Innovative dengue vector control interventions in Latin America: what do they cost?

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Background: Five studies were conducted in Fortaleza (Brazil), Girardot (Colombia), Machala (Ecuador), Acapulco (Mexico), and Salto (Uruguay) to assess dengue vector control interventions tailored to the context. The studies involved the community explicitly in the implementation, and focused on the most productive breeding places for *Aedes aegypti*. This article reports the cost analysis of these interventions.

Methods: We conducted the costing from the perspective of the vector control program. We collected data on quantities and unit costs of the resources used to deliver the interventions. Comparable information was requested for the routine activities. Cost items were classified, analyzed descriptively, and aggregated to calculate total costs, costs per house reached, and incremental costs.

Results: Cost per house of the interventions were $18.89 (Fortaleza), $21.86 (Girardot), $30.61 (Machala), $39.47 (Acapulco), and $6.98 (Salto). Intervention components that focused mainly on changes to the established vector control programs seem affordable; cost savings were identified in Salto (–21%) and the clean patio component in Machala (–12%). An incremental cost of 10% was estimated in Fortaleza. On the other hand, there were also completely new components that would require sizeable financial efforts (installing insecticide-treated nets in Girardot and Acapulco costs $16.97 and $24.96 per house, respectively).

Conclusions: The interventions are promising, seem affordable and may improve the cost profile of the established vector control programs. The costs of the new components could be considerable, and should be assessed in relation to the benefits in reduced dengue burden.

Keywords: Dengue, Vector management, Vector control, Cost analysis

Introduction

The re-emergence of dengue has increasingly become a public health problem globally[1,2] and in Latin America.[3] Vector control is a key measure to prevent the disease, but traditional approaches have known limitations in adapting to the changing complexities of the ecologic and social determinants of *Aedes aegypti* L. (Diptera, Culicidae) infestation. Such determinants include difficulties in properly identifying the ecological and social factors underlying vector breeding and dengue transmission, the vector's changing behavior and in contrast, the lack of responsiveness and adaptability of control programs.[4] In this context, the Special Programme for Research and Training in Tropical Diseases of the World Health Organization (WHO) and the International Development Research Centre led a multi-country research initiative to assess innovative tools/strategies for *Aedes*/dengue control directed at households and/or public locations in five urban

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settings of Latin America–Brazil (Fortaleza), Colombia (Girardot), Ecuador (Machala), Mexico (Acapulco), and Uruguay (Salto).[5] In each city, a local research team developed a situational analysis that explored the ecological, biological, and social determinants of *Ae. Aegypti*, and designed community-driven interventions, tailor-made to tackle the major factors associated with vector density. The effect of these interventions on vector density was evaluated using cluster randomized controlled trials. Overall, the results suggest the interventions led to a reduction of vector densities[6] (the effects varied across countries, entomological indicators, timing and components of the intervention[7–11]). We report here on the costs of the interventions delivered in these specific urban settings, compare them with those from the routine vector control activities and explore their scope for cost-effectiveness. This evidence is meant to be an additional input for researchers and decision-makers examining the affordability, feasibility, and sustainability of the proposed interventions.

Previous studies on dengue in Asia, using the same research approach and conceptual strategy for integrated vector management,[12] demonstrated the potential of such an approach for the design of vector control interventions; however, the evidence on the costs and sustainability of such interventions was limited. The studies in Fortaleza, Girardot, Machala, Acapulco and Salto expand such literature, and this study provides evidence on the costs of the interventions which complements existing evidence on the costs of vector control interventions at least in two ways. First, all the interventions involve a component of community involvement and, as of a few years ago, there was little evidence on the costs and sustainability of community-based dengue control programs.[13] This has been changing and evidence on the costs and economic consequences of community involvement has been accumulating,[14,15] and this study adds to such literature. Second, the use of insecticide-treated materials for dengue vector control has shown promising results[16–19] and the evidence on the costs of insecticide-treated materials used as curtains is also accumulating.[14,18,20,21] This study also complements such literature, in particular, by documenting the costs of insecticide-treated materials installed as screens for doors/windows of houses and covers for water tanks.

Methods and Study Settings

Context and study settings

The cost analysis was conducted alongside cluster-randomized controlled trials to assess the effect of the interventions on entomological indicators. Dengue studies were conducted in selected cities of five countries: Fortaleza (Brazil), Girardot (Colombia), Machala (Ecuador), Acapulco (Mexico), and Salto (Uruguay). All are urban areas and four of them are dengue endemic areas with continuous presence of *Ae. aegypti.* Table 1 summarizes the characteristics of the cities as described elsewhere.[5]

Interventions and comparators

The interventions varied across study sites, but shared two key features: an explicit effort to involve the community as active participants in vector control and, in most cities, a targeted intervention that focuses only on the most productive containers.

In Fortaleza, the intervention focused on modifying how the routine program in order to favor mechanical over chemical control, to target the most productive containers and to involve the community and improve their relationship with the agents who visit the houses. In Girardot, the intervention focused on using long-lasting insecticide-treated nets (LLIN) to cover doors, windows, and water tanks used to store water. In Machala, the intervention focused on reducing mosquito-breeding sources in households with the support of community volunteers, and on educating students on actions for dengue control in their own homes. In Acapulco, besides the targeted treatment of most productive containers, the intervention focused on using LLIN installed as screens to protect doors and windows of the houses. In Salto, the intervention focused on involving the community to remove containers in and around their homes. Table 2 describes the interventions delivered in each city and routine programs, as described in detail elsewhere.[7–11] Interventions were delivered mostly during 2013, although timing is different in each study site.

