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Low Entomological Impact of New Water Supply Infrastructure in Southern Vietnam, with Reference to Dengue Vectors

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Abstract. We did a prospective study in southern Vietnam where new water infrastructure was added. New 1,200-L tanks may present potential breeding grounds for *Aedes aegypti*, particularly when sealed lids were not always supplied. Some householders in these communes received a piped water supply, however there was no reduction in water storage practices. The prevalence of *Aedes aegypti* immatures in tank and tap households reached 73%, but were non-significantly different from each other and from control households that received no infrastructure. In all three communes, standard jars comprised from 48% to 71% of containers but were associated with > 90% of III–IV instars and pupae on occasions. In contrast, project tanks contributed from 0–21% of the total population. Non-functional or no lids were apparent 4 months after installation in 45–76% of new tanks, but there was no difference between communes with lids and without lids.

INTRODUCTION

The provision of adequate water for personal, agricultural, and industrial use is a cornerstone for poverty alleviation as part of the Millennium Development Goals, but this may be constrained by public health issues.[1] Since 2000, the Government of Vietnam has committed to providing rural communities with increased access to safe water through a variety of household water supply schemes including wells, water tanks and jars, and piped water[2]. Through investments from the Government of Vietnam and various international donors, the current water supply initiatives aim to provide 85% of rural households with access to at least 60-L of water per person per day. The effect of this new infrastructure (tanks, jars, and piped water) on householder water-storage behavior, particularly those that could be associated with a concomitant increase in dengue mosquito abundance, is unknown. Dengue viruses are a leading cause of mortality and morbidity in Vietnam[3,4] with the southern provinces having the majority of cases nationally.

In 2005, the Australian Agency for International Development, funded a large water supply scheme called the Cuu Long Delta Rural Water Supply and Sanitation Scheme in five southern provinces of southern Vietnam—Bac Lieu, Kien Giang, Vinh Long, Ben Tre, and Long An. The contractors went to great lengths to ascertain what type of water infrastructure was preferred by each community with a choice between large ferro-cement tanks, some without lids, and piped water. For our study, we selected three communes in Vinh Long, Ben Tre, and Long An to evaluate policy decisions to supply 1) piped water, and 2) sealed concrete lids on 1,200-L tanks in Communes 1 and 3, and to leave residents in Commune 2 to supply their own lids. Over four separate occasions during 2007 and 2008, we compared *Aedes aegypti* productivity in new project tanks compared with pre-existing infrastructure; and whether the provision of tap water would result in a decrease in pre-existing water storage containers. The third issue related to whether the provision of sealed lids on water tanks reduced mosquito colonization and was a worthwhile expenditure item.

With piped water, it is presupposed that the establishment of adequate systems can be used to reduce the level of *Ae. aegypti* breeding, because of the expectation that householders would store less water around the home.[5] However, some studies have highlighted that a piped water supply can actually result in an increased prevalence and abundance of *Ae. aegypti* because individual households may increase the amount of water they store. This observation seems to be particularly applicable to lower socio-economic areas when the piped water supply is inadequate or deficient.[5–8] In Vietnam, these water storage containers usually account for > 90% of all infested containers and > 95% of the immature productivity.[9–11]

It is also believed that the presence of lids or covers on water storage tanks or jars may prevent mosquito ingress and therefore breeding. This is often promoted as a control option by health departments. What is generally not appreciated is that adult mosquitoes, particularly *Ae. aegypti* (Linn.), are capable of entry through small gaps, caused by design or deterioration. For example, subterranean colonization by mosquitoes through the key holes of service manholes in north Queensland ensured that these habitats were most productive.[12] Lid quality and design are paramount,[13–16] to prevent colonization.

METHODS

Study area and population. Vinh Long, Ben Tre, and Long An are among the 12 provinces that make up the Mekong Delta region of Vietnam, one of the country's eight economic regions. As with all of the Delta provinces, they are built around a complex series of waterways along which a high proportion of the human population lives. Access and transportation within communes is often by means of the network of irrigation and navigation canals.

The study was undertaken in three communes in each of Ben Tre, Long An, and Vinh Long provinces. Thanh Phu Dong Commune (10° 00′N, 106° 20′E) is located in Giong Trom District, Ben Tre Province, and at the time of the 2005 census, had a population of 11,192 people (2,735 households). In 2007, the commune received water supply infrastructure (Figure 1) in the form of 1,200-L cylindrical tanks (1–2 tanks

