Incremental cost of implementing residual insecticide treatment with delthametrine on top of intensive routine *Aedes aegypti* control

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Abstract

OBJECTIVE Information on the cost of implementing residual insecticide treatment (RIT) for *Aedes* control is scarce. We evaluated the incremental cost on top of intensive conventional routine activities of the *Aedes* control programme (ACP) in the city of Santiago de Cuba, Cuba.

METHODS We conducted the cost analysis study in 2011–2012, from the perspective of the ACP. Data sources were bookkeeping records, activity registers of the Provincial ACP Centre and the accounts of an RIT implementation study in 21 clusters of on average four house blocks comprising 5180 premises.

RESULTS The annual cost of the routine ACP activities was 19.66 US$ per household. RIT applications in rounds at 4-month intervals covering, on average, 97.2% and using 8.5 g of delthametrine annually per household, cost 3.06 US$ per household per year. Delthametrine comprised 66.5% of this cost; the additional cost for deploying RIT comprised 15.6% of the total ACP routine cost and 27% of the cost related to routine adult stage *Aedes* control.

CONCLUSIONS The incremental cost of implementing RIT is high. It should be weighed against the incremental effect on the burden caused by the array of pathogens transmitted by *Aedes*. The cost could be reduced if the insecticide became cheaper, by limiting the number of yearly applications or by targeting transmission hot spots.

keywords *Aedes*, dengue, residual insecticide treatment, residual spraying, routine vector control, cost, incremental cost, Cuba

Introduction

Dengue has become one of the most pressing health concerns in tropical and subtropical regions. Over the last 50 years, incidence has increased 30-fold and spread out to new regions and rural settings [1]. Among 3.6 billion people living in >100 dengue-endemic countries [1], 284–528 million dengue infections are estimated to occur annually [2]. An average of 500 000 cases of dengue haemorrhagic fever (DHF)/dengue shock syndrome (DSS) [3] and 24 000 deaths [4] are reported each year.

There is no specific drug to treat dengue. A number of vaccine candidates are being tested, but even if they were to be licensed, it would take more than 10 years to make them fully available and to achieve adequate immunisation coverage [5]. Peaks in disease incidence can be expected if vaccine coverage and vaccine efficacy remain low [6]. This highlights the importance of concomitant dengue vector control and immunisation activities once a vaccine becomes available.

Meanwhile, the only available means to reduce transmission remains controlling the main vector, the *Aedes aegypti* mosquito. Attempts at its eradication in Latin America during the 1960s failed, and more than 50% of houses in many endemic areas are infested with *Aedes* larvae [7, 8]. At present, mainly 'classic' vector control approaches such as larviciding in water-holding containers and indoor and outdoor spraying of insecticides against adult mosquitoes are being used. In view of their insufficient effectiveness and sustainability [8–11], control tools such as insecticide-treated materials, lethal ovitraps, spatial repellents, genetically modified mosquitoes and *Wolbachia*-infected mosquitoes are being developed and tested [12]. At the same time, there is growing renewed interest

in evaluating residual insecticide treatment (RIT) [12–14]. Residual insecticides remain active on the surfaces where they are applied for weeks to months and were extensively used for *Aedes aegyti* control in the 1950s and 1960s [15].

The cost and cost-effectiveness of various dengue vector control tools and strategies has been well documented [16–21], but there seems to be no recent published report on the cost of implementing RIT against *Aedes*. We document here the incremental cost of this approach in an environment with an intensive, well-structured *Aedes* vector control programme.

Methods

Setting

Santiago is situated in the south-east of Cuba and has 506 037 inhabitants [22] living in 180 191 premises [23]. *Aedes aegypti* proliferation is favoured by, among others, the presence of on average four water-holding containers of different types in each house [11], high population density, uncontrolled urbanisation, deficient solid and liquid waste management, high temperatures (28–34 °C) and rainfall of 1037.9 mm annually. Despite an intensive routine *Aedes* control programme (ACP), the infestation with *Aedes aegypti* persists, with an average house index for Santiago of 2%, which can be substantially higher at the house block level, leading to sporadic dengue outbreaks since 1997 [24–26].

The present cost analysis study of RIT with delthametrine was set up within a cluster-randomised trial conducted in Santiago de Cuba from March 2011 to October 2012, which evaluated the effectiveness of different tools to control *Aedes aegypti* in addition to existing routine activities. In the clusters where RIT was implemented, the costs of doing so were studied.