Table 1 Characteristics of the cities in the study

	Fortaleza, Brazil	Girardot, Colombia	Machala, Ecuador	Acapulco, Mexico (Ciudad renacimiento)	Salto, Uruguay
Total population	2,447,409	132,456	281,500	48,460	123,000
Average annual temperature in °C (Min–Max)	30.0 (23–37)	28.0 (23.2–38.3)	25.0 (18–34)	27.8 (16.2–38.7)	18.1 (24.1–12.5)
Mean annual relative humidity (%)	90	61.5	84	75	72
Annual rainfall in 2011 (mm)	1378	530	448	1145	1322
Rainy season (s)	February–May	March–April and October–November	November–April	May–October	Irregular; potential virus development only from mid November–April

Source: Quintero et al.[5]

Table 2 Description of interventions and routine programs

Country, City	Description of the intervention and routine program
Fortaleza, Brazil (see [7])	'The intervention targeted productive container types, mainly small discarded and unused water containers stored in backyards and large water tanks as determined by the situational analysis. The strategy included: establishing partnerships, meeting with intersectoral groups to explain the objectives and procedures of the activities in the homes; requesting the Regional Secretariat for a truck for waste collection; organizing social mobilization through groups formed by National Health Service professionals, educators and Endemic Disease Agents (EDAs) who made home visits, delivered garbage bags, informed the community about the date on which the garbage truck was going to collect the trash and provided general health information'.[7] The routine vector control is based on larviciding water containers by the endemic diseases agents (on average, every 2–3 months). The intervention followed the same strategy as the routine approach (visits with the same frequency) but attempted to change how the routine operated by favoring mechanical over chemical control, targeting the most productive containers and involving the community and improving their relationship with the agents that visits the houses
Girardot, Colombia (see [9])	The intervention in Girardot, Colombia, involved the use of long lasting insecticide treated (LLIN) materials as curtains for doors and windows 'fixed by homeowners with a white string and two nails beneath existing curtains (in some homes) and usually supervised by research staff. At least one door per house and all unprotected and in-use windows were covered'.[9] LLIN and metallic frames were used to cover water tanks known as '*albercas*', typically used to store water for daily washing and hygiene purposes. 'Square and rectangular covers consisted of aluminum frames with a sliding mechanism fixed to PermaNet 2.0 and were made and installed by small to medium enterprises (SMEs)'.[9] 'PermaNet 2.0® (long-lasting insecticide net treated with delta-methrin 50 mg/m^2,Vestergaard-Frandsen,Lausanne,Switzerland) used as curtains on windows and doors as well as LLIN covers for household water container covers'.[9] Routine program focuses on 'larvae control through larvicides (Abate, American Cyanamid Co., Princeton, NJ, USA), health education, and occasional public space spraying of an ultra-low volume of Malathion (Southern Agricultural Insecticides Inc., Palmetto, FL, USA)'.[9]
Machala, Ecuador (see [10])	The intervention in Ecuador involved two integrated components: (i) Clean Patio and Safe Container strategy (CPSC) and (ii) Dengue Elementary School Education Program (DESE). DESE uses both conceptual and practical training for students in years 5 and 6 (8–12 years of age) on actions for dengue vector control in their own homes and neighborhoods. CPSC is a community-based program with social mobilization elements to reduce mosquito-breeding sources in households and patios with the support of trained community volunteers and coordination with health promoters and vector control services. Routine activities followed the newly introduced (April 2013) bti-biolarvicide-based control program that involves 'a vector control technician/frontline worker [that] visits each home in Machala twice per month to educate household members on mosquito-breeding source reduction, to apply biolarvicide, educate around biolarvicide application, leave a small quantity of biolarvicide for domestic use until the next visit, and inspect/ record/educate/eliminate mosquito-breeding source containers'.[10]
Acapulco, Mexico (see [8])	The intervention in Acapulco, Mexico involved: (i) 'Duranet® screens (0.55% w.w. alpha-cypermethrin-treated non-flammable polyethylene netting [145 denier; mesh = 132 holes/sq. inch]; Clarke Mosquito Control, Roselle, IL, USA; WHOPES approved for LLIS use) were mounted in *aluminum* frames custom-fitted to doors and windows of residential houses'[8] and (ii) 'Targeted treatment to prevent *Ae. aegypti* breeding in the most productive sites, was implemented 14 months after the beginning of LLIS installation (June 2013). A total of 1789 water tanks and 200 l drums/barrels in the households of intervention clusters, which were the most productive type of containers in baseline pupal surveys, were treated with the environmentally friendly larvicide Natular® DT (Spinosad 7.48%; Clarke Mosquito Control; WHOPES approved), delivering 1 tablet per 200 l. The first cycle of application was performed at the end of the dry season in 2013 (September, n = 1791 tanks and barrels) and was repeated every two months until March 2014 (November 2013 n = 1686, January 2014 n = 1658, March 2014 n = 1595)'.[8] Routine program 'included adulticiding (outdoor and indoor spraying with *Chloropyrifos* and *Propoxur*, respectively) and larviciding (Abate and Spinosad) in response to elevated dengue and entomological risk indices'.[8]
Salto, Uruguay (see [11])	The intervention in the city of Salto, Uruguay consisted of (i) a campaign with community members and public health institutions for the physical or functional removal of containers in and around their homes, distributing trash bags to houses and promoting the residents to clean their backyards and terraces by disposing small unused water containers into the bags; later, the bags are collected and discarded; (ii) a house visit to cover large water tanks, if needed. The routine program consisted of home visits and collection of unused water containers.[11] The routine program focus on the removal of the water containers through visits of workers from public health institutions to inspect the premises

As per the research design, comparators for the cost analysis were routine vector control programs in each city that typically consist of inspection of premises and larviciding.

