Demystifying Essential Containers and Places for Aedes Mosquito Control in Thailand

Naiyana Sahavechaphan¹*, Asamaporn Chatrattikorn¹, Pongsakorn Sadakorn², Darin Areechokechai² and Sopon Iamsirithaworn²

¹Correspondence: naiyana.sahavechaphan@nectec.or.th
¹National Electronics and Computer Technology Center, National Science and Technology Development Agency, 112 Thailand Science Park, Phahonyothin Road, 12120 Pathum Thani, Thailand
Full list of author information is available at the end of the article

Abstract

Background: The strategy for prevention and control of Aedes-borne diseases relies on timely elimination of key breeding containers. There is thus a crucial need to identify key breeding containers to enhance vector control activities. The visual larval survey of wet containers has then been conducted as a routine mission of the Department of Disease Control (DDC). To facilitate this, DDC has deployed a mobile application, namely TanRabad SURVEY, since May 2016. As per an inspected place, TanRabad SURVEY supports the real-time collection of its larval survey data and processing of its larval indices and key breeding containers.

Methods: Larval survey data from 2017 to 2019 were spatially and temporally collected by public health officials via TanRabad SURVEY. Several measurements were computed to identify the overall and regional key breeding containers and places; and the regional transmission potentiality of Aedes-borne diseases. The measurements for identifying essential containers were breeding potentiality, productivity, contribution and preference ratio. As for places, the larval productivity of places based on larval indices was employed. Such place productivity was also implemented for discovering the regional transmission potentiality of Aedes-borne diseases.

Results: The overall essential breeding containers were water tank, unused containers, other used containers, old tyres, anti-ant bowls, drip tray of water dispensers, pet bowls and plant leaves. As for regional aspects, different regions had different essential breeding containers wherein their most common containers were unused containers, other used containers, old tyres and drip tray of water dispensers. All regions had similar experiences that villages and temples were the top two riskiest places, followed by schools, factories, hotels and hospitals. Additionally, all regions had high transmission potentiality of Aedes-borne disease as above 30% of all their places were moderate and high risk places.

Conclusions: This study identified the overall and regional key breeding containers and places along with the regional transmission potentiality of Aedes-borne diseases. Beside this, the empirical evidence had shown that the breeding productivity of most containers and places in each type was gradually decreased from time to time. This was mainly because TanRabad SURVEY supported real-time risk communication to community participants and effective prevention and control program development.

Keywords: Aedes Mosquito; Dengue; TanRabad; Visual Larval Survey

Background

Aedes mosquito is an important vector of arboviruses [1, 2] such as dengue [3], zika and chikungunya. It is breeding in a variety of water-holding containers [4, 5, 6]
that are typically sit on different places. The classic breeding containers for *Aedes* mosquitoes are artificially flooded sites which can produce a large number of larvae or pupae even when rainfall is low [7]. In recent decades, the incidence of *Aedes*-borne diseases (especially dengue) has grown dramatically around the world [3, 8, 9]. As for Thailand, over 50,000 people [10, 11, 12, 13] infected with *Aedes*-borne diseases are annually reported throughout the country. The strategy for prevention and control of *Aedes*-borne diseases relies on timely elimination of key breeding containers [14, 15, 16, 17, 18, 19]. There is thus a crucial need to identify key breeding containers to enhance vector control activities [7, 20].

To achieve targeted vector control, the visual larval survey of wet containers has been conducted as a routine mission of the Department of Disease Control (DDC) [11, 21]. DDC has adopted the larval survey guideline from WHO [15, 22, 23, 24] to suite Thai culture and tradition. Particularly, containers are grouped into 12 types (see Figure 1): *water tanks, water drinking jars, vases, anti-ant bowls, plant saucers, lotus basins, plant leaves, pet bowls, drip tray of water dispensers, old tyres, other used containers and unused containers*. Places the accommodate those containers are classified into 6 categories (see Figure 2): *villages*¹, *schools, temples, hospitals, hotels and factories*. The visual larval survey in all districts at risk must be performed. A district at risk is defined when a number of patients in the past 4 weeks is greater than an average number of patients in such 4 weeks of the previous 5 years. As per a district at risk, at least one place in each particular place type must be randomly examined. A random of 40% of houses should be examined as per a village while all buildings are for other places. In each examination, a number of indoor and outdoor wet containers with and without larvae must be reported. Upon a survey completion for a particular place, its larval indices [25] are calculated along with key breeding containers.

