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Field Epidemiology Training Program, Bureau of Epidemiology
Department of Disease Control, Ministry of Public Health, Thailand
Tel: +6625901734-5, Fax: +6625918581, Email: osireditor@osirjournal.net, http://www.osirjournal.net

A Systematic Evaluation of Dengue Vector Surveillance, Tainan City, Taiwan, 2011-2013

Chin-Sheng Chi[1], Chen WC[2], Lo YC[2,*]

1 Southern Regional Center, Centers for Disease Control, Taiwan

2 Field Epidemiology Training Program, Office of Preventive Medicine, Centers for Disease Control, Taiwan

*Corresponding author, email address: loyichun@cdc.gov.tw

Abstract

Outbreaks of dengue fever (DF) are more common in southern than northern Taiwan, with primary transmission through *Aedes aegypti* mosquito vectors. A dengue vector surveillance system (DVSS) was established in 2005, with the objectives of characterizing dengue vector distribution and evaluating the effectiveness of DF control measures. We evaluated DVSS in Tainan City, a southern city in Taiwan with DF transmission. During 2011-2013, *Ae. aegypti* predominance was found in 31% of 36 districts. Breteau, container and household indices decreased following district-level vector control campaigns in 2011 and 2013. Levels of data validity and entry error types were more than 90% and less than 10% respectively. Program completeness was found to be low at 17%, primarily influenced by rural neighborhood findings. Completeness of pupal indices was unsatisfactory (12%), limited by time and manpower in collecting pupae. This evaluation of DVSS showed that the system collected complete and valid data necessary for meeting the surveillance objectives. We recommended that completeness of DVSS be further improved in rural districts, pupal index be removed from routine dengue vector surveys, and on-the-job training of survey personnel be established and maintained.

Keywords: dengue, dengue vector surveillance system, *Ae. aegypti*, Taiwan

Introduction

Dengue virus is transmitted principally by *Aedes aegypti* and the less efficient vector, *Ae. albopictus*.[1-4] In Taiwan, *Ae. aegypti* is distributed mainly in the southern part whereas *Ae. albopictus* is extensively distributed nationwide.[5] Dengue outbreaks have occurred almost annually in Taiwan since 1987 and mainly in southern Taiwan[6-7] where *Ae. aegypti* and *Ae. albopictus* coexist, especially during May to December.

In 2005, Taiwan Centers for Disease Control (TCDC) established the dengue vector surveillance system (DVSS). The surveillance is performed throughout the year in all cities and counties, with survey frequencies and resources focused on southern Taiwan. The objectives of dengue vector surveillance in Taiwan are to monitor geographic distribution of vectors and facilitate appropriate and timely decisions regarding interventions.[8] Understanding the spatial and temporal distribution of entomological information allows planners to deploy resources to high risk areas for the greatest impact on reducing disease.[9] This was the first evaluation of the DVSS in Taiwan.

Tainan City, the second largest city in southern Taiwan, is an area where *Ae. aegypti* and *Ae. albopictus* coexist. In 2012, Tainan City had a large dengue outbreak with 744 indigenous cases, and in 2011 and 2013, there were 95 and 38 indigenous cases identified respectively. Our aim was to ascertain that the objectives of the DVSS were being achieved.

Methods

Identification of Target Area

Tainan City has 37 districts divided into 752 neighborhoods. We defined six districts (East, West Central, South, North, Anping and Annan Districts) in Tainan metropolitan area as urban (41% of population) and the remaining districts as rural.

Study Design

Our study design was a descriptive approach and ecological analysis. We described the operation of DVSS and evaluated DVSS following the guidelines from United States Centers for Disease Control and Prevention (CDC)[10]. Resources of personnel time and cost were also calculated. Selected attributes for the evaluation were usefulness, data quality, simplicity, representativeness and timeliness. Sensitivity, specificity and positive predictive value were not assessed as no good alternative data was available for comparison.

Data Collection and Indicator Definitions

We extracted the DVSS data on all variables submitted from 2011 to 2013, including number of inspected houses, positive inspected houses, water-holding containers, positive water-holding containers, and larvae, pupae and adult *Aedes* mosquitoes (*Aedes aegypti* and *Aedes albopictus*). A positive house or water-holding container was defined as any house or water-holding container found to have *Aedes* larvae or pupae.

