SPATIAL DATA WAREHOUSE AND INTERACTIVE MAPPING APPLICATION FOR SUPPORTING DENGUE FEVER SURVEILLANCE

Duangduen Asavasuthirakul
Lecturer, Department of Computer Science and Information Technology, Faculty of Science, Naresuan University, 99 Moo 9, Thapho, Muaeng, Phitsanulok, 65000, Thailand

ABSTRACT

Health information systems, like other information systems, store huge amount of spatial data in various forms distributed over databases of responsible agencies. Turning such data into useful geographic information is needed in order to support insightful and timely decision making especially for controlling epidemic diseases such as dengue fever. Therefore, this study focuses on designing and implementing a spatial data warehouse and developing an interactive mapping application as a prototype system. The clinical data relating to dengue cases as well as public health resources obtained from the Kamphaeng Phet Provincial Health Office were used as a case study. The snowflake schema model was adopted for denormalizing data from various data sources into the data warehouse. The system interface was implemented as a web application. It provides tools for the interactive analysis of multidimensional data with various granularities through maps and charts, which helps to facilitate effective monitoring and controlling of the disease outbreaks. The system was implemented using open-source software including PostgreSQL/PostGIS and Leaflet. The result of the user satisfaction evaluation showed that they satisfied using the system at the highest level in terms of effectiveness ($\bar{x}$ = 4.58 out of 5), design ($\bar{x}$ = 4.35 out of 5) and user satisfaction ($\bar{x}$ = 4.83 out of 5).

KEYWORDS: Spatial data warehouse, dengue fever, online mapping, map representation

1. Introduction

Health information system (HIS) is a huge system that health-related records are associated with a location in one form or another. Thus, there are many health-related studies utilizing Geographic Information System (GIS) tools for visualizing data on the map and performing spatial analysis to support data interpretation and decision-making [1]. HIS in

Thailand has reached a milestone that it can collect clinical data from most healthcare facilities throughout the country into data centers or warehouses [2]. However, the usage of such data is mainly focused on administrative reports. For example, the national vector-borne diseases prevention and control program under the ministry of public health (MOPH) publishes weekly reports on dengue fever cases in forms of data tables and graphs. Static maps showing case density are also provided but it is difficult to compare such picture maps across areas within a period. The geographical aspect has left unimportant so it is difficult to represent and analyze some phenomena on a map. Hence, the integration of geographic information in a health data warehouse becomes essential to the process of epidemiologic surveillance and decision making.

Research related to spatial data warehouse (SDW) for public health has been scarce. However, basic issues can consult from a number of work. For example, Cembalo et al. [3] designed a data warehouse using spatial online analytical processing (SOLAP) approach and develop a decision support application for epidemiology domain. Derbal et al. [4] propose a data warehouse model as a snowflake schema by integrating the geographic object of roads to support road risk analysis. Park and Hwang [5] designed a spatial data warehouse based on snowflake schema and implemented a pilot system to estimate the targeted marketing area from spatial analysis of the customers' purchasing power.

This research attempts to incorporate geographic information into data warehouse to facilitate spatial query and analysis on dengue fever data. The contributions of this work are (1) design of the SDW that integrates health information with spatial components and (2) development of a geospatial decision support prototype based on the SDW to support dengue disease analysis, control and surveillance through interactive maps and charts.

This paper is organized as follows. Section 2 describes the user's needs and data sources for developing our system. Section 3 presents the design of the proposed SDW and Section 4 presents the architecture of the prototype system. In Section 5, we present the developed system with sample queries and reports. The user satisfaction evaluation was presented in Section 6. This paper ends with a conclusion and discussion on future issues.

2. User's requirements and data sources

According to an interview to public health experts and information and communications technology (ICT) officers at the Kamphaeng Phet provincial health office (KPHO), we found out even though KPHO had been continuously published summaries of dengue data online in forms of tables and charts, it was difficult to search for a certain data at a specific administrative area with a few clicks. The users, mostly officers, must be familiar and remember where the data was located. Therefore, if we could represent dengue data on the map, it would escalate data searching time and also promote a quick understanding of dengue situations.