Figure 1: Container Habitats

To facilitate the visual larval survey, a mobile application, namely *TanRabad SURVEY* [4, 26, 27], is developed. Essentially, as per an inspected place, *TanRabad SURVEY* supports the *real-time* collection of its larval survey data and processing of

¹Villages here are a collection of only houses.
its larval indices and key breeding containers. TanRabad SURVEY has initially been deployed in May 2016. With its capabilities, DDC has taken it as one of surveillance tools in the national strategic plan 2018-2021 for the prevention and control of Aedes-borne diseases. The deployment result from 2016 to 2019 has shown that the larval survey data collection has been entirely transformed from a manual-based to a digital-based throughout Thailand.

Accordingly, this study relied on the larval survey data spatially and temporally collected by public health officials via TanRabad SURVEY. The aim of this study was to identify (i) the overall and regional key breeding containers and places that serve as primary sources and accommodation of Aedes mosquito breeding; and (ii) the regional transmission potentiality of Aedes-borne diseases. These identifications enable DDC to develop and implement an effective and sustainable prevention and control program. With this targeted vector control, there would be a minimized use of chemicals that may be costly and have long-term health and environment impacts [20].

Method
Study Area
Thailand is located at the centre of the Indochinese Peninsula and roughly between 5.61° N to 20.45° N in latitude and 97.37° E to 105.62° E in longitude [28]. Thailand is administratively divided into 77 provinces and 4 regions as shown in Figure 3, covers an area of 513,120 square kilometers, and has a population of over 70 million people. Thailand has three official seasons [29] - summer, rainy and winter. The summer season runs from mid-February through to mid-May, with April and May the hottest months of the year. The rainy season is from mid-May to mid-October. The winter season is between mid-October and mid-February. In this study, the analysis was performed with respect to both national and regional aspects.

Data Source
This study relied on the larval survey data spatially and temporally collected via TanRabad SURVEY and stored in TanRabad database. The larval survey data is reported by public health officials under DDC. Essentially, all inspected containers and places throughout Thailand from 2017 to 2019 was chosen for data analytics. The number of inspected containers and places from 2017 to 2019 are illustrated in Table 1 - 2, respectively.
| Year | Types of containers | North | Regions | Total |
|------|---------------------|-------|---------|-------|
|      |                     | Indoor| Outdoor| indoor| Outdoor| Total |
| 2017 | Water tank          | 17,069| 8,669  | 25,738| 10,209  | 35,947|
|      | Water drinking jar  | 4,474 | 2,241  | 6,715 | 3,483   | 10,208|
|      | Vase                | 4,806 | 4,271  | 9,077 | 5,035   | 14,112|
|      | Anti-ant bowl       | 1,634 | 6,956  | 8,590 | 3,002   | 11,592|
|      | Plant saucer        | 1,120 | 3,987  | 5,107 | 3,955   | 9,062|
|      | Lotus basin         | 1,633 | 9,238  | 10,871| 5,035   | 15,906|
|      | Plant leaf          | 420  | 4,765  | 5,185 | 3,315   | 8,500|
|      | Pet bowl            | 270  | 1,275  | 1,545 | 1,032   | 2,577|
|      | Drip tray of water dispenser | 513 | 130 | 643 | 424 | 1,067 |
|      | Old tyre            | 134  | 1,417  | 1,551 | 366 | 1,917 |
|      | Other used container | 4,147 | 4,668 | 9,659 | 4,136 | 14,066|
|      | Unused container    | 720  | 3,909  | 4,629 | 1,101 | 5,730|
| Total|                     | 34,988| 47,178 | 82,166| 14,141 | 96,307|
| 2018 | Water tank          | 67,066| 47,157 | 114,223| 50,517 | 164,740|
|      | Water drinking jar  | 3,098 | 3,812  | 6,910 | 3,326   | 10,236|
|      | Vase                | 10,998| 20,983 | 31,981| 4,030   | 36,011|
|      | Anti-ant bowl       | 3,940 | 9,322  | 13,262| 1,143 | 14,405|
|      | Plant saucer        | 3,979 | 7,953  | 11,932| 1,045 | 13,977|
|      | Lotus basin         | 3,879 | 24,074 | 27,953| 1,405 | 29,358|
|      | Plant leaf          | 321  | 8,266  | 8,587 | 104 | 8,791|
|      | Pet bowl            | 1,178 | 3,720  | 4,898 | 738 | 5,636|
|      | Drip tray of water dispenser | 2,068 | 299 | 2,367 | 1,778 | 4,145|
|      | Old tyre            | 1,049 | 5,790  | 6,839 | 1,516 | 8,355|
|      | Other used container | 3,381 | 8,247 | 11,628| 2,155 | 13,783|
|      | Unused container    | 1,197 | 12,045 | 13,242 | 6,518 | 19,765|
| Total|                     | 100,774| 144,131| 244,905| 73,515 | 318,420|
| 2019 | Water tank          | 119,910| 104,613| 224,523| 77,611 | 302,134|
|      | Water drinking jar  | 21,538| 15,129 | 36,667 | 10,522 | 47,189|
|      | Vase                | 29,726| 50,311 | 79,037| 9,795 | 88,832|
|      | Anti-ant bowl       | 8,508 | 2,081  | 10,589 | 6,337 | 16,926|
|      | Plant saucer        | 8,223 | 37,705 | 45,928| 1,039 | 47,067|
|      | Lotus basin         | 6,722 | 17,916 | 24,638| 1,822 | 26,460|
|      | Plant leaf          | 792  | 12,087 | 12,879 | 157 | 13,036|
|      | Pet bowl            | 4,217 | 13,393 | 17,610 | 4,800 | 22,410|
|      | Drip tray of water dispenser | 1,107 | 18,855 | 19,962 | 4,660 | 24,622|
|      | Old tyre            | 1,097 | 18,855 | 19,952 | 4,660 | 24,615|
|      | Other used container | 8,133 | 27,255 | 35,388 | 2,845 | 38,233|
|      | Unused container    | 3,965 | 26,233 | 30,198 | 11,914 | 42,117|
| Total|                     | 110,774| 144,131| 254,905| 73,515 | 328,420|