Perspective of the cost analysis

We took the perspective of the service provider,[22] the vector control program. Therefore, the analysis included only the costs to the agency in charge of the interventions. As a result, we excluded some costs not relevant for our analysis that might be important for other purposes (e.g. cost-effectiveness analysis[23]). In particular, two major costs were excluded: the economic burden of dengue cases (costs for households and health care system) and the costs for the community. Although the perspective chosen might be limited for an economic evaluation, it is useful for the assessment of the feasibility and affordability of the interventions.

Estimating resources and costs

We used a micro-costing approach[24]; based on a detailed description of the interventions, we developed data collection tools to measure resource consumption in physical units and gather data to value each resource item (unit cost). The local team in charge of the dengue study in each city collected standardized information based on direct observation, field reports, expenditures reports and interviews. Comparable information was requested from the agencies in charge of the routine activities.

Resource items were classified following the cost components proposed in the literature[25,26] and previous cost analysis of similar interventions.[18] Thus, we classified first on recurrent costs (personnel, consumables, and other recurrent costs) and capital costs. Consumables are further divided into information materials (leaflets, calendars, etc.) and materials used for source reduction (e.g. trash bags) or chemical control (larvicides). Other recurrent costs include expenses related to meetings for community mobilization, transport costs, and training. Capital costs comprise vehicles and equipment and the cost of LLIN. We did not include overhead costs.

We measured the time that the personnel involved used in the intervention from daily records whenever available or through interviews, and the time was valued at actual salaries. We did not include volunteer work. For consumables, quantities used were measured and valued at procurement unit cost (market price). The information on quantities and prices of consumables, as well as the expenditures on meetings and trainings, was obtained from records of the project (accounting records, invoices). Transport costs were estimated by measuring the kilometers travelled and using average fuel consumption per kilometer and market price of the fuel.

For capital costs, we obtained equivalent annual costs by an annuitization procedure[22] using 3% discount rate. For old vehicles and equipment, we used the replacement cost of the equipment, full useful life and 20% resale value. When the equipment was not used exclusively on the intervention, the cost was allocated proportional to the fraction of time used on the intervention. LLIN and installation was treated as a capital cost. Thus, expenditures in both LLIN materials and installation were considered as a capital outlay that were annuitized using 3% discount rate, 3 years of useful life, and no resale value. That is, we assume it would have to be replaced every 3 years. Although hard evidence on the lifetime is still missing, 3 years is a reasonable assumption taking into account that according to the manufacturer, the nets would maintain their effectiveness for a lifetime of up to 5 years. In addition, other authors have assumed a lifetime between 2[17,27] and 2.5 years[18] for LLIN installed as curtains, but in the interventions for this study LLINs were installed using metallic frames,[8,9] which should help extend useful life. For example, in the Mexico study, the LLIN installed in metallic frames have already showed an impact up to 2 years after deployment.[8]

Costs were analyzed descriptively and aggregated to calculate total costs, costs per house reached and incremental costs of the interventions over the routine activities. Whenever possible, costs were adjusted to approximate the costs without the constraints of the research project. We did not include costs that belonged exclusively to the research project. Also, following Tun-Lin et al.,[20] when an activity was performed by the research team, we used the time of the personnel involved and valued it using salaries from personnel of the vector control program that would have to do such activity on a routine basis. Similarly, when an activity involved research and intervention (e.g. source reduction and household surveys), we allocated to the costs of the intervention only the fraction of the time spent by the personnel actually delivering the intervention.

Currency and conversions

Data on prices and unit costs were collected in local currency and converted to United States dollars (USD) using average exchange rates for the period of implementation of the interventions (2013). We also report costs in international dollars using International Monetary Fund implied conversion rates.[24]

Results

Fortaleza, Brazil

Total cost per house of the intervention was $18.89, covering an intervention area of around 1000 houses. Personnel (11 endemic disease agents and 1 field coordinator during 7 months valued at $185 and $277 per month, respectively) was the main cost driver accounting for 86% [16.21/18.89] of total cost. Consumables represented nearly 12% [2.22/18.89] of total cost, including $1.57 per house (8% [1.57/18.89]) for information materials such as educational calendars and $0.65 per house (3% [0.65/18.89]) in materials used for source reduction/protection such as bags to collect small unused water containers. Meetings' related expenses to mobilize the community amounted to $0.33 per house (2% [0.33/18.89]) and transport costs (fuel) $0.13 per house (1% [0.13/18.89]) (See Table 3).