Vector surveillance indicators included the Breteau index (BI, number of positive containers per 100 houses inspected), house index (HI, percent of positive houses), container index (CI, percent of positive water-holding containers), pupal index (PI, number of pupae per 100 houses inspected) and adult index (AI, number of female adult mosquitoes per house inspected)[8,11]. In addition, percent of *Ae. aegypti* was defined as the cumulative number of *Ae. aegypti* larvae among *Ae. albopictus* and *Ae. aegypti* larvae during a designated time period. Finally, "*Ae. aegypti* predominant districts" were defined if percent of *Ae. aegypti* larvae at the district level is 50% or more. Vector surveillance data was displayed on maps using geographic information systems software Quantum GIS (version 1.7.4).

Evaluation of Attributes

Usefulness was evaluated by looking at the findings of spatio-temporal analysis of DVSS data which identified the distribution and density of areas at risk for dengue transmission. Ecological analysis was performed by linking DVSS data to control measures and the burden of dengue cases. This was performed for one district identified with dengue disease burden higher than other districts.

Data quality was evaluated by assessing data completeness and validity. Data completeness was defined as percent of records with complete data (no missing) which represented surveys conducted in neighborhoods (over 50 households). Validity was defined as percent of records with logically recorded data for each variable. We reviewed all variables and identified seven illogical data scenarios and combinations of values for these variables. Next, we calculated percent of these illogical (error) data entries. We defined 90% or above as a satisfactory level of completeness/validity and reported results as "satisfactory" or "unsatisfactory" if results were 90% and more, or less than 90% respectively[12].

Simplicity was evaluated through face-to-face or telephone interviews of key surveillance staff using a semi-structured questionnaire. The questionnaire asked about understanding on the objectives of DVSS, and whether the interviewee found the system useful, easy and quick to use. Interviewees were selected based on their availability and willingness to participate as well as their expertise in vector survey and/or technology experience.

Representativeness was evaluated by geographic and temporal findings, which was also associated with program completeness. We defined program completeness as percent of neighborhoods in each district which achieved the survey standard, which was that all neighborhoods were to be surveyed at least once every two months[13].

Timeliness was evaluated by measuring the duration between date of survey by field investigators and date of data entry into the web-based system, which should be within seven days, according to the dengue control guideline of Tainan City[13].

Ethical Considerations

Since this study did not involve human subject research, it was exempted from an Institutional Review Board review.