Table 1: The number of indoor and outdoor wet containers inspected from 2017 to 2019 (unit: pieces)
| Year | Types of places | Central | North | Northeast | South | Total |
|------|-----------------|---------|-------|-----------|-------|-------|
| 2017 | Villages        | 263     | 126   | 399       | 75    | 863   |
|      | Temples         | 105     | 67    | 238       | 35    | 445   |
|      | Schools         | 219     | 68    | 230       | 43    | 560   |
|      | Hospitals       | 118     | 95    | 131       | 68    | 412   |
|      | Factories       | 84      | 27    | 38        | 2     | 151   |
|      | Hotels          | 16      | 42    | 43        | 17    | 118   |
|      | Total           | 805     | 425   | 1079      | 240   | 2,549 |
| 2018 | Villages        | 792     | 727   | 1,546     | 75    | 3,266 |
|      | Temples         | 359     | 277   | 644       | 35    | 1,369 |
|      | Schools         | 565     | 226   | 647       | 43    | 1,585 |
|      | Hospitals       | 536     | 567   | 735       | 68    | 1,999 |
|      | Factories       | 163     | 65    | 70        | 2     | 307   |
|      | Hotels          | 123     | 85    | 73        | 17    | 309   |
|      | Total           | 2,538   | 1,947 | 3,715     | 635   | 8,835 |
| 2019 | Villages        | 2,250   | 1,083 | 2,162     | 286   | 5,781 |
|      | Temples         | 495     | 349   | 847       | 88    | 1,779 |
|      | Schools         | 737     | 393   | 919       | 140   | 2,189 |
|      | Hospitals       | 4,126   | 592   | 949       | 198   | 5,865 |
|      | Factories       | 282     | 125   | 155       | 42    | 604   |
|      | Hotels          | 115     | 97    | 117       | 50    | 379   |
|      | Total           | 8,005   | 2,639 | 5,149     | 804   | 16,597|

Table 2: The number of places inspected from 2017 to 2019 (unit: places)

**Larval Indices**

Larval indices [25, 30] are (i) House Index (HI) – a percentage of houses infested with larvae and/or pupae; (ii) Container Index (CI) – a percentage of water-holding containers infested with larvae or pupae; and (iii) Breteau Index (BI) – a number of positive containers per 100 houses inspected. According to DDC, HI, CI and BI are for the villages, while CI alone is applicable for other places. This is mainly due to the fact that each village basically covers many houses in a large spatial area and have various residences with different ages and careers. Conversely, the others are public and sharing places with less number of buildings in a small area and has specific residences. In TanRabad SURVEY, HI, CI and BI are formally defined as per Equations 1 - 3.