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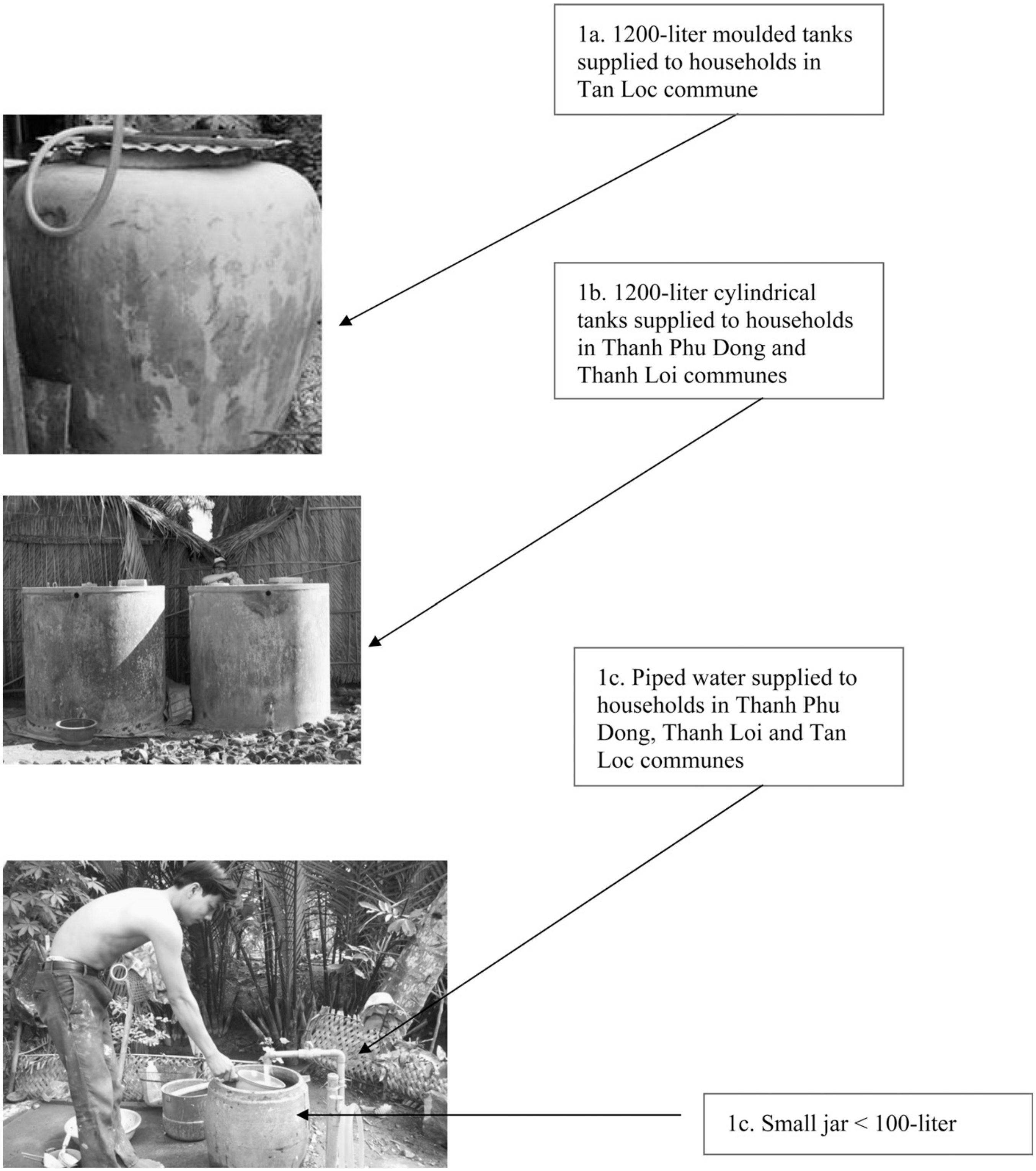

FIGURE 1. Cylindrical tanks, molded tanks, and taps provided by the project: Tanks: 520–720/commune. Piped water schemes: 292–3,000 houses/commune.

at 895 households) and a piped water supply system to deliver water to 400 households. Thanh Loi Commune (10° 31′N, 106° 37′E) is located in Ben Luc District in Long An Province, and had a population of 6,458 people (1,481 households). In 2007 the commune received 1,200-L cylindrical tanks (1–2 tanks at 450 households) and a piped water supply system to deliver water to 600 households. Tan Loc Commune (10° 18′N, 106° 42′E) is located in Tam Binh District, Vinh Long Province, and had a population of 6,164 people in 2005 (1,317 households). In 2007 the commune received water supply infrastructure in the form of 1,200-L molded tanks (1 tank at 358 households) and a piped water supply system to deliver water to 400 households.

The majority of people in Thanh Phu Dong, Thanh Loi, and Tan Loc communes were involved in farming (77%, 70%, and 61%, respectively). The climate in the three study sites is characterized by monsoonal rains between May and November (the mean monthly rainfall during the wet season was 242 mm) and a dry season from December to April (the mean monthly rainfall during the dry season was 51 mm) (Statistical Handbook of Vietnam 2007).

For convenience, the following convention has been used: Thanh Phu Dong is referred to as Commune 1; Thanh Loi is referred to as Commune 2; and Tan Loc is referred to as Commune 3. Houses that received either a piped water system or tanks are referred to as tap and tank houses, respectively.

Qualitative study. Nine separate focus group discussions (FGD) were conducted across the three communes, each with 10 participants. Ninety adult women were chosen for FGD participation because of their key role (within the family unit) conducting and influencing activities around household water sources, storage, and use.[17] Potential participants were selected randomly from a global list of households that had received infrastructure in each commune. They were approached, at home, by a local health worker who invited them to take part. In each commune, three groups were selected based on whether they 1) received tanks for rainwater harvesting as part of the water supply project; 2) received a household tap as part of a piped scheme; or 3) received neither tanks nor a tap from the project (untreated control group).