To start developing our system, we obtained a sample dataset from KPHO. In Thailand, MOPH regulates that all health records of each healthcare facilities have to transfer to the national HIS (NHIS) with the supervision of administrative health offices. The dataset contains records of patients with dengue fever between 2013 and 2014 from all healthcare facilities supervised by KPHO. The population data between 2013 and 2014 was downloaded from the Department of Provincial Administration's web service. The administrative boundaries of Kamphaeng Phet were also obtained from the Department of Provincial Administration as shapefiles. The location of each healthcare facility was queried from the MOPH's website.

3. Conceptual design of spatial data warehouse

Based on our analysis of the user's requirements and the needs for dengue reports on the maps. We designed the structure of the SDW for supporting the dengue fever surveillance as shown in Figure 1. Unlike the star schema which is popularly used for designing data warehouses, in this study we chose to model the SDW based on snowflake schema due to the relationships of administrative data and the population data and also additional information of hospital types and patient data, which cause branches of the structure. The choice of fact and dimension tables was driven by the input dataset and the requirements on the querying reports. The model contains a central fact of the patient records. The dimension tables of the schema are time, patient, disease type, healthcare facility, and age range. The patient record loaded into the fact table is normalized according to the administrative levels, which are province, district (Amphor) and sub-district (Tambon). Each level contains its geographic boundary, stored as a polygon in the Well-Known Binary (WKB) representation in geographic coordinates (latitude/longitude), and its administrative code and name and the administrative name of the former levels to expedite the query processing. The patient dimension has further information on occupation, nationality, education and house, which causes branches of the schema. The healthcare facility and house dimension also contain the spatial objects stored as points. This snowflake schema with spatial components can facilitate cartographic visualization and spatial analysis. The time dimension represents a period of temporal information through a hierarchy (day, week, month, and year). Our model contains a large fact table linking a set of dimensions by foreign keys. The fact also stored individual information necessary for the analysis and report such as mortality, age and gender. In addition, we added the population dimension to allow reports on cases per population. With increasing requirements of public health studies on spatial decision making by using geographic information, this concept can support analysis on spatiotemporal tasks.