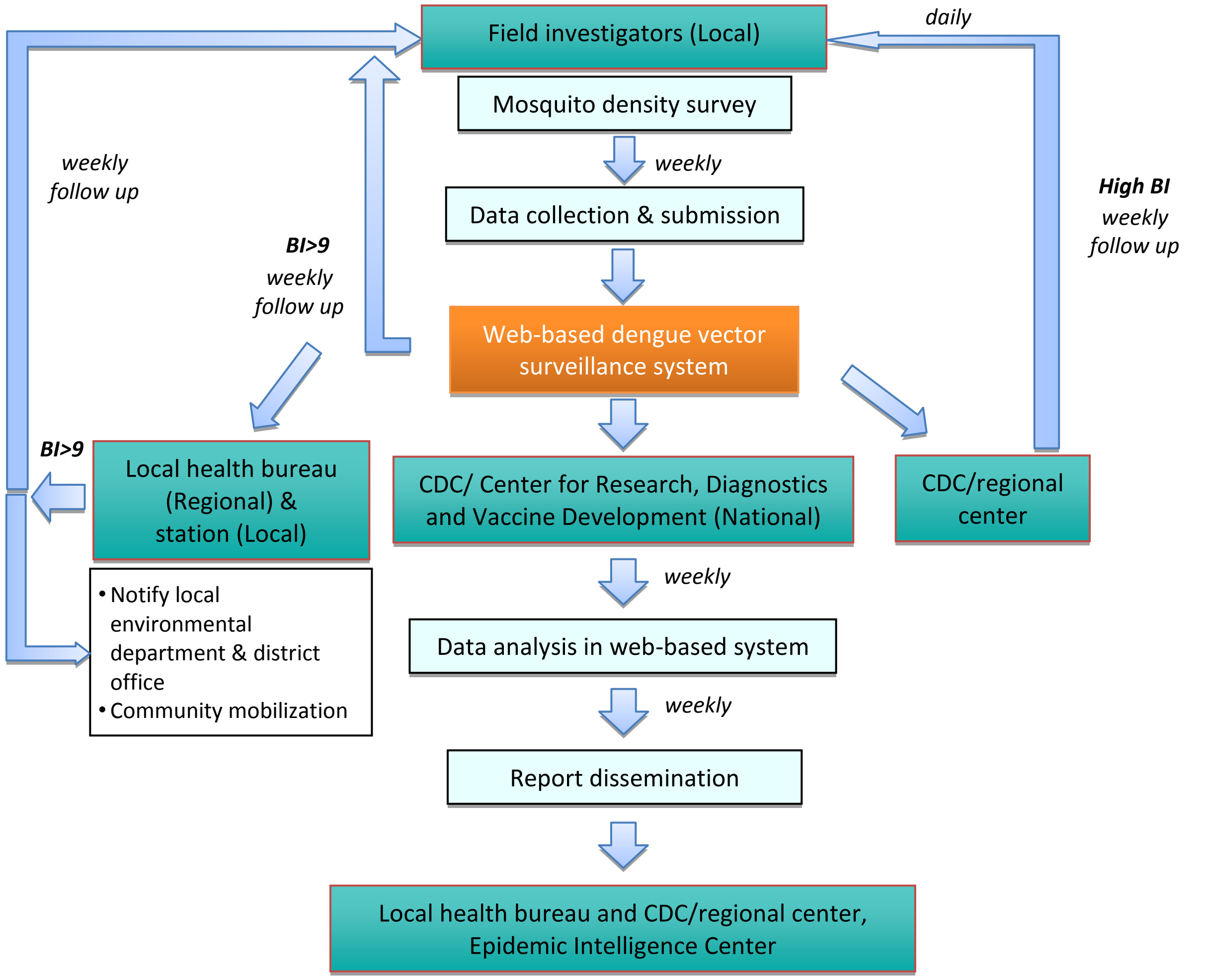
Results

Surveillance Operation

Figure 1 shows the operational flow of DVSS, including local, regional and national activities. Data generated for DVSS comes from the vector surveys program conducted by field investigators in neighborhoods, each of which should be surveyed at least once every two months. The survey should be conducted 50 or more houses and apartments in the neighborhood and inspected for containers with mosquito larvae or pupae. In addition, when a dengue case was reported or confirmed, field investigators should conduct vector inspection of 50-100 households around where dengue cases had occurred, in accordance with the dengue control guideline[7]. In each neighborhood, the data were entered into the web-based system within seven days of survey. If BI value was more than nine, community mobilization and messaging efforts were triggered to eliminate mosquito breeding sites. TCDC support all of these activities, performed data analysis and disseminated weekly reports to stakeholders (local heath bureaux, and regional centers and Epidemic Intelligence Center of TCDC) for policy or programmatic decision making.

Resources

Total number of staff operating the system was 76, including local, regional and national staff (Table 1).



** Survey frequency is adjusted during the outbreak.*

Figure 1. Flow chart of operation within dengue vector surveillance system in Tainan City, Taiwan, 2011-2013

Table 1. Resources of dengue vector surveillance system, Tainan City, Taiwan, 2011-2013

Personnel time cost	Government/ Organization	Unit	Hour per month	Hour per year
Staff (n=1)	TCDC	Epidemic Intelligence Center	8	104
Information technologist (n=1)	TCDC	Information Management Office	20	260
Analyzer (n=1)	TCDC	Center for Research, Diagnostics and Vaccine Development	24	312
Staff (n=2)	TCDC	Southern Regional Center	64	832
Staff (n=3)	Tainan City	Local health bureau	96	1,248
Staff (n=37)	Tainan City	Local health station	1,184	15,392
Field investigators (n=31)	Tainan City	Local health bureau	4,960	64,480
Total (n=76)			6,356	82,628
Cost	**Government/ Organization**		**Annual Cost (USD)**	**Cost (USD)**
System construction	TCDC			0.02 million
System new function expansion	TCDC		4-8,000	
System maintenance	TCDC		4,000	
Field investigators	Tainan City		0.19 million	
Total			0.2 million	

The only full-time staff were TCDC-funded field investigators. The annual maintenance costs covering the field investigators and hardware, including a back-up computer system, was approximately USD 0.2 million.