The FGD were held in Commune 1 in October 2007 and July 2008 (8 and 6 months after installation of tanks and taps, respectively), in Commune 2 in December 2007 and June 2008 (8 and 6 months after installation of tanks and taps, respectively), and in Commune 3 in December 2007 and June 2008 (11 and 6 months after installation of tanks and taps, respectively). Each FGD lasted between 45 and 75 minutes and was digitally recorded with the consent of all participants. Recordings were later transcribed from local Vietnamese dialect and translated into English.

Householder perspectives and preferences on water storage and use and a fuller explanation of the qualitative process and its analysis is given in an earlier work.[18] Relevant to this present study are questions about water supply reliability, water storage practice, lid use, water quality, and community understanding of the importance of dengue and its etiology.

Survey methods. Four groups assisted with surveys, each consisting of five people (one from the Entomology Department of the National Institute for Hygiene and Epidemiology [NIHE], one from the Department of Public Health of Pasteur Institute in Ho Chi Minh City [PIHCM], one from the Provincial Center for Preventive Medicine, one from the District Center for Preventive Medicine, and one from the commune health clinic or the commune people's committee [acting as a community guide]), undertook the study in each survey round. Householders were invited to participate in the study and verbal consent was sought from the head of the selected household, or an adult person from the house, if the recognized household head was unavailable. The study was approved by Queensland Institute of Medical Research (QIMR) Human Ethics Research Committee (P1055) and the Pasteur Institute, Ho Chi Minh City.

At each house, all water holding containers were inspected and the type of container, location (inside or outside the house), capacity, lid status (whether the container had a lid or not), estimated volume of water available in the container, were recorded. Only containers that were covered with lids without spaces for mosquito ingress were classified as being covered, whereas containers that were ill-fitting, with damaged lids or no lids were classified as being uncovered. Damaged could also refer to a lid that was misshapen and had irregularities, forming an imperfect seal.

Four full entomological surveys were done in August 2007 and 2008 (wet season) and in December 2007 and 2008 (dry season) to include abundance estimates. Three extra surveys during April 2007, 2008, and 2009 enumerated standard jars and lid status in water holding containers. There were five types of water storage containers in the study areas 1) project tanks (either cylindrical 1200-L tanks in Commune 1 and Commune 2 or molded 1,200-L tanks in Commune 3); 2) other tanks including cylindrical tanks > 1,000 L or molded jars > 1,000 L that householders had constructed themselves; 3) box tanks ≥ 500 L or smaller; 4) standard jars ≥ 100 L including concrete jars and ceramic jars ≥ 100 L and drums, and 5) small jars < 100 L. Additional containers including ant traps, aquaria, discards, and flower vases were classified as "Others." A 200 mm diameter circular net, 334 mm deep of 100 μm gauze was used for sampling as it collected both culicids and copepods, as well as fish. The 5-sweep netting technique[11] was used to sample large containers and *Ae. aegypti* III/IV instars and pupae were counted and identified, and then multiplied by predetermined calibration factors[11] to obtain absolute population estimates. With small containers such as ant traps or buckets, all mosquito immatures were removed using nets or pipettes and counted directly.

RESULTS

Knowledge, attitude, and practice about mosquito habitat and dengue. The participants explained how experiences had led them to link disease and ill-health with water use. In addition to dengue, the participants also identified gynecological diseases, diarrhea, and dermatological conditions as being water related diseases. There was a clear understanding among many of the participants that dengue fever was a water-related disease. Moreover, these women often identified their own water storage containers (among other sites) as potential breeding grounds for mosquito larvae as follows:

"Once mosquitoes get access to water in the containers, they can produce larvae and then mosquitoes bite people and then cause dengue fever" (Dong, Tap-FGD 5).

Participants from FGD regarded lids as a means for preventing dry leaves, dust, and mosquitoes from entering containers. It was found from the FGD that householders, as a common local practice, had removed lids from the project tanks in Communes 1 and 3 to gain entry to clean them. When the lids were put back on, they no longer fully sealed the tanks. Some householders forgot to replace the lids.

In Commune 2 where tanks were supplied without lids, there was a variety of covers ranging from corrugated iron or wooden planking over the aperture, to cloth or vegetation. Some had no covers.

Impact of new infrastructure on water storage behavior. Herein, we summarize relevant qualitative data from our previous study.[18] Householders that received new water supply/infrastructure (whether project tanks or project taps) did not discontinue their use of existing containers for water storage.

TABLE 1
Mean number of wet standard jars per house in control, tank, and tap households*