Unfortunately, no detailed information on the cost of routine activities was available to compare each cost item. However, the intervention was delivered by personnel working in the vector control program routinely, and required a similar team and staff-time as the routine activities in the same area. So, no additional personnel costs would be incurred by the vector control program. However, additional costs could arise as a result of greater emphasis on education and community mobilization and activities such as covering large water tanks that are not routinely undertaken by the vector control program. On the other hand, there may be cost-savings due to reduced use of larvicides (routine activities used larvicides at a cost of $0.18 per house, based on an average of 2,000 l water tank per house, 1 g of larvicides required per 1,000 l and $44 per 500 g of larvicides). Costs associated with materials and activities not routinely used by the vector control program add up to $2.06 per house and net of the cost of larvicides (assuming cost-savings), we estimate the incremental cost would be $1.88 per house (around 10% [1.88/18.89] of the total costs).

The impact of the intervention on vector densities revealed an improvement in the efficacy of vector control. The entomological indicators – House Index – HI: percentage of inspected houses with immature stages of *Ae. aegypti*, Container Index – CI: percentage of water-holding containers with immature stages of *Ae. aegypti*, and Breteau Index – BI: number of containers with immature stages of *Ae. aegypti*/100 houses and the number of pupae per person index (PPI) – were measured in both control and intervention areas during the dry season (before the intervention) and during the rainy season (after the intervention), and the increase in the control areas was significantly higher than in the intervention areas.[7]

More information will be needed to ascertain the incremental cost accurately; however, results suggest that the proposed intervention could be integrated into the routine activities and although there may be some additional costs, these do not seem to be prohibitive. Furthermore, the intervention would bring additional benefits in reduced vector abundance that should be considered along other criteria such as budgetary limits and willingness to pay for further reduction in vector indices and dengue cases. As a positive signal, based on the results of the Brazil study, the government decided to implement the intervention on a larger scale in two big cities of the country,[7] suggesting the costs are seen as affordable.

Girardot, Colombia

Total annual cost per house was $21.86, covering 947 houses that accepted the intervention.[9] Cost per house for personnel ($2.89; 13% of total cost [2.89/21.86]), transport costs ($0.48; 2% of total cost [0.48/21.86]), and costs associated to community mobilization ($1.52; 7% of total cost [1.52/21.86]) were relatively small compared to the LLIN materials and installation that amounted to an annual equivalent cost of $16.97 per house which accounts for 78% [16.97/21.86] of total cost per house (treating the costs of LLIN and installation as a capital outlay and assuming three years of useful life and 3% discount rate) (See Table 3). Overall, 1,556 nets of LLIN material were used for curtains and 136 for water tanks covers. Nets were donated and valued at a unit cost of $18.51.

During 2013, the routine vector control program in Girardot covered 20,845 houses at an estimated cost of nearly $4.9 per house. Personnel was the main driver of the costs of the routine activities accounting for 57% [58303/101852] of total costs, while larvicide represented only 1.5% [1492/101852] of the total costs (Table 3).

The LLIN curtains alone led to a reduction of BI (57% reduction in the intervention group vs. 38% in the control group) and an increase in PPI (17% increase in intervention group vs. 22% reduction in the control group). The additional intervention using LLIN covers for water containers showed a significant reduction of PPI (71% decline in the intervention group vs. 25% reduction in the control group).[9]

The proposed intervention could add considerable costs to the vector control program, largely due to the LLIN and installation. Yet, it is likely that better prices for LLIN and installation could be achieved in a large-scale implementation. Also, the constraints imposed by the research project influenced the costing in a way that made it particularly challenging to separate the costs of the intervention from those of the research project; the latter could have led to artificially high costs of the intervention (e.g. testing the differential effect of curtains and water tank covers implied delivering them at different moments, which could lead to higher costs compared to an integrated delivery of the whole package). So, in any case, the cost estimates reported here are an upper bound for the costs of the intervention. As a positive signal, the Colombian Ministry of Health decided to support the scaling up of the activities in the city of Girardot.

Machala, Ecuador

Total cost per house was $30.61 estimated for the intervention area of around 1000 houses. Out of this, $17.33 correspond to the Clean Patio and Safe Container strategy (CPSC) and $13.28 to the Dengue Elementary School Education Program (DESE). The main cost driver of both components was personnel, accounting for 55% [9.59/17.33] and 78% [10.32/13.28] of the total costs of CPSC and DESE, respectively. Given that the intervention is intensive in education and community mobilization, costs incurred in information materials were also sizeable in both components (16% [2.78/17.33] CPSC and 10% [1.39/13.28] DESE). Materials used for source reduction were a major cost driver in CPSC (16% [2.8/17.33] of the costs of CPSC) (See Table 3).

The total cost per house of the routine program was $19.78, covering 30,000 houses. The total costs break down into personnel costs $11.85 (60% [11.85/19.78]), source reduction materials $5.76 (29% [5.76/19.78]), information materials $1.23 (6% [1.23/19.78]), and meetings ($0.05), transport ($0.03), and equipment annual equivalent cost ($0.87). The costs of source reduction/chemical control materials are explained by the use of bio-larvicide (*Bacillus thuringiensis israelensis*), on average, 360 ml of larvicide per house at $0.48 per 30 ml.