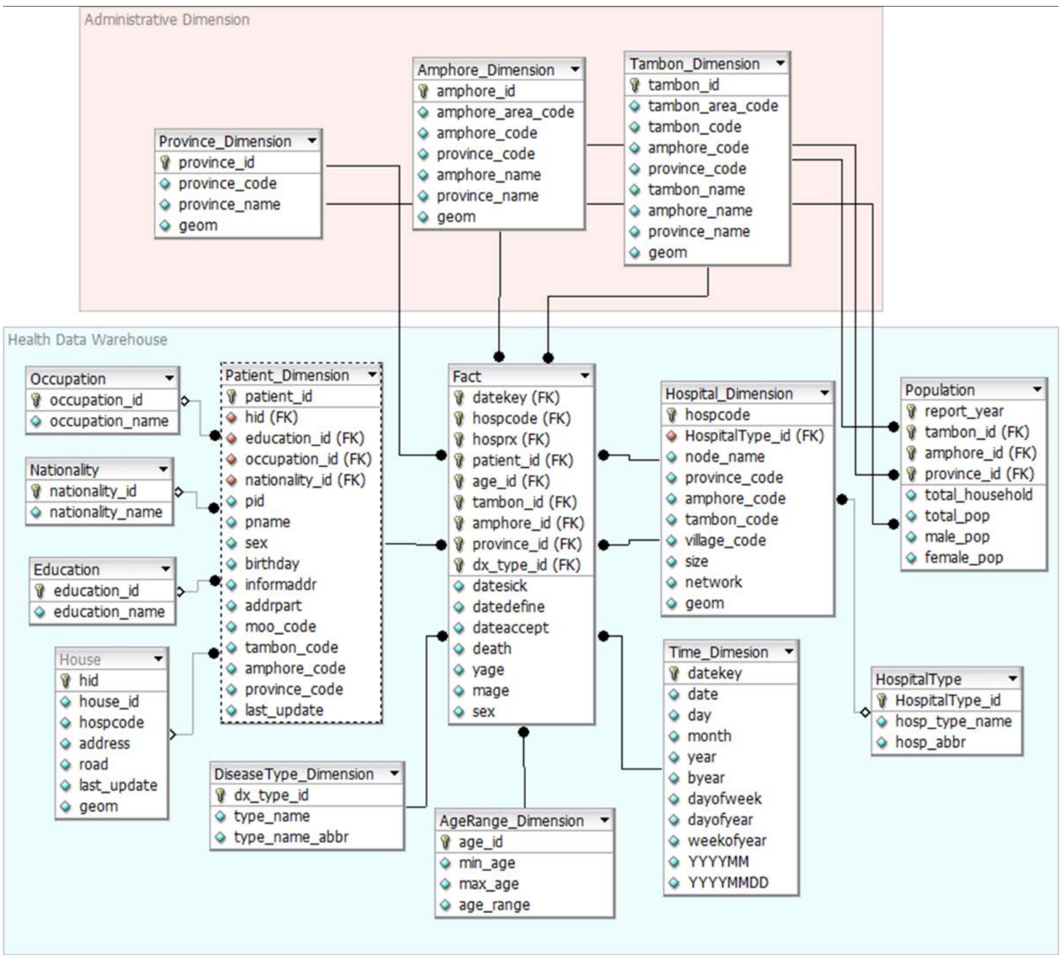


Figure 1 Snowflake schema of a SDW

4. Architecture of the system prototype

The overview of the system architecture presents in Figure 2. The data was pulled from the data center at KPHO, then the data was extracted, transformed, and loaded (ETL) into the designed SDW. The prototype system was developed using open-sourced software tools. The SDW was implemented using PostgreSQL with PostGIS extension which has spatial functions for storing spatial objects and facilitating complex spatial queries. We use Apache as an application server to serve our web application. The web application has a user-friendly interface that allows the user to quickly observe the data in several aspects using maps, charts, and tables. We use Leaflet, open-source JavaScript library, for creating interactive maps and use Highcharts, also JavaScript library, for building dynamic charts.

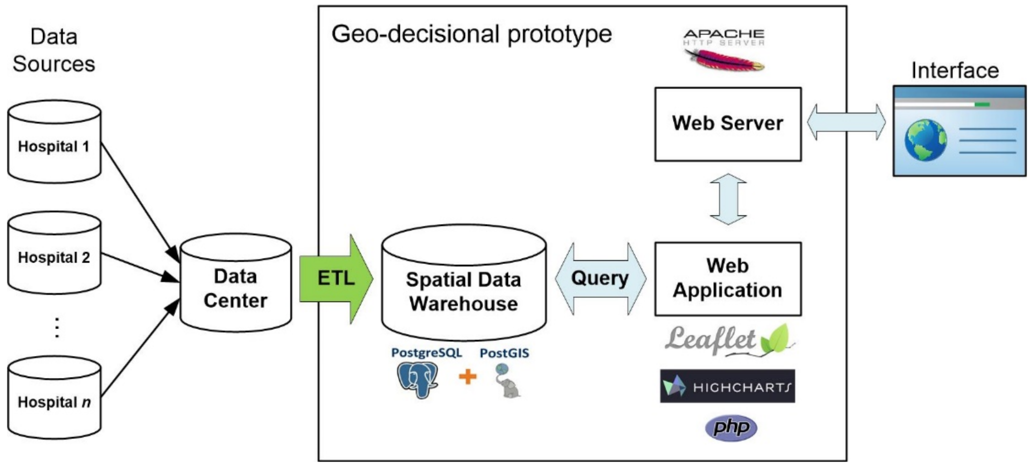


Figure 2 Overall architecture of the system prototype

5. Implementation of the system prototype

Functionalities of our prototype systems are presented through the following interfaces. Three categories of users are considered: unregistered users, health officers or decision-makers, and administrators. The main page of the application is shown in Figure 3. Unregistered users can interactively interrogate the number of dengue cases on the map across different years and administrative granularities. No authentication is required since the system provides only statistical data of dengue cases without individual information. For example, in Figure 3 shows a map of dengue case rates per 100,000 population in 2013 categorized by districts. The user can hover over on the map and click on each feature of the map, in this case is a district, then the system will show a pop-up chart of monthly case summaries containing all the historical data as shown in Figure 4. This cartographic visualization allows to users quickly realize the situation of the dengue disease as well as historical data on a specific area.