		Control HHs			Tank HHs			Tap HHs			
Commune	Date	n	Mean	SD	n	Mean	SD	n	Mean	SD	*P* value
Commune 1	Apr-07	20	7.3	4.5	68	5.1	3.1	na	na	na	0.02
	Aug-07	20	8.1	3.3	68	5.6	3.2	na	na	na	0.003
	Dec-07	19	8.3	5.4	68	5.3	3.4	48	3.9	3.0	< 0.001
	Apr-08	15	7.2	6.1	59	4.5	3.0	44	3.2	2.9	0.001
	Aug-08	19	7.4	5.0	67	5.6	3.7	46	4.0	3.4	0.004
	Dec-08	18	8.7	4.3	67	5.0	3.9	40	3.8	3.4	< 0.001
	Apr-09	17	7.6	5.5	65	5.0	3.9	47	3.0	2.5	< 0.001
Commune 2	Apr-07	49	5.1	3.3	47	5.4	2.9	na	na	na	0.6
	Aug-07	50	5.1	3.2	47	5.5	3.4	na	na	na	0.5
	Dec-07	47	4.3	3.0	50	4.5	2.7	na	na	na	0.7
	Apr-08	49	4.0	2.8	49	4.6	3.1	45	3.7	3.2	0.3
	Aug-08	45	5.4	4.3	50	5.0	3.2	44	4.3	3.6	0.4
	Dec-08	43	5.5	4.8	45	5.8	3.4	45	4.6	3.9	0.3
	Apr-09	45	5.1	3.6	44	4.4	2.8	43	3.2	2.9	0.02
Commune 3	Apr-07	48	3.9	2.8	46	3.8	3.0	na	na	na	0.8
	Aug-07	48	5.1	4.0	45	4.7	2.7	47	4.7	2.8	0.8
	Dec-07	49	4.7	3.7	47	4.1	2.8	46	4.1	2.6	0.6
	Apr-08	47	4.8	3.2	44	3.7	2.6	46	4.1	2.6	0.2
	Aug-08	43	4.6	3.0	43	3.8	2.5	45	4.1	2.7	0.4
	Dec-08	47	4.4	3.4	46	4.6	2.8	42	4.4	2.9	0.9
	Apr-09	40	3.5	2.6	43	3.5	2.5	48	3.9	2.3	0.7

*HHs = households; n = number of households surveyed; Mean = mean number of wet standard jars per house; na = not applicable;

In the case of those that received project tanks, they explained that rain water was precious and maximizing storage was important, especially in the dry season:

"*I keep my old existing containers because the project tanks, alone, are not sufficient [to store water for purposes in dry season]*" (Tuong, Tank- FG8).

The majority of those FGD participants that received project taps also continued to use their existing containers to store rain water, and in these cases, as with project tank recipients, a central motivation was a fear of limited water supply:

"When it's raining heavily, I store rain water in case the tap water supply is cut. Every time there is power cut, tap water is cut as well" (Truc, Tap-FG6).

For those women supplied with tap water, rain water was seen as superior on the basis of cost:

"I use more rain water in the rainy season because it's free of charge" (Xua, Tap-FG5).

"Regarding the price of tap water, I would prefer to pay a lower fee per cubic metre because we are farmers with low family income" (Tram, Tap-FG4).

Other participants described their negative perceptions of tap water, primarily related to its odor, taste, and color (compared with rainwater), and how this influenced their behavior:

"Tap water smells of disinfectant chemicals, so we don't drink it" (Thuy, Tap-FG5).*"It smells of chemicals. In terms of colour, I recognize that tap water is turbid 2–3 days per week, but it is not as turbid as river water"* (Hanh, Tap-FG5).

For those receiving project tanks, FGD data also revealed that taste, odor and color of water were important. These participants explained that tank water (often in newly provided tanks) smelled and often tasted of cement and as a result, they continued to use their existing containers for storing water for drinking:

"*Water stored in new tanks smells like cement so I dare not drink it. We use that water for washing and only drink water stored in old ceramic jars. When I first received the tanks, I did not use water stored inside to cook. Now, we can cook with that water"* (Xiem, Tank-FG2).

Impact of tap water and water storage in standard jars. Because the construction of water supply infrastructure was

TABLE 2
Storage of tap water in standard jars and other tanks by season in tap households in the three study communes*

		Wet season (Aug 07)				Dry season (Dec 07)				Wet season (Aug 08)				Dry season (Dec 08)			
Commune	Container type	*N*	%[a]	n[b]	%[c]	*N*	%†	n‡	%§	*N*	%†	n‡	%§	*N*	%†	n‡	%§
Commune 1	Standard jar	na	na	na	na	26	54	97	51	22	48	73	40	24	60	71	47
	Other tank	na	na	na	na	15	13	42	24	11	25	31	17	2	5	3	2
Commune 2	Standard jar	na	na	na	na	na	na	na	na	25	57	66	36	26	58	75	39
	Other tank	na	na	na	na	na	na	na	na	3	7	6	13	7	17	10	22
Commune 3	Standard jar	23	49	73	33	12	26	28	15	19	42	56	31	20	48	60	33
	Other tank	4	7	4	25	6	13	7	47	7	16	9	47	5	12	6	30

**N* = number of tap households using a particular container to store tap; na = not applicable because tap water was not available.
†Proportion of tap households using a particular container to store tap water.
‡Number of a particular container used to store tap water.
§Proportion of a particular container used to store tap water.

