011). High-high: Hot spots or locations with high values with similar neighbors, Low-low: Clod spots or locations with low values with similar neighbors, High-low: Potential spatial outliers or locations with high value with low-value neighbors and Low-high: Potential spatial outliers or locations with low value with high-value neighbors (Figure 3). The DHF spatial autocorrelation analysis map was transformed to grid cells and used to spatial multi criteria evaluation.

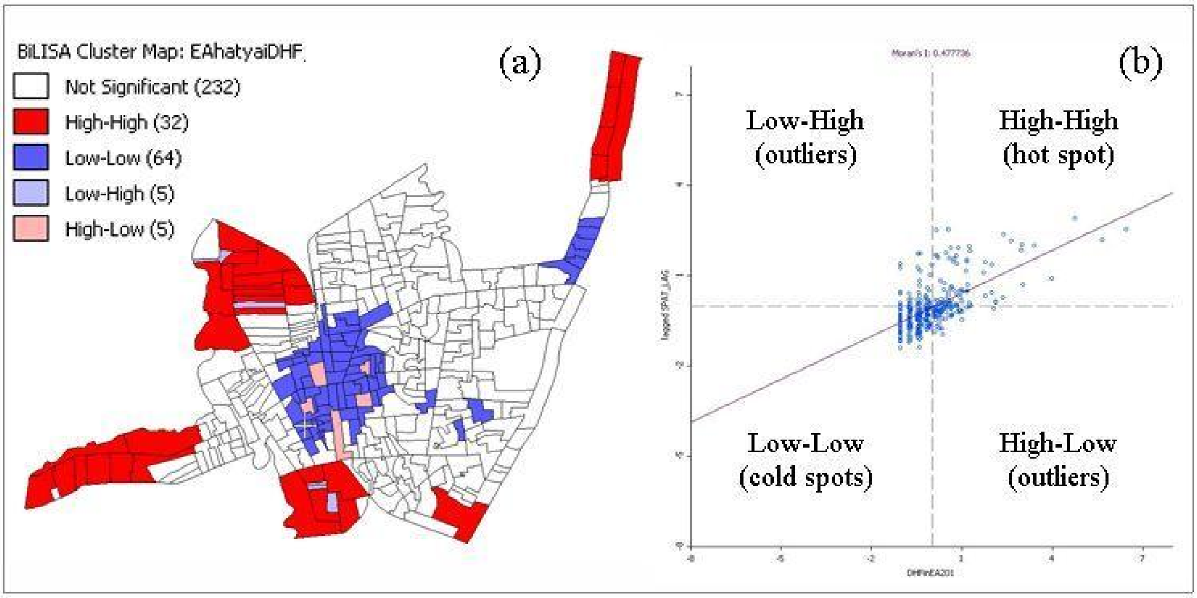


**Figure 3** DHF spatial autocorrelation analysis map from 2009-2011 in Hat Yai City municipality by using the univariate LISA statistics (a) and a Moran scatterplot (b).

*Entomology Data*

The mosquitoes surveillance data in Hat Yai City municipality obtained results of entomological surveys from The Office of Disease Prevention and Control 12 Songkhla between 2009-2011. *Aedes aegypti* abundance was commonly represented by three indices (WHO, 2009), House index (HI) which measures the percentage of premises positive with water containers infested with *Aedes aegypti* larvae/pupae, Container index (CI): Number of habitats positive for *Aedes aegypti* larvae and/or pupae per 100 potential habitats and Breteau index (BI): Number of habitats positive for *Aedes aegypti* larvae and/or pupae per 100 locations. The data of entomological indices grouping by urban structure data, building characteristic such as shop house, single house, apartment building and slum house, were used to create spatial weight for building density grid mapping and spatial multi criteria evaluation.