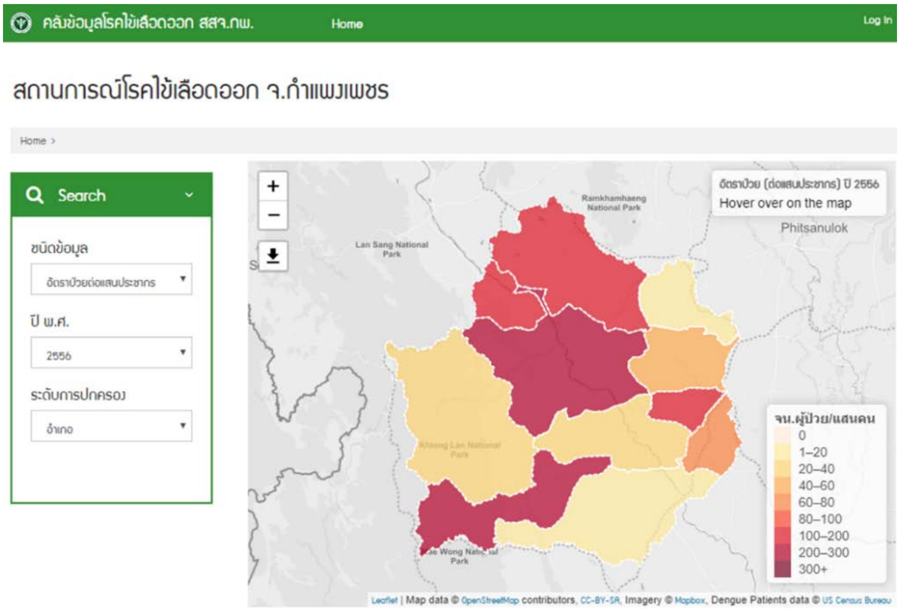


Figure 3 Main page of the prototype system

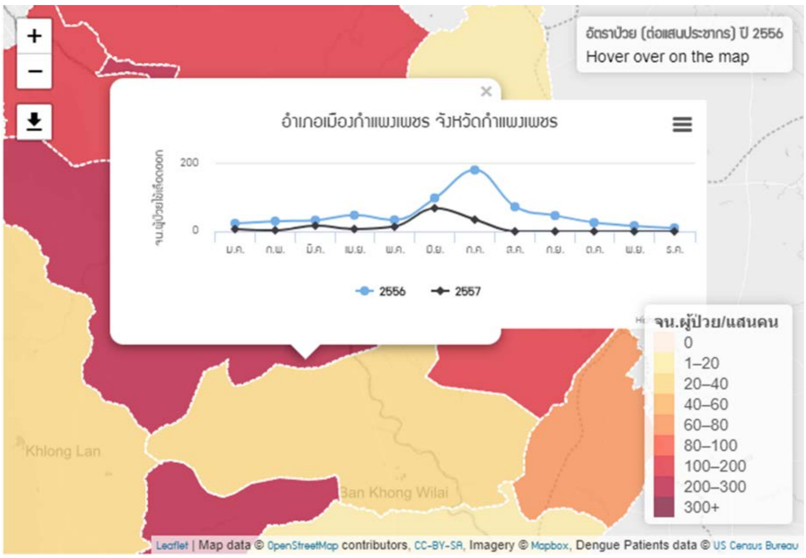
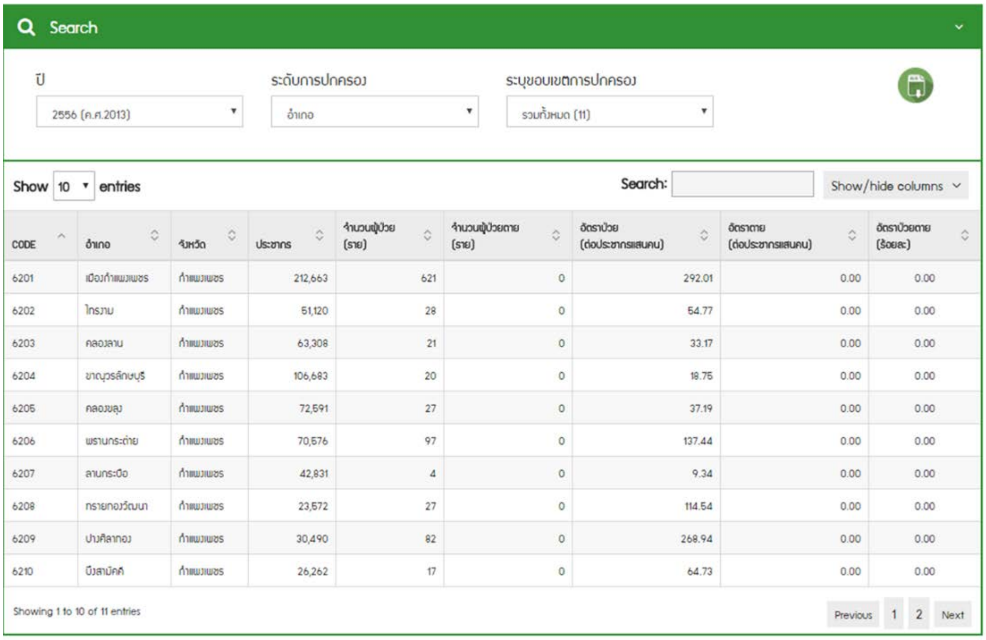