\[
HI = \frac{|B'|}{|B|} \times 100
\]  

\[
CI = \frac{\sum_{b \in B} \sum_{c \in C} (\alpha_{b,c} + \gamma_{b,c})}{\sum_{b \in B} \sum_{c \in C} (\alpha_{b,c} + \gamma_{b,c})} \times 100
\]  

\[
BI = \frac{\sum_{b \in B} \sum_{c \in C} (\alpha_{b,c} + \gamma_{b,c})}{|B|} \times 100
\]

where \( B \) is a set of buildings inspected as per a particular place, \( b \) a building in \( B \), \(|B|\) a number of buildings inspected, \(|B'|\) a number of buildings infested, \( C \)
a collection of container categories, \( c \) a container category in \( C \), \( \alpha_{b,c} \) and \( \gamma_{b,c} \) a total number of indoor and outdoor wet containers with category \( c \) inspected for a building \( b \), and \( \alpha'_{b,c} \) and \( \gamma'_{b,c} \) a total number of indoor and outdoor wet containers with category \( c \) infested for a building \( b \).

**Statistical Data Analysis**

A descriptive analysis was done to investigate types of breeding containers and places that were primary sources for *Aedes* mosquito breeding. For breeding containers, different measurements were calculated: (i) breeding potentiality (BT) – the percentage of each container category to total containers [7, 20]; (ii) breeding productivity (BP) – the percentage of each container category infested [20] to determine its larval productivity; (iii) breeding contribution (BC) – the percentage contribution of each container category to total infested containers [20]; and (iv) the breeding preference ratio (BPR) [7] of breeding contribution (BC) against breeding potentiality (BT). Formally, BT, BP, BC and BT are defined as per Equations 4 - 7.

\[
BT = \frac{\sum_{b \in B} (\alpha_{b,c} + \gamma_{b,c})}{\sum_{b \in B} (\alpha_b + \gamma_b)} \times 100
\]  

\[
BP = \frac{\sum_{b \in B} (\alpha'_{b,c} + \gamma'_{b,c})}{\sum_{b \in B} (\alpha_{b,c} + \gamma_{b,c})} \times 100
\]  

\[
BC = \frac{\sum_{b \in B} (\alpha'_{b,c} + \gamma'_{b,c})}{\sum_{b \in B} (\alpha_b + \gamma_b)} \times 100
\]  

\[
BPR = \frac{BC}{BT}
\]

where \( B \) is a set of buildings inspected as per a particular place, \( b \) a building in \( B \), \( c \) a particular container category, \( \alpha'_{b,c} \) and \( \gamma'_{b,c} \) a total number of indoor and outdoor wet containers with category \( c \) infested for a building \( b \), \( \alpha_{b,c} \) and \( \gamma_{b,c} \) a total number of indoor and outdoor wet containers with category \( c \) inspected for a building \( b \), \( \alpha'_b \) and \( \gamma'_b \) a total number of indoor and outdoor wet containers infested for a building \( b \), and \( \alpha_b \) and \( \gamma_b \) a total number of indoor and outdoor wet containers inspected for a building \( b \).

Similarly to breeding containers, places that accommodate those essential containers must be investigated to reflect the targeted vector control. DDC has classified
risk levels of places based on their larval indices as shown in Table 3 [11]. In particular, places are expected to have promising vector control and hence be (very) low risk places. Villages should thus have their HIs less than or equal to 10, while the CIs of other places should remain 0. To assess larval productivity of places, place productivity (PP), the percentage of each place category in moderate or high risk levels, is thus calculated and formally defined as per Equation 8.

\[
PP = \sum_{p \in P_t} \frac{LI(p)}{|P_t|} \times 100
\]  

(8)

\[
LI(p) = \begin{cases} 
1, & \text{if } HI(p) > 10 \text{ or } CI(p) \neq 0 \\
0, & \text{otherwise}
\end{cases}
\]  

(9)

where \( t \) is a particular place type, \( P_t \) a set of inspected places with type \( t \), \( p \) a place in \( P_t \) and \( LI(p) \) a function to evaluate the category of an appropriate larval index as per a place \( p \). It should be noted that \( HI \) is for villages while other places rely on \( CI \).