Study type, analytic horizon and costed strategies. We carried out a cost analysis from the perspective of the ACP. We estimated the cost of the routine ACP activities and the additional cost of RIT on top of it. The analytical horizon ran from 2011 to 2012 for costing the routine ACP and for four application rounds of RIT.

The activities of the routine ACP, which cover the whole city, have been described in detail elsewhere [18, 20]. In brief, they consist of intensive entomologic surveillance and source reduction through monthly inspection of all premises, larviciding with temephos in water-holding containers, selective adulticiding when *Aedes* foci or dengue cases are detected, providing health education and enforcing mosquito control legislation through fines.

Residual Insecticide Treatment. We used K-Othrine 25 WG bought from Bayer Environmental Sciences Co. The granular 25% delthametrine formulation was dissolved in water (20 g in 8 l of water to treat 200 m², attaining 25 mg a.i./m²). The duration of the residual activity depends on the type of surface treated, but is expected to be 12 weeks on non-porous surfaces if not manipulated. The insecticide was applied by ACP workers in 21 clusters of on average four house blocks each, totalling 5180 premises and 20 720 inhabitants. Spraying started in April/May 2011 and continued in five rounds roughly 4 months apart until the last round was interrupted in October 2012 by hurricane Sandy and could not be completed.

Before the first application, five meetings to inform the target population were conducted and collective community consent was obtained. The individual households could refuse RIT at the moment of each application. Before each application round, ACP workers were retrained to perform the RIT activities in a standardised way, with the support of a short video showing the correct application procedures.

The insecticide was sprayed using the sprinkler ® X-Pert Hudson compression sprayer, which is recommended by WHO for residual treatments, with a 8002 nozzle. Spraying occurred in vertical bands of 20 cm wide, with an overlap of 5 cm, keeping the tip of the sprinkler 45 cm from the treated surfaces [27]. The average house in Santiago has an area of 35 m² (range 30–50 m²): living room, kitchen, two bedrooms, bathroom and a small backyard, where water-holding containers are usually kept. The insecticide was applied on surfaces where the mosquitoes usually rest. Inside the house, this was on under beds, kitchen sink and furniture, at the back of doors (especially bathroom doors), behind refrigerators and inside closets. It was also applied intra- and peri-domestically on the external surfaces of (ground-level) water tanks and on the surrounding wall areas, covering the surface behind the tank and an area of 50 cm on both sides and above it. Insecticide dilution and application were sampled by supervisors to ensure quality.

Data collection and analysis

Data on ACP resource utilisation and cost for routine activities were collected by macro-costing, using book-keeping records and the activity registers of the Provincial ACP Centre. Data on resource utilisation for the RIT activities were collected using forms specifically designed for this purpose. The total amount of delthametrine used and the number of households sprayed were obtained from the registers of the trial and signed-off application forms, respectively.

Costs were classified according to Johns *et al.* [28] by activity and further by nature of the cost. To do so, the ACP routine activities we restratified by larval and adult control and further divided into recurrent and capital cost. The former included labour, larvicides or insecticides, other consumables (i.e. fuels, office and computer consumables) and operations (utilities, transport, meals, maintenance, rent). Capital costs included amortisation of the means of transport, furniture and equipment. Costs of the routine ACP activities not directly related to larval and adult mosquito control, for example administrative cost, were directly allocated [29] to larval and adult control using the human resources mobilised as the key for apportionment. For RIT, we distinguished between insecticide purchase, supportive activities and insecticide application costs and then further divided into recurrent and capital cost.

Capital costs were estimated by annuitising [29] at 3% discount rate, average useful length of life as assumed by WHO-CHOICE [30], 20% scrap value and international market price replacement cost. All costs were collected in national currency (CUP), calculated at 2011 prices and converted to US$ using the official exchange rate of 1 CUP = 1 US$ for goods and a rate of 10 CUP = 1 US$ for salaries, following Rodriguez [31].

We calculated the average annual total cost and cost per inhabitant (p.i.) and per household (p.h) of the routine ACP, overall and for larval and adult control separately. For RIT, the total annual average cost was estimated by averaging the cost of the four full application rounds and multiplying by 3 (the number of rounds in 1 year). The average annual cost p.i and p.h. was calculated through dividing total costs by the average number of inhabitants and households covered.