Figure 4 A chart report of the selected map feature

Decision-makers and administrators require login to make a detail analysis on patient data. Before running any report, the decision maker must define two querying parameters: a time period and an administrative level. Three types of reports are predefined: data table, analytical chart, and classification report. The data table report summarizes population, dengue cases, dengue death cases, and case rates per 100,000 population as shown in Figure 5. The user may opt to download the data as an Excel file. The analytical chart allows the user to observe dengue cases and rates by interrogating on the interactive choropleth map with the historical data on the synchronized charts presenting the number of cases, case accumulation, and case rates per 100,000 population as shown in Figure 6.


Search
ปี 2556 (ค.ศ.2013)
ระดับการปกครอง อำเภอ
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CODE	อำเภอ	จังหวัด	ประชากร	จำนวนผู้ป่วย (ราย)	จำนวนผู้ป่วยตาย (ราย)	อัตราป่วย (ต่อประชากรแสนคน)	อัตราตาย (ต่อประชากรแสนคน)	อัตราป่วยตาย (ร้อยละ)
6201	เมืองกำแพงเพชร	กำแพงเพชร	212,663	621	0	292.01	0.00	0.00
6202	ไทรงาม	กำแพงเพชร	51,120	28	0	54.77	0.00	0.00
6203	คลองลาน	กำแพงเพชร	63,308	21	0	33.17	0.00	0.00
6204	ขาณุวรลักษบุรี	กำแพงเพชร	106,683	20	0	18.75	0.00	0.00
6205	คลองขลุง	กำแพงเพชร	72,591	27	0	37.19	0.00	0.00
6206	พรานกระต่าย	กำแพงเพชร	70,576	97	0	137.44	0.00	0.00
6207	ลานกระบือ	กำแพงเพชร	42,831	4	0	9.34	0.00	0.00
6208	ทรายทองวัฒนา	กำแพงเพชร	23,572	27	0	114.54	0.00	0.00
6209	ปางศิลาทอง	กำแพงเพชร	30,490	82	0	268.94	0.00	0.00
6210	บึงสามัคคี	กำแพงเพชร	26,262	17	0	64.73	0.00	0.00