CPSC, which is the component directly comparable to the routine program, has an overall lower cost per house than the routine ($17.33 vs. $19.78). Lower costs are achieved mainly due to reduced personnel costs ($9.59 vs. $11.85) and source reduction/chemical control materials ($2.80 vs. $5.76). Lower personnel costs are possible because the number of days worked by promoters and other field personnel is considerably lower for CPSC than for the bio-larvicide program (205 vs. 320 days-worker needed to cover 1,000 houses). Lower costs for source reduction/chemical control materials is achievable because CPSC did not use bio-larvicide, and the savings in this item outweighed the additional costs of information materials to support education and social mobilization within participant communities in peridomestic mosquito source reduction (bags, calendars, stickers for the doors, flyers, pamphlets, t-shirts, and caps).

Comparing control and intervention areas originally enrolled in the study to receive the integrated intervention strategy (CPSC and DESE), there was a significant reduction of PPI values in the intervention areas (0.524 in 2012 and 0.080 in 2013) compared to a non-significant reduction in the control areas (0.817 in 2012 and 0.353 in 2013), which suggests a potential effect of the intervention, although not statistically detectable. When only the cluster pairings that had remained consistent with the study design were included in the analysis, the effect was stronger and statistically significant. There was also a reduction in both HI and BI in the households of the 230 children that participated in the DESE.[10]

In summary, the intervention may lead to additional costs due to the introduction of the new component DESE. Importantly, this integrated approach engages explicitly in transdisciplinary and intersectoral collaboration strategies potentially linking Ministry of Education and Ministry of Health efforts; there is good precedence of collaboration and resource-sharing with school-based public health program for children. Building DESE program elements into regular year 5 and 6 curricula would leverage existing capacities, and reduce medium- and long-term costs of the program ultimately. CPSC – which can be viewed as the intervention's counterpart to the routine bio-larvicide program – brings cost savings compared to the government mandated approach, in particular, in field personnel and consumables (larvicide). So, scaling-up and intersectorally integrating the new interventions may require some additional resources initially, but only because it provides a more extensive, holistic, and context-relevant approach to dengue prevention than the current bio-larvicide program.

Considering costs and benefits, the integrated approach evaluated in Machala looks promising as there are opportunities for cost savings in the CPSC, and possibilities for enhanced vector control through the integration of CPSC and DESE that could be worth the additional costs. However, it is yet to be seen how the costs and effects behave in a larger scale implementation and how sustainable the effects are.

Acapulco, Mexico

Total annual equivalent cost of the intervention was $39.47 per house, including 780 houses that received LLIN. Installation of LLIN (including aluminum frames, equipment, personnel, transport, etc.) was the most important cost of the intervention accounting for 63% [24.96/39.47] of the total annual equivalent cost per house. It was commissioned to a local business at $65.5 per house effectively covered; unfortunately, it was not possible to obtain details of the cost structure for such work. Such cost, together with the costs of LLIN material (11,475 m^2 of LLIN were used at a unit cost of $0.35 per m^2), make up the costs of the protection with LLIN that amounted to a capital outlay of $70.60 per house. The equivalent annual cost of this (treating it as capital outlay and assuming three years of useful life and 3% discount rate), was $24.96 per house or 63% [24.96/39.47] of total cost. Personnel for the targeted treatment (TT) were also a major cost ($10.15 per house; 26% of total cost [10.15/39.47]) followed by larvicides ($2.59 per house or 7% [2.59/39.47] of total cost, estimated based on 1 tablet per 200 liters applied in four cycles to 1791, 1686, 1658 and 1595 tanks and barrels; $0.38 per tablet) (See Table 3).

Unfortunately, it was not possible to obtain detailed information on the costs of the routine activities. However, similar approaches of TT have shown to reduce costs in a number of contexts – including Mexico,[20] particularly for personnel and transport costs. Other cost differences in Mexico would include the use of a different larvicide – in the intervention NatularwDT (Spinosad 7.48%; Clarke Mosquito Control; WHOPES approved) and the routine Temephos and Spinosad as well[8]; cost per house in the intervention was $2.59 and an estimated cost per house in the routine of $0.31, assuming only Temephos is used (the routine uses both Temephos and Spinosad, so this estimate is a lower bound) – and the increased costs to engage the community in the intervention through meetings and other activities that were not part of the routine program (this cost item was $0.49 per house in the intervention). LLINs are a completely new component that adds considerable costs. The TT in turn, on one hand, might entail additional costs (e.g. larvicides, community mobilization as shown above) and on the other hand, might bring cost savings that could compensate or perhaps even surpass the additional costs. Comparing targeted and non-targeted interventions in Merida city, Mexico, it has been shown that the TT reduced recurrent costs in nearly 62% [7381/19185-1] including cost reductions in transport and nearly 22% [6439/8240-1] lower costs in personnel that was the main cost driver of the intervention.[20] In summary, the net effect on costs is unclear and more information would be needed to ascertain the incremental cost of the intervention (either positive or negative) accurately. Nonetheless it seems unlikely that the TT would add considerable costs compared to the routine.

The evaluation of the effect of the intervention on vector indices[8] showed that areas protected with LLIS had lower adult indices at 5 and 12 months after installation and lower PPI after 12 months. After TT, immature and adult stage indices remained significantly lower in the treated clusters until month 18 (except for blood fed females) and up to 24 months for the adult indices and PPI only.