Results

Overall Key Breeding Containers and Places

All above measurements were computed to identify (i) the overall key breeding containers for both indoor and outdoor locations; and (ii) the overall key places that accommodated those essential containers. These investigations were designed to unveil those key containers and places from time to time.

Figure 4 illustrates the overall breeding potentiality (BT) of containers, the percentage of each container category to total containers. Results of the investigation demonstrated that potential containers for indoor location in each year of 2017 to 2019 were water tanks (64.0-66.2%). The rest containers varied from time to time. The next potential containers in 2017 were vases (8.59%), other used containers (7.56%) and plant saucers (5.26%), while water drinking jars (9.93-11.9%) and vases (6.9-8.61%) were for 2018 and 2019. Each of the rest containers had potentiality below 5%. For outdoor location, each year had water tanks (36.0-44.2%)
Figure 4: Overall Breeding Potentiality of Containers

with the highest BT. The rest containers varied from time to time. In 2017, lotus basins (14.9%), other used containers (10.5%), plant saucers (8.5%) and unused containers (7.2%) were the next potential containers. Lotus basins (14.9%), water drinking jars (11.8%) and unused containers (7.29%) were for 2018 while lotus basins (8.64%), other used containers (8.53%), vases (8.47%), water drinking jars (7.76%) and unused containers (7.7%) were for 2019.

Figure 5 illustrates the overall breeding productivity (BP) of containers, the percentage of each container category infested with Aedes larvae. Results of the investigation demonstrated that productive containers in each year of 2017 to 2019 were similar in sequence. They were unused containers (9.67-17.54%), followed by old tyres (9.74-17.42%), anti-ant bowls (6.06-15.11%), other used containers (7.56-
7.71%), drip trays for water dispensers (4.73-8.15%), water tanks (4.72-7.13%) and pet bowls (3.77-7.09%). Most of infested old tyres (9.14-16.83%), unused containers (8.54-15.67%), other used containers (5.62-6.24%) and pet bowls (1.03-2.16%) were found at outdoor location, while anti-ant bowls (5.03-12.95%), drip tray of water dispensers (4.11-6.62%) and water tanks (2.66-4.71%) were mostly at indoor location.

Figure 5: Overall Breeding Productivity of Containers

Figure 6 depicts the overall breeding contribution (BC) of containers, the percentage contribution of each container category to total infested containers. Results of the investigation demonstrated that contributed containers for indoor location in each year of 2017 to 2019 were water tanks (72.8-73.9%) while each of the rest containers had contributed below 5%. For outdoor location, each year had water tanks (32.6-39.1%) with the highest BC, followed by unused containers (15.9-20.2%), other used containers (10.4-14.6%) and old tyres (9.29-10.3%).

Figure 7 shows the overall breeding preference ratio (BPR) of containers classified by years (2017-2019) and 2 locations (indoor and outdoor). BPR for indoor containers slightly varied each year. The essential containers at indoor location were pet bowls (1.32-4.21), unused containers (1.57-2.25), anti-ant bowls (1.40-2.55), old tyres (1.41-1.85), other used containers (1.35-1.53), plant leaves (1.12-1.41) and water tanks (1.10-1.13). For outdoor location, the common essential containers for every year were unused containers (2.07-2.73), old tyres (2.12-2.61), anti-ant bowls (1.11-1.82), drip tray of water dispensers (1.35-1.53), other used containers (1.33-1.41) and plant saucers (1.31).

Figure 8 illustrates the overall place productivity (PP) classified by place types and years. Interestingly, PP was decreased from time to time for all place types except hotels. In particular, villages (53.36-66.63) had the highest PP, followed by temples (43.45-55.96%), schools (31.84-44.46%), factories (24.34-46.36%), hotels (26.12-33.01%) and hospitals (6.02-25.97%).
Regional Key Breeding Containers and Places
The breeding preference ratio (BPR) and place productivity (PP) were computed to identify regional key breeding containers and places. These were done based on the combination of all larval survey data from 2017 to 2019 altogether.