*Urban Structure Data*

The map of Urban Structure, Hat Yai City municipality area, such as building, tree cover and high resolution (QuickBird) satellite images from Southern Regional Geo-Informatics and Space Technology Center, Faculty of Environmental Management, Prince of Songkla University. Tree cover maps were produced from the QuickBird scenes by applying supervised image classifiers to each QuickBird image, and the resultant classified images were mosaiced by using the Erdas, GIS software program. According to tree cover is associated with more suitable larval habitats and directly correlated with DHF incidence (Bisset-Lazcano et al., 2006; Barrera et al., 2006, Troyo et al., 2009). Therefore, the areas and percentage of tree cover were used to create spatial weight for tree cover density grid mapping and spatial multi criteria evaluation. While building map was obtained from Hat Yai City Municipality Office. Building characteristic such as shop house, single house, apartment building and slum house were classified by entomology data, used to create spatial weight for building density grid mapping and spatial multi criteria evaluation (Figure 4).

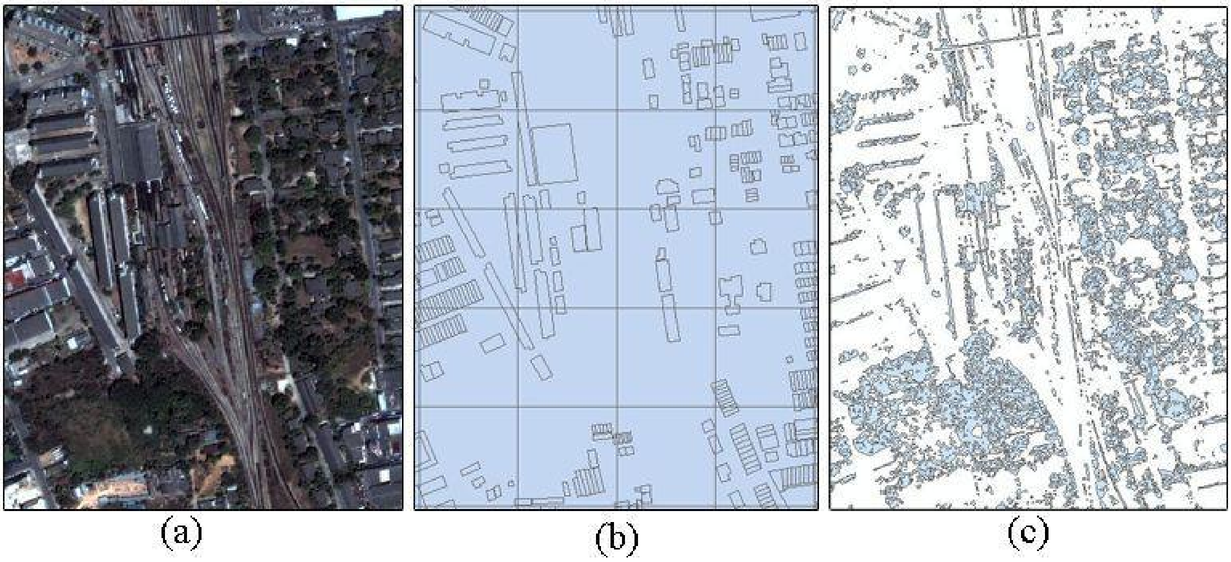

**Figure 4** QuickBird satellite image of Hat Yai City municipality area (a), building density grid map (b) and tree cover density grid map (c) (20 grid cells of map scale 1:4,000).

*Climatic Data*
Average monthly rainfall (mm) for the 30 years (1981-2011) were obtained from 10 weather stations around the study site of Thai Meteorological Department (TMD). The interpolated surfaces were based on 10 weather stations by using Kriging prediction map, a moderately quick interpolator that can be exact or smoothed depending on the measurement error model using statistical models that allow a variety of map outputs including predictions, prediction standard errors and probability, in Geostatistical analyst Tools for ArcGIS. The Kriging prediction map were used to create spatial weight for rainfall interpolation grid mapping and spatial multi criteria evaluation.

*Software*
Various GIS softwares were adopted in this study such as Erdas (www.erdas.com), ArcGIS (www.esri.com), GeoDa (www.geoda.uiuc.edu), CrimeStat (www.icpsr.umich.edu/CRIMESTAT).

*Grid Cell*
A cell size of 100 × 100 $m^2$ was considered for surveillance or field survey in half a day and the average number of houses per cell was 13 houses (Troyo et al., 2009).