Usefulness

During 2011-2013, dengue vector surveillance data from 37 districts in Tainan were submitted into DVSS, and 36 of these had data on *Aedes* species. One district had no *Aedes* species data because this district was surveyed less and had neglected to classify *Aedes* species. Total 11 (31%) of the 36 districts were *Ae. aegypti* predominant (i.e. percent of *Ae. aegypti* larvae 50%), including five urban districts (Figure 2). In some districts, percent of *Ae. aegypti* larvae was 50% for all three years (Figure 3).

During 2011-2013, the West Central District in Tainan had yearly dengue outbreaks with district-level campaigns for breeding site elimination. Therefore, we used West Central District as an example to evaluate control measures. Increased BI, CI and HI showed seasonality and appeared to precede outbreaks of disease (Figure 4). In general, campaigns appeared to result in decreasing levels of BI, CI, HI and dengue cases. Although, in 2012, number of dengue cases and the three indices decreased initially after the campaign, it rebounded, triggering elevation of the command level and coordination efforts in week 40 of 2012. It was only after these enhanced measures, BI, CI, HI and case levels went down.

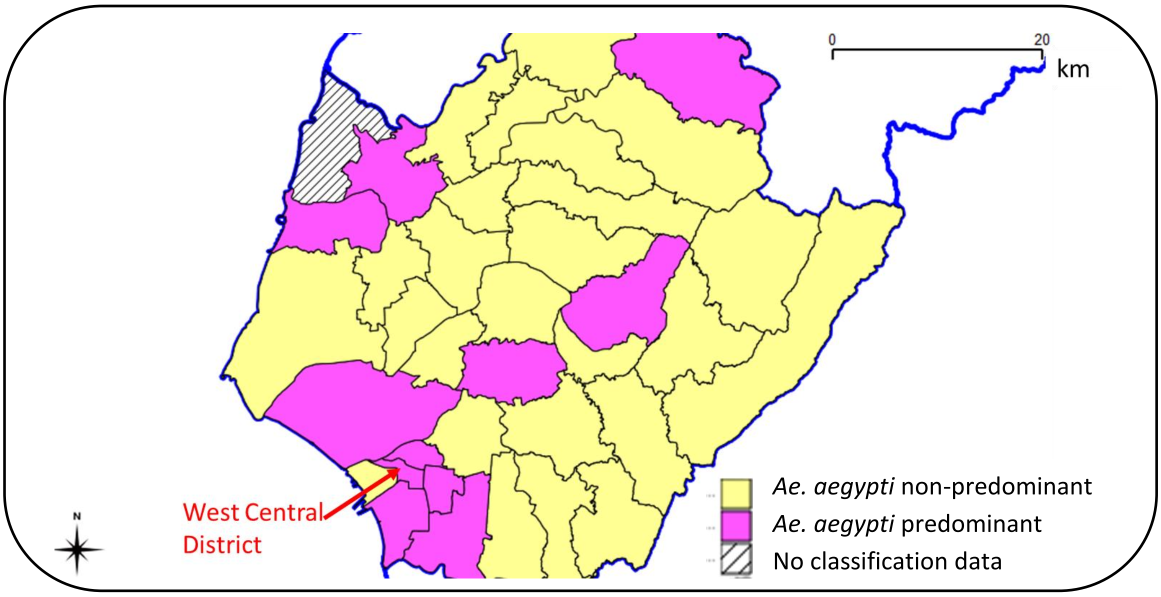


Figure 2. ***Ae. aegypti*** **predominant and non-predominant areas in Tainan City, Taiwan, 2011-2013**