Figure 9 illustrates the breeding preference ratio (BPR) of containers classified by 4 regions (central, north, northeast and south) and 2 locations (indoor and outdoor). For the Central region, indoor unused containers (2.49) had the highest BPR, followed by old tyres (1.29) and water tanks (1.25). The Northern region had indoor old tyres (2.51) with the highest BPR, followed by unused containers (2.11), other used containers (1.84), anti-ant bowls (1.73), pet bowls (1.58) and drip tray of water dispensers (1.29). In the Northeastern region, indoor pet bowls
(5.66) had the highest BPR, followed by anti-ant bowls (1.79), old tyres (1.67), plant leaves (1.65), other used containers (1.51), drip tray of water dispensers (1.24) and unused containers (1.11). For the Southern region, indoor old tyres (8.43) had the highest BPR, followed by anti-ant bowls (2.90), unused containers (2.46), plant saucers (2.20), other used containers (1.71), drip tray of water dispensers (1.35) and water tanks (1.19). For outdoor locations, the common essential containers for all regions were unused containers (1.61-2.67), old tyres (1.93-2.67), other used containers (1.37-1.97) and drip tray of water dispensers (1.31-2.03). Besides this, anti-ant bowls (2.05), vases (1.87) and water tanks (1.55) were also significant for the Northeastern region. Figure 10 depicts the map of essential containers for both indoor and outdoor locations by regions.

Figure 11 illustrates the place productivity (PP) classified by place types and 4 regions (central, north, northeast and south). Villages (53.25-58.88%) had the highest PP for the Central, Northern and Northeastern regions, followed by temples (38.06-56.93%). Conversely, in the Southern region, temples (64.62%) had the highest PP, followed by villages (59.08%). The next places for all regions were schools (26.54-85.85%), factories (21.67-34.59%), hotels (20.60-35.71%) and finally hospitals (6.51-22.25%) with the lowest PP.
Regional Transmission Potentiality of Aedes-borne Diseases

The place productivity (PP) was computed to determine the regional transmission potentiality of *Aedes*-borne diseases. Particularly, the more PP the region had, the more transmission potentiality of *Aedes*-borne disease was likely. This was done
based on the combination of all larval survey data from 2017 to 2019 altogether regardless of place types.

Figure 12 illustrates the overall place productivity (PP) classified by regions. The Southern region (44.84%) had the highest PP, followed by the Northern region (42.37%), the Northeastern region (35.47%) and the Central region (30.42%). Similarly, the Southern region (47.15%) had the highest proportion of high risk places to moderate places, followed by the Northern region (44.51%), the Northeastern region (40.29%) and the Central region (37.51%).

**Discussion**

In Thailand, according to Thai culture\(^2\), water tanks were the most potential (frequently found) containers for both indoor and outdoor locations. Although water tanks were regularly used containers, they were found as the most contributed (frequently infested) containers. Most abundance containers were unused containers,\(^2\)

\(^{2}\)Water reservation is a typical for most houses.
other used containers, old tyres, anti-ant bowls, drip tray of water dispensers and pet bowls. These containers were considered as productive and contributed containers. Particularly, the productive and contributed unused containers, other used containers and old tyres were found at outdoor location. The productive and contributed anti-ant bowls and drip tray of water dispensers were sat on both indoor and outdoor locations while pet bowls were found at indoor location. Beside these artificial containers, plant leaves as natural containers were also recognized as productive and contributed containers (for indoor location). It was thus important to pay much attention to these artificial and natural containers at breeding location preferences. Essentially, the garbage disposal in the environment surrounding houses/buildings must be well managed. Old tyres must be transformed into useful items. As for places, villages and temples were the top two riskiest places that accommodated most of key breeding containers. Schools and factories were the next risk places, followed by hotels and hospitals. To achieve (very) low risk places, the prevention and control program must thus be regularly conducted for all places regardless of their types.

For regional aspects, different regions had dissimilar geographies, climates and livelihoods. They thus had different essential containers in term of the number and types of containers in concern. However, they had essential containers in common which were unused containers, other used containers, old tyres and drip tray of water dispensers. Particularly, unused containers and old tyres were found at both indoor and outdoor locations for all regions. The rest containers were at only outdoor location for the Central region, while other regions had them at both indoor and outdoor locations. Besides these common containers, water tanks were essential for the Central and South regions. Pet bowls and anti-ant bowls were significant for the Northeastern and Northern regions. Plant saucers were for the Northeastern and Southern regions. Essentially, the Northeastern region must be aware of 9 different containers types, followed by the Southern (7), Northern (6), and Central (5) regions. As for places, all regions had similar experiences in which villages and temples were the top two riskiest places, followed by schools, factories, hotels and hospitals. Moreover, all regions had suffered with moderate and high risk places above 30% of all places and hence high transmission potentiality of *Aedes*-born diseases. The Southern region was found with the most number of moderate and high risk places, followed by the Northern, Northeastern and Central regions. This was due to the fact that the Southern region had rainfall for 8 months while it took about 5 months for the other regions.