**Spatial Multi Criteria Evaluation**
Spatial multi criteria evaluation is a spatial decision support tool that could improve the efficiency and accuracy of dengue vector surveillance, determining the best location of breeding sites for targeting often limited prevention and control resources (Hongoh et al, 2011). The evaluation criterion maps, DHF incidence density map, DHF spatial autocorrelation analysis map, tree cover density grid map, building density grid map and rainfall interpolation grid map, are generated to evaluate the performance of alternatives. Constraint maps can also be generated to display the limitations of the values that decision variables may assume. Following this, all criteria are weighted by Analytical Hierarchy Process (AHP), ordering techniques such as pair wise comparison. Next, a mathematical combination of the criteria is performed using a decision rule and a recommendation consisting either of the best-ranked alternative or group of the best location for breeding site areas (100 × 100 $m^2$ grid sizes). (Figure 5)

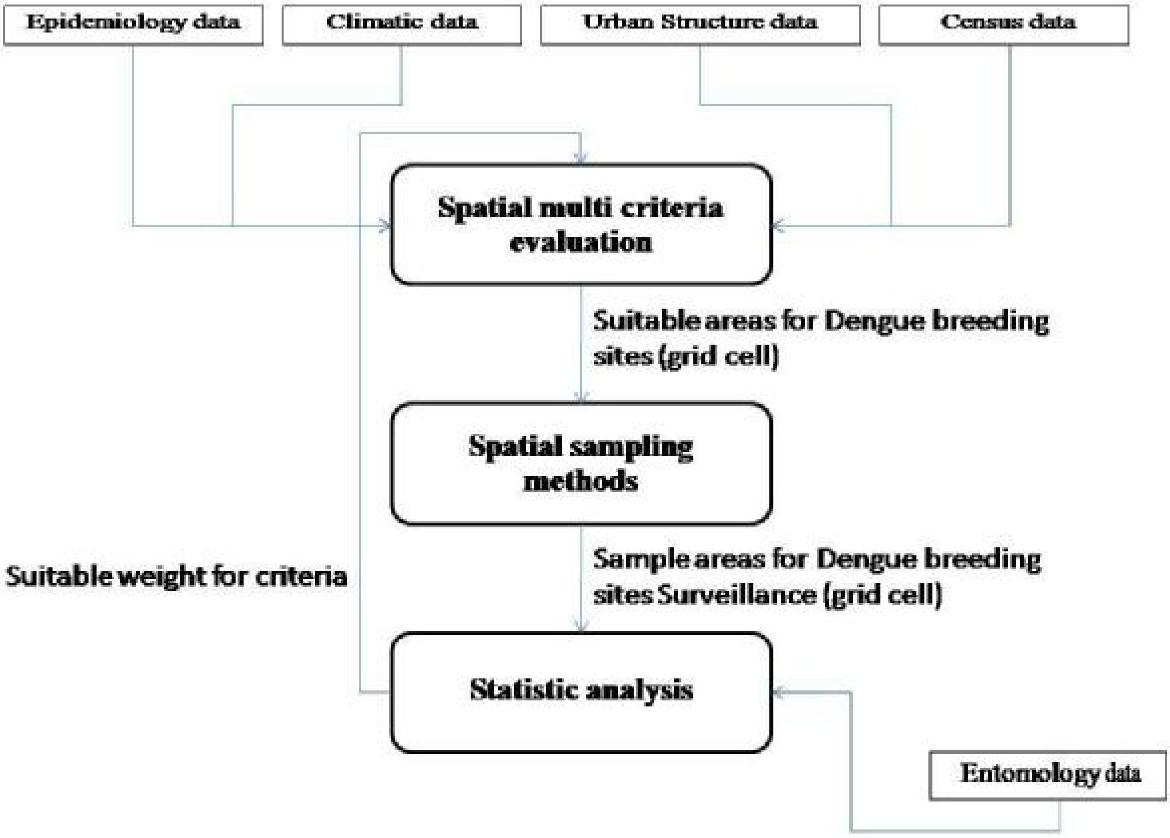


**Figure 5** The conceptual framework of the study

**Spatial Sampling Methods**

Spatial sampling methods, a sample is selected based on geographic locations and/or their associated characteristics, developed and tested so far and epidemiological studies through the use of spatial sampling are relatively new (Rinaldi et al., 2006, Kumar, 2007), moreover this methods have been use to study vector borne diseases mostly in very broad scales and non local or urban areas (Troyo et al., 2009). Spatial random sampling which provides the selection and the distribution of sampling randomly of the sites in the territory, leads to "not biased" samples and is necessary to use software and apply appropriate algorithms in order to locate the sampling points (Rinaldi et al., 2010). Therefore, high-resolution satellite imagery and geographical information systems appears useful for evaluating urban sites and randomly selecting locations for accurate entomological surveys (Troyo et al., 2009). However, the sample size for routine surveys can be calculate by statistical methods based on the expected level of infestation and the desired level of confidence in the results (WHO, 2009). Hence, this study aims to develop a geographic sampling strategy for vector breeding sites surveillance and ecologic studies in urban map scale by using new patterns of composite or mixed samples. An example was calculated by a systematic grid sampling with proportional allocation of suitable areas from a spatial decision support tool (Figure 5). Stratified random sampling and cluster sampling were conducted in this study site by using “Create Random Selection” and “Generate Random Points” in Hawth's Analysis Tools for ArcGIS.