TABLE 3

Mean number of *Aedes aegypti* immatures per positive household by season and recipient group

		Aug 07 (Wet season)										Dec 07 (Dry season)									
		Control			Tank			Tap				Control			Tank			Tap			
Commune	Immature	n	$\overline{X}$	(95% CI)	n	$\overline{X}$	(95% CI)	n	$\overline{X}$	(95% CI)	*P*-level	n	$\overline{X}$	(95% CI)	n	$\overline{X}$	(95% CI)	n	$\overline{X}$	(95% CI)	*P*-level
Commune 1	III/IV instars	16	66	(37–119)	47	45	(29–71)	NA	NA		0.4	11	39	(15–101)	37	28	(18–45)	30	43	(22–81)	0.5
	Pupae	11	9	(5–17)	30	9	(7–12)	NA	NA		1.0	3	6	(1–26)	12	4	(3–7)	14	22	(10–49)	0.004
Commune 2	III/IV instars	19	24	(14–44)	20	40	(21–78)	NA	NA		0.2	7	15	(4–54)	18	17	(10–30)	NA	NA		0.8
	Pupae	8	9	(6–16)	9	8	(4–20)	NA	NA		0.8	5	3		15	4	(3–5)	NA	NA		0.2
Commune 3	III/IV instars	27	84	(48–147)	32	67	(39–115)	33	67	(39–114)	0.8	22	20	(13–32)	24	30	(18–49)	27	28	(15–50)	0.6
	Pupae	13	26	(13–53)	19	13	(7–23)	13	11	(6–21)	0.1	16	4	(3–6)	11	9	(4–18)	8	16	(7–37)	0.004

		Aug 08 (Wet season)										Dec 08 (Dry season)									
		Control			Tank			Tap				Control			Tank			Tap			
Commune	Immature	n	$\overline{X}$	(95% CI)	n	$\overline{X}$	(95% CI)	n	$\overline{X}$	(95% CI)	*P*-level	n	$\overline{X}$	(95% CI)	n	$\overline{X}$	(95% CI)	n	$\overline{X}$	(95% CI)	*P*-level
Commune 1	III/IV instars	16	56	(25–125)	45	44	(28–67)	29	74	(44–127)	0.3	9	29	(9–94)	25	22	(14–37)	20	43	(19–98)	0.4
	Pupae	10	22	(8–61)	19	12	(7–20)	16	11	(5–22)	0.3	3	16	(0–754)	7	5	(3–8)	10	6	(3–11)	0.2
Commune 2	III/IV instars	25	22	(12–39)	24	24	(13–44)	24	19	(10–34)	0.8	11	28	(10–78)	16	18	(8–41)	7	9	(4–21)	0.3
	Pupae	8	9	(4–21)	9	13	(5–31)	3	6	(1–22)	0.5	3	8	(0–376)				1	6	–	0.9
Commune 3	III/IV instars	23	104	(49–219)	25	79	(31–201)	33	35	(21–58)	0.07	16	29	(15–55)	14	23	(11–49)	13	46	(23–93)	0.3
	Pupae	12	26	(10–64)	13	16	(10–64)	16	10	(6–17)	0.2	4	6	(2–22)	4	4	(1–17)	5	6	(3–12)	0.7

*n = number of households that were positive for *Ae. aegypti* immature; NA = not applicable.
$\overline{X}$ (Mean), 95% confidence interval (95% CI) were calculated on the natural-log scale and were back-transformed for presentation.

Table 4
Lid status of wet project tanks in the three study communes

Commune	Data	Total no. of project tanks	No lid* n	No lid* %	Months after installation
Commune 1	Apr-07	92	50	54	4
	Aug-07	126	43	34	8
	Dec-07	120	14	12	12
	Apr-08	101	23	23	16
	Aug-08	94	51	54	20
	Dec-08	124	50	40	24
	Apr-09	114	30	26	28
Commune 2	Apr-07	82	62	76	4
	Aug-07	75	37	49	8
	Dec-07	90	35	39	12
	Apr-08	91	48	53	16
	Aug-08	82	37	45	20
	Dec-08	79	46	58	24
	Apr-09	75	17	23	28
Commune 3	Apr-07	33	15	45	4
	Aug-07	38	25	66	8
	Dec-07	42	27	64	12
	Apr-08	34	22	65	16
	Aug-08	36	32	89	20
	Dec-08	41	25	61	24
	Apr-09	34	25	74	28

*No lid: Project tanks that were not fully fitted with lids or had no lids.

not undertaken simultaneously in each commune, tank, tap, and control households could be surveyed simultaneously (Table 1) from December 2007, April 2008, and August 2007 in Communes 1, 2, and 3, respectively. Standard jars were the most common container type in all three communes, and therefore of greatest value as an indicator of behavioral change resulting from new water infrastructure. The mean number of containers per house in control, tank, and tap households in Communes 1, 2, and 3 were 15.0, 11.6, and 10.3 (N = 118); 6.3, 8.3, and 6.9 (N = 143); and 7.3, 7.0, and 6.7 (N = 137); respectively. In Commune 1, the mean number of wet standard jars among control, tank, and tap households (Table 1) was significantly different (P = 0.02 < 0.001) but in Communes 2 and 3, there were no significant differences in the mean numbers of standard jars, except for numbers in Commune 2 in April 2009 (P = 0.02). Longitudinally, there no were significant changes in the average number of standard jars from the time of installation of either tank or tap infrastructure, nor in control households.