Ethical aspects

The study was approved by the Ethical Committee of the Institute of Tropical Medicine 'Pedro Kouri', Havana, by the Provincial Health authorities of Santiago de Cuba and by the IRB of the Institute of Tropical Medicine, Antwerp. The delthametrine insecticide is approved for residual treatment by the WHO Pesticide Evaluation Scheme.

Results

In 2011 and 2012, ACP staff visited a household on average 9.18 times per year for larval control and applied 0.79 kg of temephos per household per year, using 0.05 Full Time Equivalent (FTE) personnel. Each house was fogged intra-domiciliary on average 15.18 times per year,

using 0.02 FTE, personnel, 2.08 l of fuel and 0.02 l of different non-residual insecticides. Extra-domiciliary spatial spraying covered each house block in the city on average 6.92 times per year, using 0.22 l of fuel per household per year and 0.003 l of insecticides per household per year.

In 2011 and 2012, the routine ACP expended 3 542 515.72 US$ annually, equivalent to 7.00 US$ per inhabitant and 19.66 US$ per household. About 42.3% of the total annual amount was used for larval control, mainly to pay salaries (26.9% of the total) and for operations (7.0%); 57.7% of the total were expended on *Aedes* adult stage control, where the main costs were other consumables (24.4%, mainly fuels), operations (13.8%), labour (11.3%) and insecticides (7.0%). (Table 1)

The RIT coverage was on average 5033 premises (range 5016–5063 per round) or 97.2%. The average time needed to apply on average 1.16 l (range 0.5–3.0 l) of insecticide mix (containing 2.9 g of insecticide) per application per household was 16.7 min (range 7–44 min). About 42.61 kg of delthametrine was used annually (three application rounds per year; 14.20 kg per application; range 13.76–14.64) with on average 26.39 FTE personnel during 21.7 (range 19–27) work days per round. The average productivity was 8.78 houses per FTE per day. The workers sprayed on average 2.49 (range 0–8) ground water deposits and 21.53 (range 14–43) resting sites per house per round.

The total annual cost of RIT was 15 383.07 US$. Of this, 10 225.80 (66.5%) were used to purchase delthametrine at a CIF price of 240.00 US$ per kg. For both supportive and application activities, the most important cost was labour. The annual cost per household of the RIT was 3.06 US$. This corresponds to 15.6% of the total cost per household of all routine ACP activities and to 27.0% of the cost for adult stage mosquito control activities (Table 2).

Discussion

The annual costs of routine ACP to control *Aedes aegypti* in Santiago de Cuba and of three incremental RIT applications were 19.66 US$ and 3.06 US$ per household, respectively. The largest cost components for RIT were insecticide and labour expenses. Costs amounted to 15.6% of the total annual expenditure per household of all routine ACP activities and to 27.0% of the routine expenditure for controlling adult stage mosquitoes. To the best of our knowledge, this is the only recently published report on the cost and incremental cost of RIT to control *Aedes aegypti* .

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Table 1 Average annual expenditure, cost per inhabitant and cost per household (US$) of the routine *Aedes* control programme (ACP) dengue vector control activities. Santiago de Cuba, Cuba 2011–2012

Activity/Cost item	Average annual total expenditure	Cost per inhabitant (*n* = 506 037)	Cost per household (*n* = 180 191)	% of sub total	% of total
Larval control					
Recurrent					
Labour	954 112.69	1.89	5.30	63.6	26.9
Larvicides	144 377.52	0.29	0.80	9.6	4.1
Other consumables	113 632.88	0.22	0.63	7.6	3.2
Operations	248 107.12	0.49	1.38	16.5	7.0
Capital	39 888.50	0.07	0.22	2.7	1.1
Subtotal	1 500 118.71	2.96	8.33	100.0	42.3
Adult control					
Recurrent					
Labour	400 074.80	0.79	2.22	19.6	11.3
Insecticides	246 566.27	0.49	1.37	12.1	7.0
Other consumables	864 197.79	1.71	4.80	42.3	24.4
Operations	487 319.14	0.96	2.70	23.8	13.8
Capital	44 239.01	0.09	0.24	2.2	1.2
Subtotal	2 042 397.01	4.04	11.33	100.0	57.7
Total	3 542 515.72	7.00	19.66		100.0

We applied the costing method previously used in Cuba, Venezuela and Thailand to report on the cost of *Aedes aegypti* vector control strategies and tools [16, 18, 19]. To convert salaries from the national currency to US$, we used an accepted non-official exchange rate [31], in order to give a more realistic picture of the total costs and of the relative weight of imported goods and to enhance the comparability of our results. We chose to take the ACP perspective and not the societal one because other sectors and the community did not incur additional costs. In other contexts, there could be significant additional costs for other societal actors, especially if the community has to pay for insecticide application.