Although the effect varies with time and indicators used, overall, the results suggest the interventions were more effective than the routine. The costs reported, however, tell two different stories. While the TT is not likely to add considerable costs, the installation of LLIN entails sizeable additional costs to the vector control program that should be examined carefully by the decision-makers in relation to the expected benefits of such investment. Nonetheless, there seem to be opportunities to cut on those costs in a large-scale implementation by obtaining better prices for the insecticide-treated materials and installation.

Salto, Uruguay

Total cost per house of the intervention was $6.93, covering 1000 houses. Major cost drivers were personnel ($3.69 per house, 53% [3.69/6.98] of total costs), consumables including information materials and materials for source reduction ($1.04 and $0.71, respectively), meetings and transport costs.

Total cost per house of the routine program was $8.82, estimated also for 1000 houses according to the routine removal of the containers by the public health institution (Ministry of Public Health) in the control clusters. The major cost driver was also personnel ($5.82 per house, 66% [5.82/8.87] of total costs), followed by information materials ($1.04), meetings expenses ($0.85), materials for source reduction ($0.60), transport costs ($0.27).

The total cost per house of the intervention was nearly 21% [6.98/8.87-1] lower compared to the routine activities. The cost savings are largely explained by a reduction in personnel costs (nearly 37% [3.69/5.82-1]) that outweigh the increase in other resources. It is worth noting, that the intervention showed lower costs even though it included additional activities not considered in the routine approach (particularly, to cover big water tanks).

The cost reduction is largely driven by reduced personnel costs achieved by a combination of factors. First, a reduction of 37% [798/1260-1] in the number of personnel hours required for the elimination of water containers. Second, lower salaries for field personnel in a number of activities by taking advantage of personnel available in the Ministry of Social Development (MIDES). MIDES personnel carried out some routine activities conducted usually by personnel of the Municipality of Salto and the Institute for Economic and Social Promotion in Uruguay (IPRU), agencies that have a relatively higher pay scale. Interestingly, cost savings do not vanish without MIDES lower salaries; a scenario assigning MIDES personnel the same salary paid by IPRU showed that there would still be lower costs, overall (−2% [8.63/8.82-1]); in personnel costs for all the activities (−7% [5.39/5.82-1]); and personnel costs for the elimination of water containers (−37% [0.797/1.26-1]) (Table 3).

The analysis of the entomological indicators found no statistically detectable effect of the intervention.[11] However, indicators such as BI or the average PPI suggested there might have been an effect given that from spring (baseline; low vector density due to low temperatures) to autumn (post intervention; elevated vector densities due to higher temperatures), the vector densities in intervention areas on average increased less than those in the control areas. These differences are not statistically significant, according to the authors, probably due to the reduced sample size of the clusters.[11]

In summary, the intervention in Uruguay resulted in cost-savings due to a combination of factors that include reduced personnel requirements for the elimination of containers and changes in the composition of the team. A key factor was that distributing trash bags for the community to clean by themselves is less labor-intensive than the routine approach which involves entering the premises to remove water containers. In addition, the intervention is at least as effective as the routine approach in controlling vector abundance and it can also bring not-so-tangible benefits such as community participation and empowerment that could contribute to the sustainability of prevention measures.[11] Hence, from the viewpoint of the efficiency in the allocation of resources, the intervention piloted in Salto would dominate the routine approach. As a positive signal, the Uruguayan Ministry of Health and the municipality of Salto decided to scale up the activities in the city of Salto, which suggests that the interventions are likely to be sustainable because they seem to be affordable and the national and local governments seem committed to prevent autochthonous dengue cases in Uruguay.

Cross-country variation

Cross-country comparison was not a main goal of this study because the differences in context, programs' design, epidemiology and other factors make cross-country comparisons difficult,[14] and sometimes even dangerous. Yet, we attempted some comparisons. After the conversion into international dollars (Table 4), considerable cross-country differences remain. Cost variations are sometimes clearly explained by differences in the intensity of vector control activities or other context-specific factors (e.g. Uruguay requires only a short intervention once a year, while Mexico and Brazil require a much more intensive intervention). However, there is also variation in the costs of some items that should be comparable (e.g. installation costs using metallic frames). Thus, the teams that conducted the studies are analyzing together options for cost savings and learning from each experience to design more efficient implementations of the interventions.

In line with systematic literature reviews,[25,28,29] we also found a wide range of costs and costing approaches for similar interventions[14,18,20,21] (Table 5). In addition, although our estimates for Brazil, Ecuador (CPSC) and Uruguay are within those ranges, the cost estimates for Colombia and Mexico are considerably higher due to the costs of installing LLINs using metallic frames, which none of the previous studies have done.