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Figure 5 Data table report

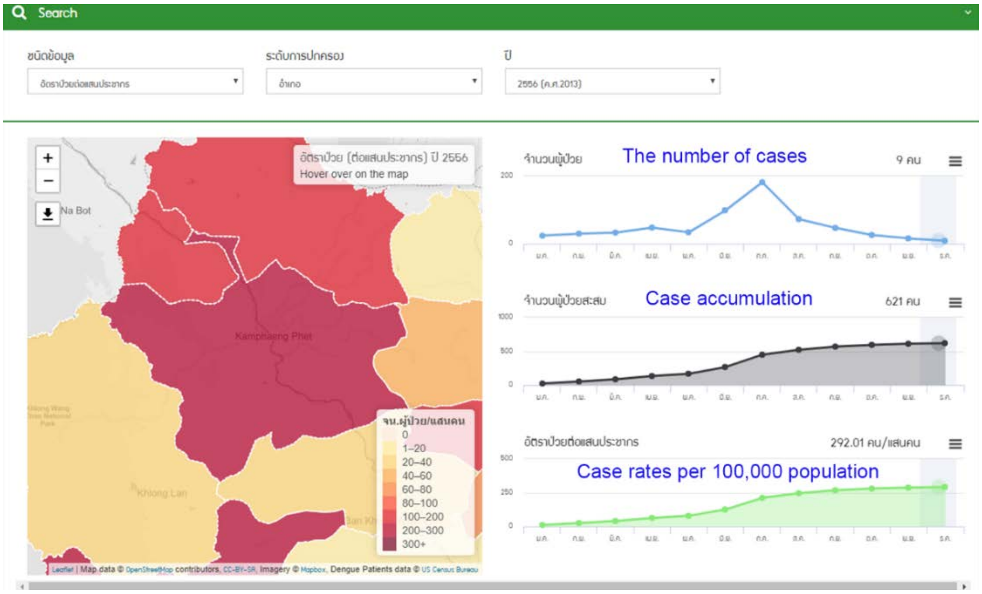

Figure 6 Data table report

The classification report adds querying parameters on disease types, healthcare types, and patient location. The dengue disease types are dengue fever (DF), dengue hemorrhagic fever (DHF), and dengue shock syndrome (DSS). Figure 7 shows the query result for the DHF cases in Tambon Nai Muang, Muang, Kamphaeng Phet during Jan 1st – Jun 30th 2013, which consists of a choropleth map, a chart of the monthly number of DHF cases, and a stack chart represents gender and age range of the DHF cases. This study adopted the types of healthcare facilities given by MOPH [2]. Figure 8 presents the querying result of the dengue cases for health promotion hospitals in Prankratai District hovering over the Tha Mai health promotion hospital for more details of cases.