Across surveys in both dry (December 2007 and 2008) and wet (August 2007 and 2008) seasons, standard jars (Table 2) were mainly used to store tap water in Commune 1 (40–51%), 2 (36–39%), and 3 (15–33%) . In Commune 1, 54% and 60% of the tap households used standard jars to store tap water in the dry season (December) of 2007 and 2008, respectively (with an average of 3.9 and 3.8 standard jars per house), whereas the corresponding proportion in the wet season (August) of 2008 was 48% (4.0 standard jars per house). In Commune 2, more than half of tap households used standard jars to store tap water in the 2008 wet season (57%) and dry season (58%), with an average of 4.3 and 4.6 jars per house. In Commune 3, nearly half of the tap households used standard jars to store tap water in the wet season of 2007 and 2008 (49% and 42%, respectively), with an average of 4.7 and 4.1 standard jars per houses. In the dry season of 2007 and 2008, 26% and 48% of the households stored tap water in their standard jars, with an average of 4.1 and 4.4 jars per house. Compared with standard jars, households were less likely to use other tanks to store tap water.

Impact of project tanks on water storage in standard jars. Although project tanks accounted for less than one-third of the total number of water storage containers in tank households (12.9–17.7% in Commune 1, 19.8–23.4% in Commune 2, and 12.8–14.8% in Commune 3) across surveys, project tanks were used to store relatively high volumes of water (23–65% of total volume of water per house), particularly in the dry season surveys (December 2007 and December 2008) when these containers accounted for 29–59% of total household water (mean = 694–1,924-L per house).

For Commune 1, across surveys in both dry (December 2007 and 2008) and wet (August 2007 and 2008) seasons, water was predominantly stored in standard jars that comprised 48.1–52.1% of containers, and produced 63.0–79.1% of III–IV instars and 66.3–91.9% of pupae. The project tanks accounted for only 1.7–8.8% and 0.4–5.1% of III–IV instars and pupae, respectively.

For Commune 2, standard jars comprised 59.1–68.8% of containers but III–IV instar and pupal abundance represented 53.9–88.4 and 88.0–98.2% of the total standing crop. The new project tanks contributed from 2.3–17.2% and 0–4.0% of III–IV and pupae, respectively.

For Commune 3, standard jars comprised 65.5–71.1% of containers, but III–IV instar and pupal abundance represented 48.5–90.9% and 67.9–89.9% of the total standing crop. The new project tanks contributed from 0–20.8% and 0–11.8% of III–IV and pupae, respectively.

When the mean numbers ±95% confidence interval (CI) were compared for each commune by season and recipient group (Table 3), there were no significant differences for the mean numbers of III–IV instars per household for control (15–104), tank (17–79), and tap households (9–74) in surveys during the wet (August 2007 and 2008) and the dry (December 2007 and 2008) seasons. Mean numbers of pupae were also

Table 5
Mean number of *Aedes aegypti* III/IV instars in positive project tanks by season and lid status in tank households in the three study communes*

Survey time	No lid* n	No lid* Mean	No lid* (95% CI)	Lid† n	Lid† Mean	Lid† (95% CI)	P-level
Aug-07 (Wet season)	11	48.9	(15.4–155.3)	10	39.8	(14.5–109.2)	0.8
Dec-07 (Dry season)	6	16.9	(10.3–28.0)	7	24.0	(7.2–79.5)	0.6
Aug-08 (Wet season)	19	33.0	(13.5–80.6)	10	36.2	(16.0–81.8)	0.7
Dec-08 (Dry season)	4	31.5	(2.5–401.2)	5	26.4	(6.8–102–8)	0.9

*No lid: Project tanks that were not fully fitted with lids or had no lids.
†Lid: Project tanks that were fully fitted with lids.
n = number of project tanks that were positive for *Ae. aegypti* immature.
Mean, 95% confidence interval (95% CI) were calculated on the natural-log scale and were back-transformed for presentation.
Mean number of pupae was too low to report in this table

TABLE 6
Prevalence of *Aedes aegypti* immatures in standard jars by lid status and recipient group

		Aug 07 (Wet season)					Dec 07 (Dry season)				
		No lid		Lid			No lid		Lid		
Recipient	Immature	%	(N)	%	(N)	P-level	%	(N)	%	(N)	P-level
Control	III/IV instars	18.1	(509)	14.1	(149)	0.26	15.4	(429)	8.1	(161)	0.020
	Pupae	7.5	(509)	2	(149)	0.015	5.1	(429)	2.5	(161)	0.16
Tank	III/IV instars	22.1	(697)	16.2	(154)	0.11	12.9	(512)	10.7	(270)	0.38
	Pupae	8.9	(697)	7.1	(154)	0.48	6.1	(512)	1.9	(270)	0.008
Tap	III/IV instars	25.0	(104)	16.5	(115)	0.12	26.5	(275)	9.6	(104)	< 0.001
	Pupae	6.7	(104)	5.2	(115)	0.64	8.4	(275)	4.8	(104)	0.24
		Aug 08 (wet season)					Dec 08 (dry season)				
		No lid		Lid			No lid		Lid		
Recipient	Immature	%	(N)	%	(N)	P-level	%	(N)	%	(N)	P-level
Control	III/IV instars	19.8	(450)	18.9	(132)	0.83	8.9	(428)	4.6	(173)	0.08
	Pupae	5.8	(450)	5.3	(132)	0.84	2.3	(428)	0.0	(173)	0.07*
Tank	III/IV instars	21.5	(675)	18.4	(114)	0.46	9.6	(613)	7.2	(195)	0.30
	Pupae	6.7	(675)	3.5	(114)	0.20	2.0	(613)	1.0	(195)	0.54*
Tap	III/IV instars	27.0	(456)	16.5	(103)	0.027	11.1	(388)	2.6	(151)	0.002
	Pupae	7.5	(456)	1.9	(103)	0.04	2.8	(388)	0.0	(151)	0.04*

*Fisher's exact test.
N = number of wet standard jars at the time of the survey.

non-significantly different for 10 of 12 seasonal comparisons except for December 2007 for Communes 1 and 3, when tap households had significantly more pupae than tank or control communes.