The empirical evidence had shown that the breeding productivity of most containers and places in each particular type was gradually decreased from time to time. This was mainly because TanRabad SURVEY made significant contributions: (i) all prevention and control actions toward those essential containers and places could promptly be directed to community participants via health education; and (ii) the strategic prevention and control program could effectively be developed and implemented which was driven by spatially and temporally collected larval survey data.
Conclusions
The descriptive analysis of larval survey data from 2017 to 2019 had shown that
(i) the regularly used containers (e.g. water tank), abundance containers (e.g. un-
used containers, other used containers, old tyres, anti-ant bowls, drip tray of water
dispensers and pet bowls) and natural containers (e.g. plant leaves) were essential
breeding containers; (ii) villages and temples were the top two riskiest places,
followed by schools, factories, hotels and hospitals; (iii) different regions had different
essential breeding containers due to dissimilar geographies, climates and livelihoods;
(iv) all regions had high transmission potentiality of Aedes-born diseases as above
30% of all their places were moderate and high risk places; and (v) the breeding
productivity of most containers and places in each particular type was gradually
decreased from time to time due to the benefits of TanRabad SURVEY. The key mes-
sages for controlling Aedes mosquito larvae would be the introduction of biological
agents, the garbage disposal in an environment and the transformation of old tyres
into useful items.

Abbreviations
BT, Breeding Potentiality; BP: Breeding Productivity; BC: Breeding Contribution; BPR: Breeding Preference Ratio;
DDC, Department of Disease Control; PP, Place Productivity; WHO, World Health Organization

Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
The datasets used and/or analysed during the current study available from the corresponding author on reasonable
request.

Author’s contributions
NS has written, read and approved the manuscript. AC has analyzed the visual larval survey. PS has written the
discussion section. All authors have read and approved the manuscript.

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Author details
1 National Electronics and Computer Technology Center, National Science and Technology Development Agency,
112 Thailand Science Park, Phahonyothin Road, 12120 Pathum Thani, Thailand. 2 Department of Disease Control,
88/21 Tawanon Road, 11000 Nonthaburi, Thailand.

References
1. Alonso-Palomaresa, L.A., Moreno-García, M., Lanz-Mendoza, H., Salazar, M.I.: Molecular basis for arbovirus
transmission by aedes aegypti mosquitoes. Intervirology 61(2), 255–264 (2018). doi:10.1159/000499128
2. Jones, R., Kulkarni, M.A., Davidson, T.M.V., Team, R.-L.R., Talbot, B.: Arbovirus vectors of epidemiological
concern in the americas: A scoping review of entomological studies on zika, dengue and chikungunya virus
vectors. PLOS One, 1–17 (2020). doi:10.1371/journal.pone.0220753
3. Gubler, D.J.: Dengue and dengue hemorrhagic fever. Clinical Microbiology Reviews 11(3), 480–496 (1998)
4. Sahavechaphan, N., Ponharn, J., Chatrattikorn, A., Sadakorn, P., Iamsirithaworn, S.: Improving data quality for
better control of Aedes-borne disease risk. IEEE Access (8), 189189–189202 (2020).
doi:10.1109/ACCESS.2020.3013945
5. Haddawy, P., Wettayakorn, P., Nonthaleerak, B., Yin, M.S., Wiratsudakul, A., Schöning, J., Laosiritaworn, Y., Balla, K., Euuungkanakul, S., Quengdaeng, P., Choknitipakin, K., Traivijitkhun, S., Erawan, B., Kraisang, T.: Large scale detailed mapping of dengue vector breeding sites using street view images. PLOS Neglected Tropical Diseases (2019)

6. Biogents USA: Controlling tiger and other container breeding mosquitoes. https://us.biogents.com/controlling-container-breeding-mosquitoes/

7. Mahmud, M.A.F., Mutalip, M.H., Lodz, N.A., Shahar, H.: Study on key aedes spp breeding containers in dengue outbreak localities in cheras district, kuala lumpur. International Journal of Mosquito Research 5(2), 23–30 (2018)

8. World Health Organization: Dengue and severe dengue. https://www.who.int/news-room/factsheets/detail/dengue-and-severe-dengue (2020)