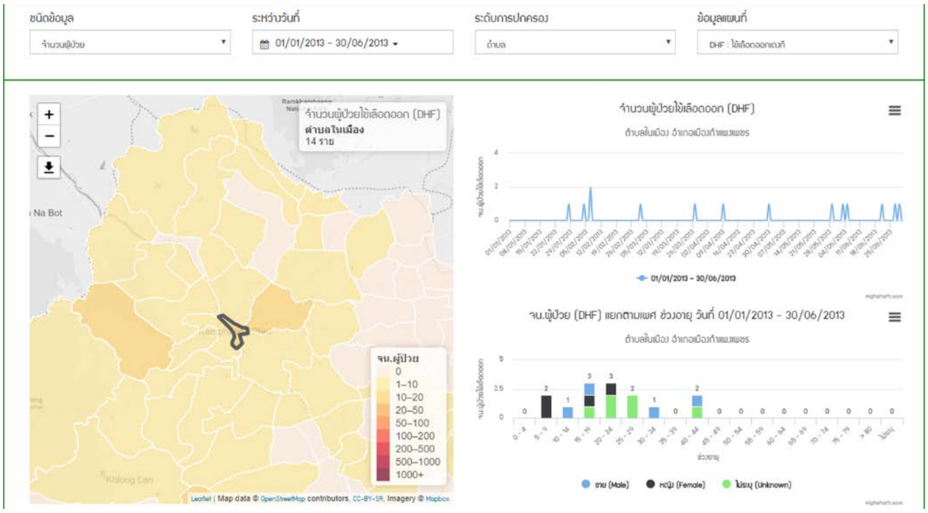

Figure 7 **A classification report based on dengue disease types**

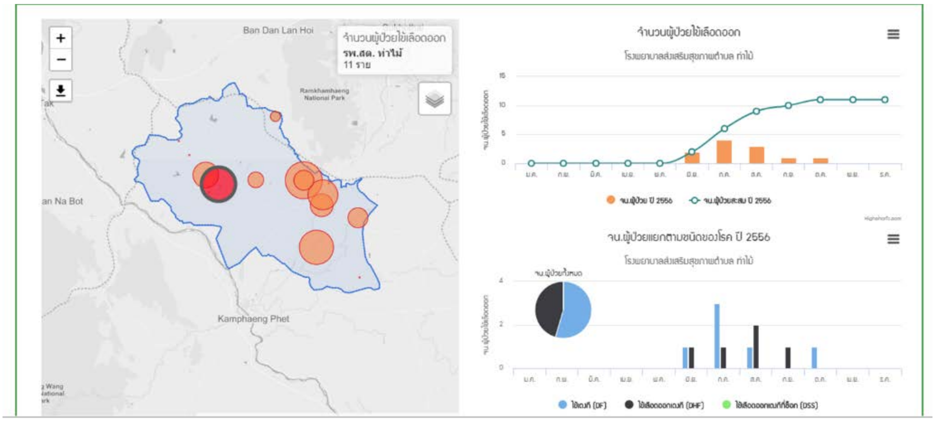

Figure 8 **A classification report based on healthcare facility types**

The prototype also provides a classification report based on the location of patients. On the map, the user has options to show or hide layers, which are heat map, the location of patients, and the location of healthcare facilities in case the location of patients is unknown. Figure 9 presents a heat map of all dengue cases reported in Kamphaeng Phet in 2013. The user can change values of intensity and radius for calculating heat map to represent data density of each area appropriately. Besides, the user can interactively examine each point location to obtain details of each patient, which will benefit individual case investigation as shown in Figure 10.

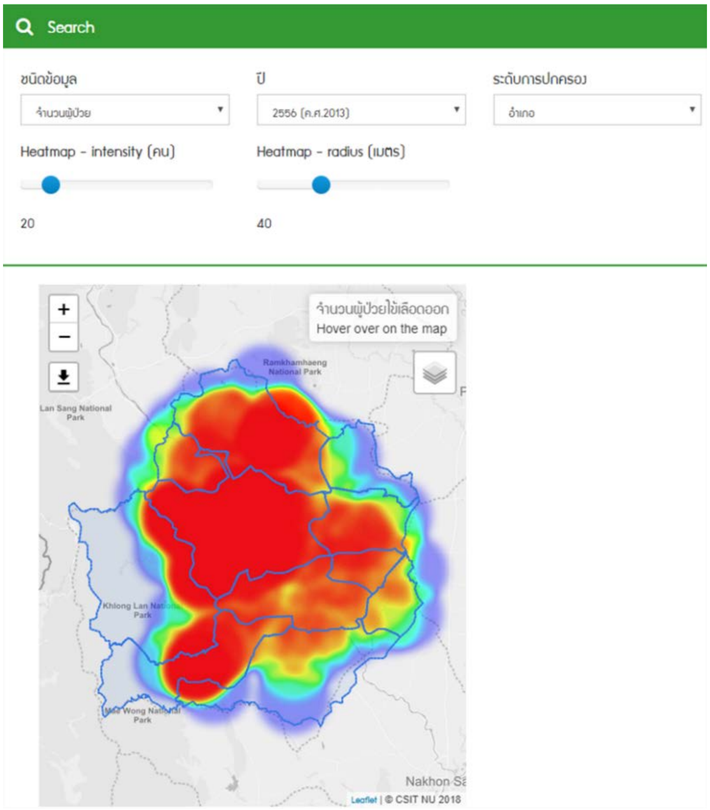

Figure 9 A heat map of the patients' location

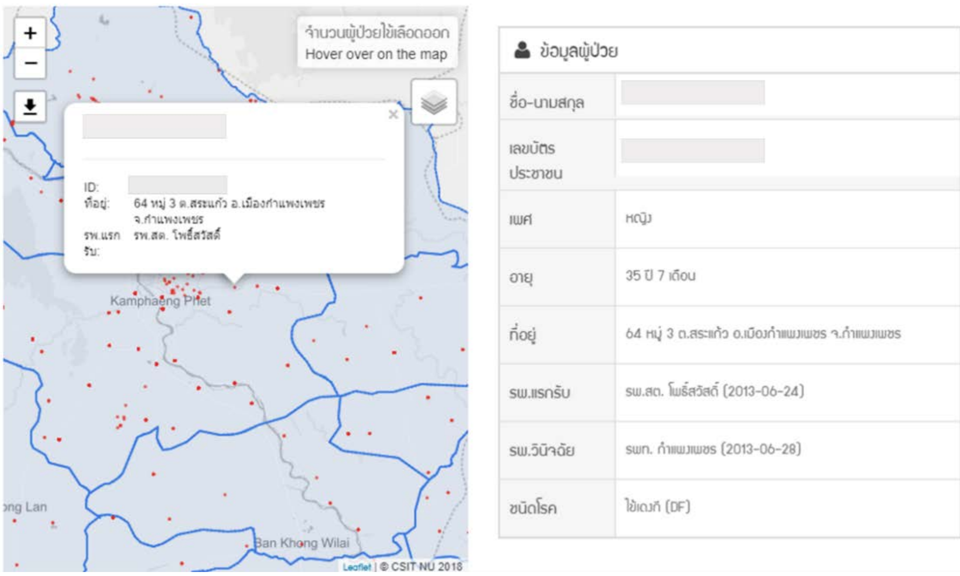

Figure 10 A map showing points of the patient location and individual information at a selected point

Only administrator can perform tasks that allow maintaining the SDW. He can update the information stored in dimension tables and verify the validity of the data through the interface. The administrator can download data from the data sources via the ETL script.