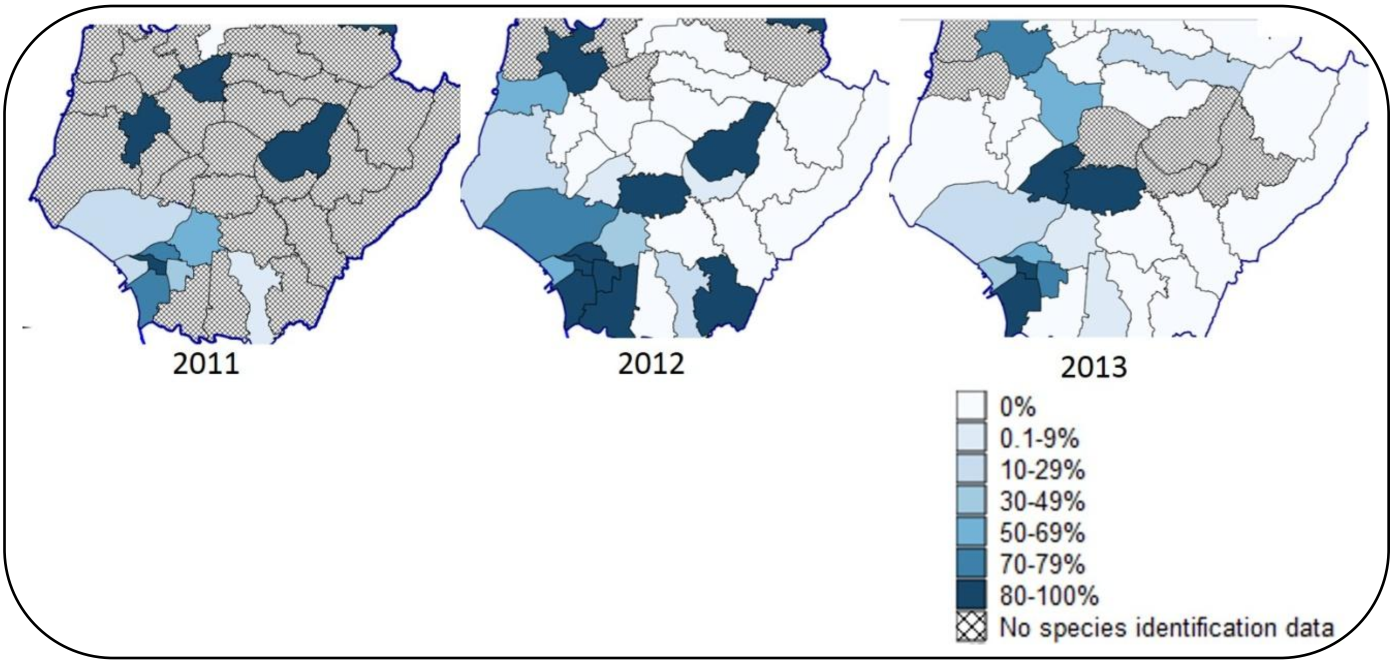


Figure 3. Yearly percentage of ***Ae. aegypti*** **in Tainan City, Taiwan, 2011-2013**

Data Quality

During the 3-year period, 25,877 neighborhood-vector surveys were recorded to DVSS in Tainan. Data quality was evaluated by data completeness and validity of measured indices (BI, CI, HI, PI and AI). Completeness of the indices in 2011-2013 varied from 11.81% to 99.95% (Table 2). The variable "PI" displayed an unsatisfactory level of completeness, with only 12% of records completed. For validity, variables of logical entry error ranged from 0.01% to 4.56% (Table 3).

Table 2. Completeness of indices survey in Tainan City, Taiwan, 2011-2013 (n= 25,877)

Indices	Completeness (%)			
	2011	2012	2013	2011-2013
Breteau index	99.89	100	100	99.95
House index	99.89	100	100	99.95
Container index	97.70	99.02	98.91	98.41
Pupal index	10.55	10.96	15.38	11.81
Adult index (*Ae. aegypti*)	99.89	100	100	99.95
Adult index (*Ae. albopictus*)	99.89	100	100	99.95

All respondents agreed that DVSS was clear, easy to use, useful, quick, and the skills required to use the system existed in their teams. Moreover, the indices were automatically calculated after data entry with debugging mechanisms like warning messages during data entry. *Ae. aegypti* and *Ae. albopictus* could be simply identified by microscopy. However, questions about the ease of identifying *Aedes* pupae were not included in the interviews.

Representativeness

During the 3-year period, 727 (97%) neighborhoods were surveyed at least once. Of which, 231 (32%) were in the urban and 496 (68%) in the rural. In accordance to the program requirement, i.e. all 752 neighborhoods in Tainan to be surveyed at least once every two months, we found that only 17% of the neighborhoods complied with this standard. Compliance in urban versus rural district surveys was 46% (107 among 231 neighborhoods in urban districts) versus 4% (21 among 521 neighborhoods in rural districts) respectively. In addition, 75% of the survey was conducted during May to December, the time period considered to be the outbreak season.