The cost of the intensive, well-structured routine dengue vector control programme in Cuba is high. The estimates we are reporting here are at the upper boundary of annual cost per household reported for other settings, which ranged from 0.60 US$ in Cambodia to 31.75 US$ in Mexico [16, 17, 19, 21, 32]. However, comparisons are hindered by the different costing approaches used and by lack of detail in some reports. Also, costs vary as a function of the mix, frequency and attained coverage of activities. The main cost drivers for routine control activities in Santiago are salaries and supplies associated with chemical control and the chemicals themselves. This seems common to all ACP, but the Cuban programme invests heavily in larval control activities that make up over 40% of the overall expenditure, while other national programmes mainly focus on adult *Aedes* control, which is less labour-intensive [17, 19].

There are no published figures to compare to our costing results of RIT for *Aedes aegypti* control. Economic studies were conducted on the application of residual insecticides in the framework of malaria control, but the surfaces to be treated are different and more extensive, due to the difference in resting places of both vectors. Also, the number of application rounds per year tends to be small. Still, White *et al.* [33] in their systematic review on costs of malaria interventions all over the world reported that annual costs per inhabitant of indoor residual spraying (IRS), from the provider perspective, can vary from 2.22 US$ to 12.87 US$, depending on the country and the type of insecticide used. For IRS with delthametrine, the annual cost was 3.88 US$ in India, well above the 0.77 US$ for the RIT in Santiago. The main cost in IRS studies was insecticide, on average 49% of the total, which is similar to our results.

The cost breakdown presented here may be valuable for programme planning when considering roll out of RIT regardless of context, but will be particularly useful in settings similar to Santiago. In different contexts a variety of factors that can affect the cost per inhabitant or per household will have to be considered household size, house area, the surfaces – resting sites to be sprayed (which may not be linearly related to house area), RIT coverage, the annual number of applications, the price of the insecticide, population density, remoteness of the area, the number or workers that have to be hired and

Table 2 Average annual cost per inhabitant and per household covered (US$) of the residual insecticide treatment programme. Santiago de Cuba, Cuba 2011–2012

Activity	Cost item	Average annual expenditure	Annual cost per inhabitant	Annual cost per household	% of the total cost
Insecticide purchase (42.61 kg distributed)		10 225.80	0.51	2.03	66.5
Supportive activities					
Community meetings, negotiation with families and informed consent	ACP labour	446.25	0.02	0.09	2.9
	Consumables	150.34	0.01	0.03	1.0
Training	ACP labour	116.73	0.01	0.02	0.8
	Consumables	203.89	0.01	0.04	1.3
Subtotal support		917.21	0.05	0.18	6.0
Insecticide application					
	ACP labour	2710.56	0.13	0.54	17.6
	Consumables	450.00	0.02	0.09	2.9
	Transport	937.50	0.05	0.19	6.1
	Capital	142.00	0.01	0.03	0.9
Subtotal application		4240.06	0.21	0.85	27.5
Total		15 383.07	0.77	3.06	100.0

trained to apply RIT at a specific scale and whether the government, the community or both, will bear the costs.

At any rate, the cost of RIT for *Aedes* control will be high. The annual cost per household documented here is higher than the cost per household of the majority of routine ACPs worldwide. However, it could be lower if the insecticide (the main cost driver) became cheaper, or if the number of applications per year were limited to just before the usual seasonal peak(s), or if transmission hot spots were targeted. Still, the willingness of decision-makers to pay for a RIT strategy, at the appropriate scale, will depend on the incremental cost-effectiveness in any specific setting. Unfortunately, in terms of effectiveness, the impact of RIT on the burden of disease caused by the array of pathogens transmitted by *Aedes* remains largely unknown.

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