**RESULTS**

Suitable dengue vector breeding sites based on spatial multi criteria evaluation method were classified with four suitable levels i.e. very high, high, medium and low suitable sites. Out of 2,276 grid cells (22.76 square kilometers), 264 grid cells covering an area of 2.64 $km^2$ (i.e.11.60 %) are falling with in very high suitable breeding sites, 594 grid cells covering an area of 5.94 $km^2$ (i.e.26.10 %) in high suitable breeding sites, 785 grid cells covering an area of 7.85 $km^2$ (i.e.34.49 %) in moderate suitable breeding sites and 633 grid cells covering an area of 6.33 $km^2$ (i.e.27.81 %) in low suitable breeding sites (Table1).

**Table 1**: Total areas and percentage of Suitable Breeding Site grid map and Data layers (Breeding Site Factor maps) were calculated by Spatial multi criteria evaluation.

| Data layers (Breeding Site Factor maps) | *Aedes aegypti* Suitable Breeding Sites (grid cells* , (%)) **100 × 100 $m^2$ per grid size* | | | | | |
|---|---|---|---|---|---|---|
| | Low | Moderate | High | Very High | Total | Weighing value |
| DHF incidence density map | 1,224 (53.78) | 777 (34.14) | 224 (9.84) | 51 (2.24) | 2,276 (100) | 0.250 |
| DHF spatial autocorrelation analysis map | 1,265 (55.58) | 416 (18.18) | 305 (13.40) | 290 (12.74) | 2,276 (100) | 0.300 |
| Tree cover density grid map | 1,549 (68.06) | 557 (24.47) | 125 (5.49) | 45 (1.98) | 2,276 (100) | 0.175 |
| Building density grid map | 995 (43.72) | 635 (27.90) | 470 (20.65) | 176 (20.65) | 2,276 (100) | 0.175 |
| Rainfall interpolation grid map | 0 | 398 (17.49) | 1,389 (61.03) | 489 (21.49) | 2,276 (100) | 0.100 |
| Suitable Breeding Site grid map from Spatial multi criteria evaluation | 633 (27.81) | 785 (34.49) | 594 (26.10) | 264 (11.60) | 2,276 (100) | 1.000 |

Sample size for dengue vector surveys based on spatial sampling methods was generated and compare with entomological surveillance system of the Office of Disease Prevention and Control 12 Songkhla. In order to compare between the activity basis of dengue vector surveillance and the new approach by area bases, the pupa demographic survey will be done indicating by the PI (Pupa Index) as evaluation index. The PI can be partly used for the prediction of the dengue fever in urban. Within 300 households in urban area, the spatial sampling methods can be applied in to two possibilities. The first one is the random selection of grid cell in the very high suitable breeding sites to get 23 grid cells covering 0.23 $km^2$ (300 households / 13 average number of households per grid). The random points can be selected randomly from surveying of 300 points in the grid cell at the very high suitable breeding sites (Figure 6).