Table 3 Annual equivalent cost per house (USD $, 2013)

	Interventions						Routine	
			Machala, Ecuador					
	Fortaleza, Brazil	Girardot, Colombia	CPSC	DESE	Acapulco, Mexico	Salto, Uruguay	Machala, Ecuador	Salto, Uruguay
Recurrent								
Personnel	16.21	2.89	9.59	10.32	10.15	3.69	11.85	5.82
	86%	13%	55%	78%	26%	53%	60%	66%
Information materials	1.57		2.78	1.39	0.31	1.04	1.23	1.04
	8%		16%	10%	1%	15%	6%	12%
Source reduction materials	0.65		2.80	0.04	2.59	0.71	5.76	0.60
	3%		16%	0%	7%	10%	29%	7%
Meetings	0.33	1.52	0.98	0.78	0.49	1.01	0.05	0.85
	2%	7%	6%	6%	1%	14%	0%	10%
Transport	0.13	0.48	0.20	0.22	0.76	0.20	0.03	0.23
	1%	2%	1%	2%	2%	3%	0%	3%
Training			0.30	0.30		0.27		0.27
			2%	2%		4%		3%
Capital								
Vehicles and equipment			0.68	0.24	0.21	0.05	0.87	0.05
			4%	2%	1%	1%	4%	1%
LLIN*		16.97			24.96			
		78%			63%			
Total cost per house	18.89	21.86	17.33	13.28	39.47	6.98	19.78	8.87

Source: Authors' calculations.
*Equivalent annual cost of LLIN material and installation, assuming 3 years useful life, 3% discount rate and no scrap value.

Table 4 Annual equivalent cost per house (International $, 2013)

	Interventions						Routine	
			Machala, Ecuador					
	Fortaleza, Brazil	Girardot, Colombia	CPSC	DESE	Acapulco, Mexico	Salto, Uruguay	Machala, Ecuador	Salto, Uruguay
Recurrent								
Personnel	18.00	4.11	17.92	19.30	14.56	4.34	22.14	6.84
	86%	13%	55%	78%	26%	53%	60%	66%
Information materials	1.74		5.19	2.59	0.44	1.23	2.30	1.23
	8%		16%	10%	1%	15%	6%	12%
Source reduction materials	0.73		5.24	0.07	3.72	0.84	10.77	0.71
	3%		16%	0%	7%	10%	29%	7%
Meetings	0.37	2.16	1.84	1.45	0.71	1.19	0.10	0.99
	2%	7%	6%	6%	1%	14%	0%	10%
Transport	0.14	0.68	0.37	0.40	1.08	0.23	0.05	0.27
	1%	2%	1%	2%	2%	3%	0%	3%
Training			0.56	0.56		0.32		0.32
			2%	2%		4%		3%
Capital								
Vehicles and Equipment			1.27	0.44	0.31	0.05	1.62	0.06
			4%	2%	1%	1%	4%	1%
LLIN*		24.13			35.80			
		78%			63%			
Total cost per house	20.98	31.09	32.39	24.82	56.62	8.20	36.97	10.43

*Equivalent annual cost of LLIN material and installation, assuming 3 years useful life, 3% discount rate and no scrap value.

Scope for cost-effectiveness

Having reported the costs of the interventions, an important question remains: do these interventions represent a more efficient use of resources compared to the routine activities? To answer this question properly, we would require the measurement/valuation of all relevant costs and health consequences of the intervention.[22] Unfortunately, the scale of the intervention was not suitable to identify changes in dengue transmission, which leaves arguably the most important health consequence of the interventions unmeasured: prevented dengue cases.

The studies did measure the effect of the interventions on vector indices and some of these could reflect the risk of transmission.[30] However, the effects on vector indices are not easily translatable to changes in dengue transmission because the evidence on the magnitude of such association is relatively scarce, sometimes weak, and overall, not sufficient to draw a reliable conclusion.[31] So, unfortunately, in

Table 5 Studies reporting costs of interventions similar to those delivered in Brazil, Colombia, Ecuador, Mexico, and Uruguay

Study	Summary of relevant cost figures and costing approach
Baly et al.[14]	Report costs of distribution of insecticide-treated curtains in Venezuela (vertical model $8.84 per house covered, $8.38 partnership model) and Thailand ($6.68 partnership model with supervision), from the perspective of the society (year 2007)
Baly et al.[21]	Report societal cost for vector control in Santiago de Cuba during 2004 that ranged between $16.2 and $30.6 per inhabitant for the community approach and between $29.8 and $38.3 per inhabitant for the routine vertical program
Rizzo et al.[18]	Report $5.31 per house protected and per cycle in Guatemala (year 2010), using insecticide-treated materials and targeted intervention, but excluding the cost of the insecticide-treated materials that had been a major cost driver in other studies[14] and in our analysis in Colombia and Mexico
Toledo et al.[27]	Report annualized cost per household of US $3.8 for installation of insecticide-treated nets as curtains. Of these, 84.0% were incremental costs over the routine program that costs US$16.8 per household (year 2009)
Tun-Lin et al.[20]	Report costs of targeted and non-targeted interventions that ranged from $2.19 in the Philippines to $31.7 in Kenya and Mexico per household covered, including only the direct costs to the vector control services (year 2007)

our case we cannot reliably estimate the effectiveness of the interventions in prevented dengue cases or other relevant health outcomes (e.g. DALYs), which hampers undertaking a full cost-effectiveness analysis. Nonetheless, we explore the scope for cost-effectiveness of the interventions under certain assumptions.

The results for Brazil, Colombia, Ecuador, and Mexico show that the proposed interventions entail additional costs compared to the routine approach but they also bring benefits in reduced vector abundance. Therefore, from the perspective of the vector control program, there is no dominant alternative and the decision-maker must also consider other criteria to assess whether or not the additional costs are affordable or if they are willing to pay the incremental cost for the enhanced vector control. Although the bottom line in these four countries is similar, the magnitudes are rather different. In Brazil, incremental costs could be around 10% [1.88/18.89] and the reduction in vector indices varies between 1- and 2-fold,[7] so it seems likely that the intervention could be considered affordable by decision-makers and may also be cost-effective. In Mexico and Colombia, the magnitude of the incremental cost is much greater. In Colombia, the additional costs could represent almost a 4-fold increase while the order of magnitude in the reduction on vector indices could be similar to Brazil.