Timeliness

Median length of time from survey data collection to data entry was three days (range 0-790 days), with adherence to the 7-day standard at 84%. If we analyzed medians of timeliness by type of districts, it

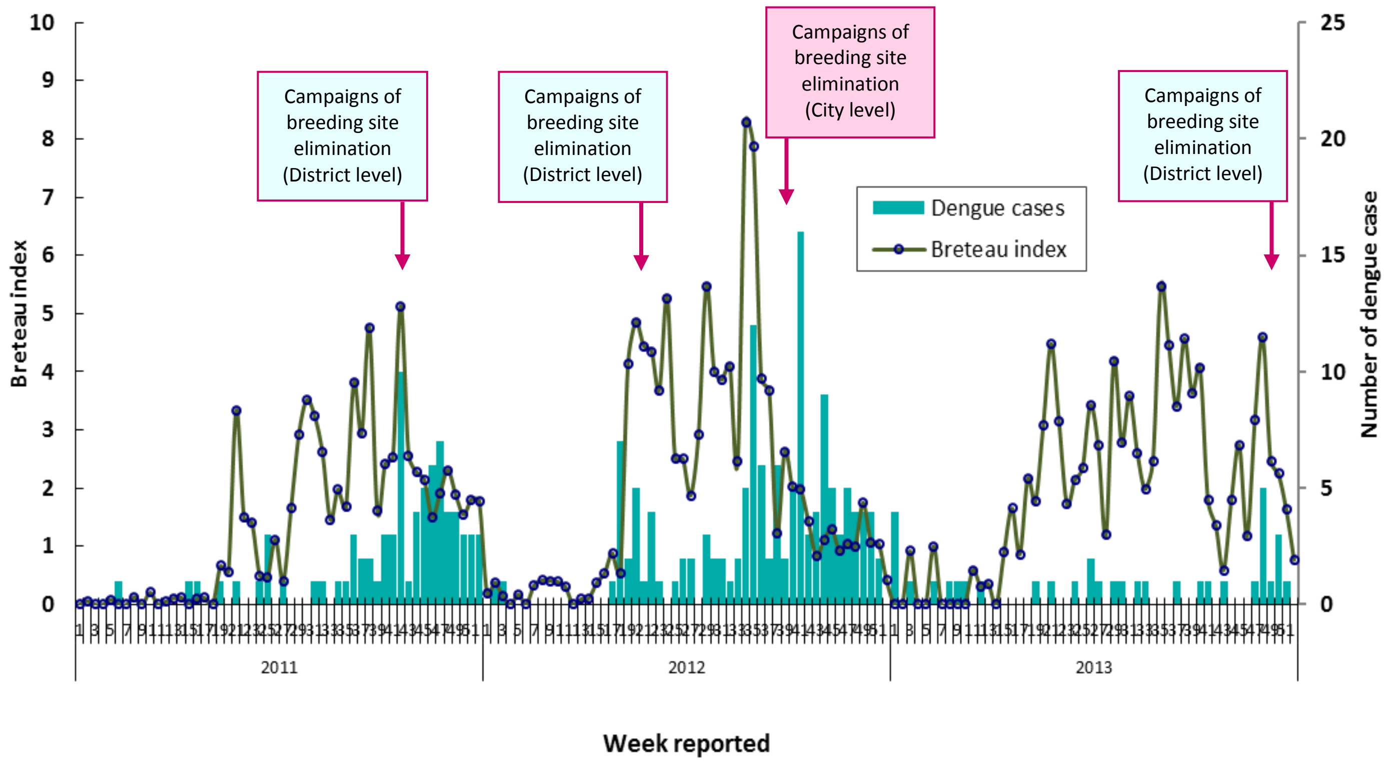


Figure 4. Number of dengue cases reported and Breteau index in West Central District of Tainan City, Taiwan, 2011-2013

Table 3. Entry errors of variables of Dengue Vector Surveillance System in Tainan City, Taiwan, 2011-2013 (n= 25,877)

Entry error type	Entry error percent (%)			
	2011	2012	2013	2011-2013
Number of household = 0	0.11	0	0	0.05
Number of (+) household > 0, but number of water-filled container = 0	0.06	0	0.02	0.03
Number of (+) household > 0, but number of (+) container = 0	0.15	0	0	0.07
Number of (+) household > number of household	0	0.01	0.02	0.01
Number of (+) container > 0, but number of (+) household = 0	0.58	0	0	0.26
Number of (+) container > 0, but number of larvae and pupa = 0	2.69	7.26	3.54	4.56
Number of (+) container > number of water-filled container	0	0	0.03	0.01

was shorter in urban districts (median 2 days, range 0-790 days, IQR 1-4 days) versus rural districts (median 4 days, range 0-517 days, IQR 1-10 days). However, the difference was not statistically significant (p-value>0.05). Although the standard interval between data analysis and use of the data (e.g. notification for control campaigns) was recommended to be weekly (seven days), we did not evaluate it in this study.