6. Evaluation Results

The prototype was evaluated by a group of participants, selected purposively at MOPH. After the participants were given the instructions on how to use the system and the purpose of each menu, they tested the system prototype and completed the user satisfaction evaluation questionnaire. 12 participants who worked at MOPH attended the evaluation. Table 1 summarizes the characteristics of participants.

Table 1 Description of participants

Gender	N	%
Male	7	58.00
Female	5	41.67
User Type	**N**	**%**
General user	4	33.33
Officer user	5	41.67
Admin	3	25.00

The questionnaire covers three aspects: effectiveness, design, and satisfaction. The results are presented in Table 2. The average scores of the system effectiveness is 4.58. The minimum scores are on completeness of the presented data and the system provides clear information. This may be due to the outdated datasets imported into the prototype and unclear descriptions on the interface. The average scores on design issues is 4.35. The most critical issue is on font size and style. Some participants addressed that the font is too small especially in charts. Overall, the participants satisfied the prototype with an average score of 4.83. Thus, the participants satisfied using the system at the highest level of the three evaluation aspects. Additional comments from the participants are 1) the system should allow the officer user or admin to edit the location of any patient's house and 2) the system should have a way for admin to update the boundary of administrative regions on the interface.

Table 2 Scores on questions of the user satisfaction evaluation questionnaire

	Effectiveness	**Mean**	**S.D.**
1.	The system's menus are enough and appropriate	4.58	0.51
2.	Accurateness of data processing, map representation, chart, and report	4.50	0.52
3.	Completeness of the presented data	4.25	0.62
4.	The system is user friendly	4.83	0.39
5.	The system provides clear information	4.25	0.62
6.	The system shortens the data searching time	4.67	0.49
7.	The system helps dengue surveillance locally and in timely manner	4.67	0.49
8.	The system facilitates on dengue reports to support executive's decision making	4.75	0.45
9.	Presenting the statistics of dengue data on maps and charts promotes the understanding of the disease cycle	4.75	0.45
	Average of effectiveness	4.58	0.53
	Design	**Mean**	**S.D.**
10.	The interface looks beautiful, modern, and favorable	4.42	0.51
11.	The layout is easy to read and use	4.50	0.52
12.	Font size and style are appropriate (readable and beautiful)	4.08	0.67
13.	Maps, charts, and data table are presented properly and quickly	4.42	0.51
	Average of the design	4.35	0.56
	Satisfaction	**Mean**	**S.D.**
14.	The system is reliable and it is helpful for practical use	4.83	0.39

7. Conclusions

This paper presents the design of a spatial data warehouse and the implementation of spatial decision supporting system in order to improve the surveillance and analysis of dengue fever epidemic. The conceptual design of the SDW is based on the snowflake schema consisting of both spatial and non-spatial dimensions at different granularities. For a better analysis and exploitation, the system presents the results on the map and charts, which allow interactive interrogation of the data. The implementation of the prototype utilizes all open-source software tools. Nevertheless, some issues remain to be addressed in future research. (1) The capability of the application could be enriched; for example, the map should automatically roll-up and drill-down to show aggregate cases after zoom. (2) There is no measure in this SDW design due to the requirement of individual information. Thus, if the system requires only aggregation of cases, the patient dimension could be removed and a measure, i.e., the number of patients, should be added to the fact instead. And (3) the current prototype does not link to the existing HIS. Therefore, there is a need to modify the ETL process to pull data from the data sources accurately.

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Author's Profile

Duangduen Asavasuthirakul received the B.Eng. degree in electrical engineering from Chiang Mai University, Thailand, and the M.S. and Ph.D. degree in Information Science from University of Pittsburgh, USA. She is currently an Assistant Professor in Department of Computer Science and Information Technology, Faculty of Science, Naresuan University, Phitsanulok, Thailand. Her research focuses on GIS, navigation systems and location-based services. Email: duangduenr@nu.ac.th