9. SB., H.: The sixteenth century dengue pandemic: need for surveillance and research. World Health Stat Q 45(2-3), 292–298 (1992)

10. Department of Disease Control: Dengue Report 2020. http://phanhospital.go.th/phanhospital/images/Disease(2020)

11. Division of Vector-borne Diseases, Department of Disease Control, Thailand: Academic Manual for Dengue Fever and Dengue Hemorrhagic Fever, (2015)

12. Wongwilai, W., Chatrattikorn, A., Wongchingchai, N.: TanRabad REPORT: Web Application for the production of regularly-used reports. https://watch.tanrabad.org (2016)

13. Sahavechaphan, N., Rattananen, M.: TanRabad WATCH: Web Application for the Surveillance of Dengue Situation and Larval Indices. https://watch.tanrabad.org (2016)

14. World Health Organization: Global Strategy for Dengue Prevention and Control 2012-2020. WHO, Geneva, Switzerland (2012)

15. Focks, D.A.: A REVIEW OF ENTOMOLOGICAL SAMPLING METHODS AND INDICATORS FOR DENGUE VECTORS. WHO, Geneva, Switzerland (2003)

16. Lloyd, L.S.: Best Practices for Dengue Prevention and Control in the Americas, Environmental Health Project 2003, Strategic report 7. http://www.ehproject.org/PDF/Strategic_papers/SRT7-BestPractice.pdf (2003)

17. Maciel-de-Freitas, R., Lourenço-de-Oliveira, R.: Does targeting key-containers effectively reduce aedes aegypti population density? Tropical Medicine & International Health 16(8), 965–73 (2011). doi:10.1111/j.1365-3156.2011.02797.x.

18. Tsuzuki, A., Duoc, V.T., Higa, Y., Yen, N.T., Takagi, M.: Effect of peridomestic environments on repeated infestation by preadult aedes aegypti in urban premises in nha trang city, vietnam. The American Journal of Tropical Medicine and Hygiene 81(4), 645–650 (2009). doi:10.4269/ajtmh.2009.08-0175

19. Medronho, R.A., Macrini, L., Novellino, D.M., Lagrota, M.T.F., Câmara, V.M., Pedreira, C.E.: Aedes aegypti immature forms distribution according to type of breeding site. The American Journal of Tropical Medicine and Hygiene 80(3), 401–404 (2009). doi:10.4269/ajtmh.2009.08-0175

20. Focks, D.A.: A Review of Entomological Sampling Methods and Indicators for Dengue Vectors. WHO, Geneva, Switzerland (2003)

21. Focks, D.A., Alexander, N.: Multicountry Study of Aedes Aegypti Pupal Productivity Survey Methodology: Findings and Recommendations. WHO, Geneva, Switzerland (2006)

22. Focks, D.A., Alexander, N.: Aedes Aegypti Pupal Productivity Survey Methodology: Findings and Recommendations. WHO, Geneva, Switzerland (2006)

23. World Health Organization: Dengue Guidelines for Diagnosis, Treatment, Prevention and Control, New edn. WHO, Geneva, Switzerland (2009)

24. Focks, D.A., Alexander, N.: Multicountry Study of Aedes Aegypti Pupal Productivity Survey Methodology: Findings and Recommendations. WHO, Geneva, Switzerland (2006)

25. World Health Organization: Vector Surveillance. https://www.who.int/denguecontrol/monitoring/vector_surveillance/en/ (2020)

26. Sahavechaphan, N., Rattananen, M., Wongwilai, W., Chatrattikorn, A., Wongchingchai, N., Noothong, W., Panickphol, P., Sadakorn, P., Iamsirithaworn, S.: TanRabad: Software Suite for Dengue Surveillance and Control. https://www.tanrabad.org (2016)

27. Sahavechaphan, N., Rattananen, M., Panickphol, P., Wongwilai, W., Iamsirithaworn, S., Sadakorn, P.: Tanrabad: Software suite for dengue epidemic surveillance and control. International Journal of Infectious Diseases 53, 118 (2016)

28. Department of Mineral Resources: Geology of Thailand. https://www.dmr.go.th/main.php?filename=GeoThaiEn (2016)

29. Meteorological Department: Thailand Climate. https://www.tmd.go.th/en/archive/thailand_climate.pdf (2015)

30. World Health Organization: Guideline for Dengue Surveillance and Mosquito Control, 2nd edn. WHO, Manila (2003)

Figure Legends
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