Discussion

Our evaluation of DVSS in Tainan City showed the system achieved its stated objectives. The simplicity of DVSS was found to be a key attribute leading to timely and accurate data entry. DVSS was also characterized by high level of data completeness and the validity of key variables was believed to represent features of a high quality dengue fever surveillance system in Taiwan.

Although entomological surveillance is used for operational purposes and evaluation of control measures, the relationship between vector indices and disease transmission in dengue virus is not well conclusive[14]. Our study findings supported the use of BI, CI, and HI as a measurement for disease control campaign impact. Although BI was considered to be the better index as it is more qualitative and has more epidemiological significance in previous studies[15-16], BI seems to perform similarly as CI and HI in our study. In 2012, the number of dengue cases and BI decreased initially after the campaign, however, it rebounded again. This might be due to the fact that new breeding sites were created or the campaign was not implemented thoroughly. However, as the three indices and the dengue incidence decrease after control campaigns, further studies were needed to confirm this.

The only variable with low data completeness was the PI. The reasons for the low PI completeness were speculative. Investigators might not record field results or entered results into the system. In addition, the investigators might think that it might not be necessary to record PI because it was not a routine index presented in the weekly report. Furthermore, it was time-consuming and laborious as samples must be transported back to the laboratory for microscopy to differentiate *Aedes* pupae from other mosquito species.

Since some studies showed that the survival rate of pupae was higher than larvae, PI could predict the risk of dengue outbreaks better than BI.[17-18] However, PI is not commonly used to monitor vector density because of limited time and manpower, especially when large containers are present as more time and manpower are needed to sort through the various larvae and pupae[19]. Furthermore, pupal surveys may be incomplete and therefore, results are not representative and limit their usefulness in predictability.[20-21] As PI seems to be less feasible and required more time and manpower to collect individual pupae from large containers and identify the co-existing *Aedes* species properly in the same container[22], we did not recommend to use for routine dengue vector surveys.

Although there was high data completeness of key variables, program completeness was low in rural districts, with most indigenous cases in urban districts (e.g. 93% in urban districts in Tainan). Even though the program required all neighborhoods be surveyed at least once every two months, it lacked an auditing mechanism. Therefore, the survey personnel often focused on urban districts, which were known to have high dengue disease burden, in response to public concerns of potential dengue outbreaks and ignored rural districts. Furthermore, during dengue outbreaks, most investigators and resources were focused on outbreak areas rather than low incidence areas. Therefore, the discrepancy in geographic program completeness might be influenced by diversion of staff during outbreaks.

This study had the following limitations. First, 50 and more inspected houses/apartments were non-randomly selected in each neighborhood to find containers positive for mosquito larvae or pupae and capture adult mosquitoes to calculate mosquito indices such as BI, HI, CI, PI and AI. As a result, inspected houses/apartments were subjected to selection bias. Furthermore, the numbers of adult mosquito found might be influenced by the skill of the investigators. In addition, interviews with stakeholders might have had reporting bias. Finally, identification of adult and larvae species might be misclassified by the investigators. Previous studies showed that education or training was successful in stimulating changes in both knowledge and behavior to identify *Aedes* larvae and reduce *Aedes aegypti* habitats.[23-24] Continuous education and on-the-job training could be instituted to reduce misclassification.

Public Health Recommendations

To effectively support a public health response, comprehensive dengue vector surveillance was necessary to establish a clear understanding of the density and distribution of dengue vectors in each region of Taiwan. The completeness of DVSS could be further improved in rural districts to elevate geographic representativeness. Furthermore, PI seemed less feasible and useful, and thus, we did not recommend its use in routine dengue vector surveys. Finally, the mechanism for continuous education and on-the-job training of survey personnel should be established and maintained.

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