Relationship between *Ae. aegypti* immatures in water holding containers and lid status. For all surveys (Table 4), 12–54% of project tanks in Commune 1, 23–76% in Commune 2, and 45–89% in Commune 3 were not covered by a lid or not fully fitted with a lid. Within 4 months of installation, 45–54% of lids had been displaced or damaged in Communes 1 and 3, whereas 76% of tanks surveyed in Commune 2 were without lids, either because of poor fit, damage, or they had not been installed.

The percent of project tanks covered with lids differed in each commune and was not seasonally dependent (Table 5). In terms of abundance in positive containers, project tanks without lids held a higher mean number of III/IV instars in the wet season than those in the dry season in 2007 (mean = 48.9 [$CI_{.95}$ = 15.4–155.3] versus mean = 16.9 [$CI_{.95}$ = 10.3–28.0], but similar numbers in 2008 (mean = 33.0 [$CI_{.95}$ = 13.5–80.6] versus mean = 31.5 [$CI_{.95}$ = 2.5–401.2]). For tanks with lids, the same pattern was observed across seasons. Nonetheless, in each of the four surveys from August 2007 to December 2008, there were no significant differences in mean numbers of III/IV instars in project tanks covered with lids compared with those not covered with lids.

Overall, the percentages of standard jars that were infested with *Ae. aegypti* immatures were lower in those covered with lids (Table 6) and 8 of 24 comparisons were significantly different. Of the tap households in the three study communes, standard jars that were covered with lids were significantly less likely to be positive for III/IV instars than those without lids in December 2007 (9.6% versus 26.5%, $P < 0.001$), August 2008 (16.5% versus 27%, $P = 0.027$), and December 2008 (2.6% versus 11.1%, $P = 0.002$).

Seasonally, there was no significant difference regarding positivity of III/IV instars in standard jars covered with lids between the wet and dry season of 2007 across three recipient groups but in 2008, standard jars fully fitted with lids in the wet season were significantly more likely to be positive for III/IV instars than those in the dry season in control households (18.9% versus 4.6%, $P < 0.001$), tank households (18.4% versus 7.2%, $P = 0.003$), and tap households (16.5% versus 2.6%, $P < 0.001$). In terms of pupae, standard jars covered with lids were significantly more likely to be positive for pupae in the wet season compared with the dry season in tank households in 2007 (7.1% versus 1.9%, $P = 0.007$) and in control households in 2008 (5.3% versus 0%, $P = 0.003$).

DISCUSSION

Our study provides an interesting insight into the community responses to water supply schemes in relation to achievement of Millennium Development Goals,[19] particularly with respect to the relationship between water storage, dengue, and other diseases.

For three communes in Ben Tre, Long An, and Vinh Long, our qualitative analyses revealed that householders knew that water storage containers can serve as potential habitats for dengue mosquitoes, consistent with findings from other dengue endemic countries[20,21] and within Vietnam.[9,10] In addition, our research has identified a range of broadly held community concerns about the limited availability of water, in addition to strongly held perceptions about water quality and cost. It also indicated that regardless of whether tanks or tap water were chosen, rainwater was most highly regarded and that traditional storage systems were unlikely to be replaced (Table 1).

In the case of existing water storage containers (150–250-L ceramic jars called "standard jars") in rural houses in southern Vietnam, these containers were considered to be very important for storage of rainwater, partly caused by the perception of rainwater as a safe source of water for drinking and cooking, and also because of perceptions that water tastes better when it is stored in ceramic jars, as opposed to ferro-cement tanks.[18] These perceptions of rainwater quality and the desirability of standard jars for household water storage were firmly held, even when householders were provided with alternative water infrastructure such as piped water and household taps, or large ferro-cement tanks. The implications of this, in terms of dengue prevention programs, is that water supply initiatives that aim to supplement household water availability, either through piped water or provision of large tanks, are unlikely to have an impact on the abundance of existing water containers that householders consider valuable (Table 2), and that may serve as habitats for dengue mosquito immatures.

The delivery of piped water systems may actually result in increased numbers of storage jars, particularly if supply is erratic. For example, studies in Venezuela have shown positive correlations between frequency of water supply interruptions and *Ae. aegypti* indices and the number of water storage containers.[8] In this latter study, interrupted water supply was not uncommon and 60% of the 365 householders surveyed said they would retain their existing containers for water storage even with a reliable and consistent supply. With the Cuu Long Delta scheme, chloramine and turbidity were seen as negatives by respondents, whereas householders in Venezuela resorted to storing tap water in containers to remove sediment. In Brazil, Caprana[22] also realized that householders in the underprivileged areas were more likely to use water containers such as tanks, cisterns, and barrels to store water because of an irregular supply of piped water. Householders in Delhi developed strategies to counter an erratic water supply by storing tap water in containers, collecting water from other sources, or by treating the tap water that households were dissatisfied with.[23] Our householders adopted the storage option of holding tap and rain water in their containers all year round.