For the sake of discussion, we can roughly estimate how many dengue cases the intervention has to prevent so the additional costs in vector control are compensated in other sectors of the society through reduced costs of dengue cases (direct medical and non-medical and indirect cost). To do this, we multiplied the estimated incremental cost per house by the number of houses in the municipality to obtain an estimate of the total incremental cost for a full-scale implementation of the intervention. Dividing the total incremental cost by the cost of a dengue case taken from the literature, we obtain the number of dengue cases needed for the intervention to be cost-saving for the society. For example, in Fortaleza, assuming nearly 370,000 houses subject to vector control and given the estimated incremental cost of $1.88 per house and the total cost per dengue case,[32] the intervention would need to prevent around 1,700 ambulatory dengue cases or 732 hospitalized cases to become a cost-saving intervention. How feasible is this? It is hard to say given the uncertainty in the relation between vector indices and dengue cases, but with more than 30,000 dengue cases in an epidemic year (2008, 2011, 2012),[33] it is not completely unrealistic. On the other hand, in the case of Colombia, Ecuador, and Mexico, the interventions would have to prevent similar or more dengue cases in settings with a smaller population at risk. For example, in Colombia, taking the annual equivalent cost of the LLIN and installation ($16.97) as incremental and the cost per dengue case reported elsewhere,[32,34] the intervention would need to prevent around 400–500 hospitalized cases to be cost-saving. That seems harder to achieve considering that the city had 6,751 cases during 1999–2010 (around 563 per year).[35]

Nonetheless, cost-saving is a strong requirement and considering the substantial economic and disease burden of dengue in these countries, there seems to be scope for the cost-effectiveness of the interventions. In addition, the interventions may have other not-so-tangible benefits that are difficult to quantify such as behavioral changes that could lead to improved quality of life ultimately, or the community involvement to address environmental and social determinants of the diseases which could empower them to achieve a self-sustained improvement of their lives.

Conclusions

The interventions discussed in this study generally reduce vector indices[7–11] and thus, they represent a potential improvement over the routine programs in each city. Comparing them to the routine programs, some of those interventions seem relatively affordable (Fortaleza, Salto and CPSC in Machala). These tend to be the interventions that introduce changes to the routine programs such as covering large water tanks instead of using larvicides or getting the community to clean their patios rather than do it through staff (Fortaleza and Salto).

However, there were also new components such as the use of LLINs in Girardot and Acapulco and the DESE component in Machala that certainly would require a considerable financial effort. However, this investment is expected to provide protection for longer periods and could also have an effect in other activities of vector control. The additional costs should be examined in relation to the health benefits and the consequences on the vector control programs, the health care system, and other sectors of the society. Nonetheless, exploratory exercises suggest there seems to be scope for a cost-effective implementation of such new components.

The costs of getting the community involved accounted for a relatively small share of total costs (around 1–2% in Fortaleza [0.33/18.89] and Acapulco [0.49/39.47], 6–7% in Girardot [1.52/21.86] and Machala [0.98/17.33]). This certainly depends on the intensity of the activities (for example, they played a prominent role in Ecuador but not so much in Mexico) but nonetheless results show that the community can get involved in the implementation of vector control measures at a reasonable cost, which may contribute to the effectiveness and sustainability of the interventions.[14,15,36,37] However, the community involvement brings new challenges that go beyond the financial resources like the behavioral changes or the required intersectoral actions required for a successful involvement of the community, and the sustainability of such changes and initiatives.

Limitations

Limitations of the cost analysis were as follows: first, the constraints of the research projects made it difficult to disentangle the costs of the intervention from those of the research, and to compare the costs of an intervention at a small scale (10 clusters of 100 houses each) against the costs of a large-scale vector control program. Second, it was challenging to obtain comparable information from the routine programs, hindering the estimation of an incremental cost in some countries (Mexico, Brazil, and Colombia). Third, given the scope of the data collection efforts for the cost analysis, we used a narrow perspective (vector control program) that excludes the costs of dengue cases and the costs for the community. These may be important given that the interventions involved the community explicitly in its implementation; for example, cost-savings in Uruguay for the vector control program are partly explained by cost-shifting from the program to the community. Such costs should be considered in further research taking care not to adopt a too reductionist approach to measure and value the economic implications of the community involvement.[38] Fourth, the scale of the intervention was not suitable to identify changes in dengue transmission and therefore we had no direct measure of health consequences (nor is it easy to extrapolate given that it is challenging to ascertain a quantitative magnitude for the relationship between vector indices and dengue transmission[31]). Therefore, we set up a cost analysis and not an economic evaluation (e.g. cost-effectiveness, -utility or -benefit analysis),[22] and thus the study provides only limited insight about the efficiency in the allocation of resources. Fifth, we still have no hard evidence on the useful lifetime of LLINs and metallic frames against dengue vector, as this is a relatively new tool; only five studies are found in a recent systematic literature review[39] with none using metallic frames.

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