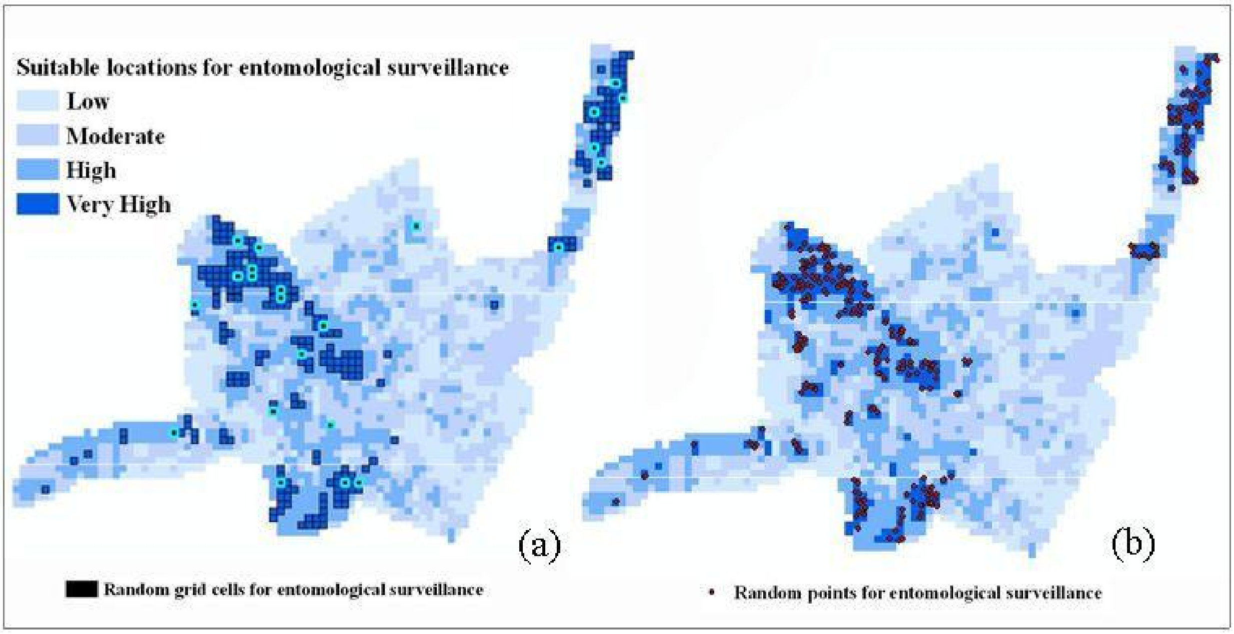


**Figure 6** Random gird cells (a) and Random points (b) for entomological surveillance

**DISCUSSION**

From the study at the very high suitable breeding sites, the dengue fever is mainly related to the factor of urbanization i.e. population density, urban structure-building and tree cover. To find out the main factor of breeding site, the defining of the weighing factor is important to the site selection. It is depending on the area, map scale, and sources of data e.g. climate data in seasonal level. For urban area, there is low difference in seasonal climate data. In view of patient (DHF case), there is no system recorded the location of patient. The epidemic analyze is therefore difficult and not reliable. The social environment is another vital factor for the decision making in the surveillance. Besides, the dynamic of population, the behavior of protection and community strength would also important for the study.

**CONCLUSIONS & RECOMMENDATIONS**

The development of a geographic sampling strategy by integrating the spatial sampling methods and spatial multi criteria evaluation is possible to be the tools for monitoring and studying by area based of the vector borne diseases. The fast expanding of urban is supposed to lead to the increasing of breeding site. The *Aedes aegypti* breeding site factor e.g. DHF incidence rate, population density, urban structure and climatic factor should be used for the spatial analysis systematically together with statistical method.

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