The introduction of new water supply infrastructure, either in the form of tanks or taps, did not appear to have any significant impact on the prevalence and abundance of *Ae. aegypti* immatures, compared with houses that did not receive new water supply infrastructure. Although up to 31% of the new tanks were infested with *Ae. aegypti* immatures, and these occasionally accounted for up to 21% of the standing crop of III/IV instars, the existing containers at these houses, mainly standard jars, accounted for 49–91% of the III–IV instar *Ae. aegypti*. Thus, they would be classified as a key container[24,25] and rightly should be the subject of targeted control. In terms of abundance per household (Table 3), there was little difference between tank and tap, compared with control households.

Project tanks and tap water-holding standard jars may represent the potential impact of the water supply infrastructure on dengue vectors. Overall, project tanks contributed 1.7–8.8% productivity of III/IV instars in tank households in Commune 1, 2.3–17.2% in Commune 2, and 0–20.8% in Commune 3. For pupae, this was 0.4–5.1% in Commune 1, 0–4% in Commune 2, and 0–11.8% in Commune 3. The low contribution of large project tanks to *Ae. aegypti* production, even though the majority of them were not protected by lids, is in direct contrast to the situation in Ninh Xuan, central Vietnam where 2000-L molded tanks contributed up to 92% of *Ae. aegypti* immatures,[10] but the ages of these tanks were largely unknown. It is possible that the gap between construction and entomological survey was much wider than up to 28 months in our present study in southern Vietnam. Furthermore, these tanks were the predominant container type.

In our present study in southern Vietnam, standard jars > 100 L outnumbered project tanks by ~4–5 times. Householders did not wash their standard jars, particularly those that stored rain or tap water until nearly empty, because of their value in terms of scarcity in the dry season and consideration of the cost of tap water. As such, standard jars may divert ovipositing *Ae. aegypti* away from the project tanks not only because of their relative abundance, but also caused by any repellency from cement residues in project tanks early but not in later surveys.

Although no organized control programs against *Ae. aegypti* immatures were implemented in the three communes during the study, *Ae. aegypti* prevalence and abundance were generally higher in the wet season compared with the dry season (Table 3). This is consistent with findings from Thailand[26] with a higher proportion of colonized containers at households (60% in the wet season, 46% positive in the hot season, and 32% in the cool season). Although the frequency of removal of lids for rain harvesting was not observed and documented in our study, householders may remove lids off their containers more regularly in the wet season to facilitate the harvesting of rain water, thereby giving access to oviposition of *Ae. aegypti*. Furthermore, the reverse may apply during the dry season when the primary reason for lid coverage was to protect water from dust. Overall, we were surprised by the high prevalence of defective or no lids even with Communes 1 and 3 where sealed lids were provided by project specification (Table 4). As expected, project tanks and tap water-holding standard jars that were fully fitted with lids had lower infestation rates (Table 6) than those without fully fitting lids. Nonetheless, the level of protection afforded by lids was not high, in that up to 18.9% of standard jars fully covered by lids still had *Ae. aegypti* III/IV instars (Table 6). Although many of these new tanks had fully fitted lids (up to 88% of project tanks in Thanh Phu Dong, 77% in Thanh Loi, and 55% in Tan Loc), there was no evidence that these lids afforded any meaningful protection against infestation with *Ae. aegypti* immatures, compared with those containers without lids. The mean abundance (Table 5) was not statistically different between tanks fully fitted with lids and those not fully fitted with lids or had no lids.

Use of lids to cover water storage containers yields different protective effects in different areas. A study in two areas in urban Ho Chi Minh City found that appropriate covers of containers effectively reduced *Ae. aegypti* infestation with an odds ratios (OR) of 4.0 and 4.9 for containers with inappropriate as opposed to appropriate covers.[16] In rural Thailand,[13] the percentage of jars infested with larvae reduced from 56.2% to 13.7% from incorrectly (or uncovered) jars compared with those covered correctly, and from 34.9% to 7.8% in urban households. In another area in Thailand,[27] jars with wood, sheet metal, or commercial aluminum lids did not prevent infestation by *Aedes*. In Cambodia, the design of lids incorporated into long-lasting insecticidal netting treated with deltamethrin for jars ≥ 200-L proved to be effective with significantly fewer pupae per house in the treated villages than in control villages.[28] However, use of larvicidal agents to treat drinking water is restricted in Vietnam because of safety concerns.

Our study raises some policy and design issues for Vietnamese authorities but also more general issues. First, the contractors were correct to ascertain the preferences of recipient communities, but additional social research to understand their water values and storage behavior may have been beneficial. Second, water storage capacity was increased by 1,200-L project tanks or by collection of tap water into pre-existing standard jars. The net increase in abundance of *Ae. aegypti* III–IV instars or pupae were no greater than 21% but usually much less. Although there were some increases in prevalence and abundance of immatures in unlidded containers, contractors should consider the cost benefits of not supplying lids, especially as so many were defective or missing within months of installation. Future programs that aim to supply water storage tanks for rural communities should also provide information, education, and communication on tank maintenance with respect to hygiene and dengue prevention issues, so that community people may desist with activities that could improve the accessibility of new infrastructure to *Ae. aegypti*.

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