Randomized Trial of a Modification of Rainwater Street Catch Basins to Physically Control the *Aedes aegypti* Dengue Mosquito Vector[*]

Modificación aleatoria de sumideros de aguas lluvias como control físico del vector del dengue *Aedes aegypti*

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[*] Research article
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Abstract

Dengue is the most important viral disease transmitted by mosquitoes. Ineffective vector control, cluttered urbanization, poor rainwater and wastewater management and increased air travel have encouraged the proliferation of the *Aedes aegypti* mosquito in Latin America, causing dengue and, more recently, zika and chikungunya, to become widespread public health problems. Vector control has targeted the reduction of breeding sites. *Objective:* For this reason, a randomized trial in a neighborhood of Cali, Colombia, subject to high dengue incidence was carried out. *Materials and methods:* Of 42 selected storm drains, 21 were randomly allocated for the installation of a filter bed that prevents water retention after a rain event (> 100 mm), with the remaining 21 being unmodified. The presence of standing water in the storm drains and the number of *A. aegypti* larvae were evaluated. *Results and Discussion:* Of the 21 modified (5 contained standing water) and unmodified storm drains (19 contained standing water), an Aedic Index (proportion positive for immature *A. aegypti*) of 5 % and 65 %, and a mean number of larvae per storm drain of 3.2 and 31.9, respectively, were obtained. A reduction of 90 % (p-value = 0.016) in the mean number was achieved. *Conclusion:* This intervention was effective against *A. aegypti* and is cost-effective ($< \$2/$ inhabitant), environmentally friendly, and a sustainable strategy for the control of one of the most important breeding sites of this vector.

Keywords: *Aedes aegypti*, physical control of mosquitoes, dengue, rainwater drain catch basins, vector control.

Resumen

El dengue es la enfermedad viral más importante transmitida por mosquitos. El ineficaz control de vectores, la urbanización desordenada, la mala gestión de las aguas de lluvia y aguas residuales y el aumento de los viajes aéreos han fomentado la proliferación del mosquito *A. aegypti* en América Latina, que trasmite el virus del dengue y, más recientemente, el zika y el chikungunya, para convertirse en un problema generalizado de salud pública. El control de vectores se ha dirigido a la reducción de los sitios de reproducción. *Objetivo:* por este motivo, se realizó un ensayo aleatorio en un barrio de Cali, Colombia, sujeto a una alta incidencia de dengue. *Materiales y métodos:* se seleccionaron 42 desagües pluviales. 21 de ellos se modificaron con un lecho filtrante que evita la retención de agua después de un evento de lluvia (> 100 mm) y 21 no se modificaron, esto de manera aleatoria. Se evaluó la presencia de agua estancada en los desagües pluviales y el número de larvas de *A. aegypti*. *Resultados y discusión:* de los 21 desagües pluviales modificados (5 contenían agua estancada) y de los no modificados (19 contenían agua estancada), se obtuvieron un índice Aédico del 5 % y 65 % y un número promedio de larvas por desagüe pluvial de 3.2 y 31.9, respectivamente. Se logró una reducción en el número promedio del 90 % (p-valor = 0.016). *Conclusión:* esta intervención fue efectiva contra *A. aegypti*, y es una estrategia rentable ($< \$2/$habitante), amigable con el ambiente y sostenible para el control de uno de los sitios de reproducción más representativo de este vector.

Palabras clave: *Aedes aegypti*, control físico de mosquitos, dengue, sumidero de agua lluvia, control de vectores.

Introduction

Over the past 50 years, the incidence of dengue has increased 30-fold, and it continues to expand [1]. This has mainly been a consequence of ineffective vector control strategies, disorganized urbanization, and increased air travel, which favor the proliferation of *A. aegypti* in Latin America and the emergence of dengue as a public health problem [2], [3]. In 2016, Colombia reported 97,527 cases of dengue, 19,329 of chikungunya and 8,826 of zika, all three being principally transmitted by *A. aegypti*. The department of Valle del Cauca is mostly first or second in terms of number of cases [4].

A. aegypti develops in a large number of habitats that fill with rainwater, including used tires, disposable food and beverage containers, blocked water channels, discarded containers, storm drains, and construction sites [5]. Vector control has principally sought to eliminate, or chemically treat, these containers which have favorable conditions for mosquito oviposition and aquatic development of immature stages, i.e., eggs, larvae and pupae [6], [7]. When the female mosquitoes emerge, they feed almost entirely on human blood, mainly during the day, both indoors and outdoors [5].

Street catch basins, or storm drains, are structures designed and constructed to capture urban runoff waters, which flow through the roadway channels, and into inspection chambers of the storm drain system [8]. A small amount of water can be retained in these structures for enough time for oviposition and development of different classes of mosquitoes to occur, especially for species of the *Culex* genus. Moreover, in Cali and elsewhere in the Valle del Cauca department, these sites have been colonized by *A. aegypti* [9], but their management has not always been prioritized for control [7]. The objective of the current work was to evaluate the physical modification of storm drains as a control measure of the dengue vector *A. aegypti*.

Materials and Methods

Table 1 shows general characteristics of the city and the study area (Floralia), in southwestern Colombia. This area is near the Cauca River, and has several rainwater channels as well as green areas with suitable conditions for mosquito breeding.

Table 1. General data of the city and study area [10]

Type of data	Information
Area of Cali	21.2 km^2
Inhabitants of Cali	2978,713
Inhabitants of Floralia	48,151
Mean temperature of Cali	25 ºC
Altitude of Cali	~1000 m a. s. l.
Altitude of Floralia	952 m a. s. l.
Mean annual precipitation	900-1000 mm

Source: Own elaboration

Preliminary Study

Data collected from a preliminary study, carried out at the Universidad del Valle, in which two storm drains were evaluated, were taken into account for the design and development of this study. One storm drain was modified by placing a gravel filter bed to prevent water retention and the other remained unchanged [11]. Based on the results obtained, a pilot trial was then carried out.

Study Area

In selecting the study site, we took into account data from the National Health Institute showing that 75 % of dengue cases in 2012 came from 10 departments of the country, among them Valle del Cauca with 7 % [12]. Moreover, this region has been the center of previous dengue epidemics [13]. The city's health department (Secretaria de Salud Pública Municipal de Cali or SSPM) found that in Commune 6, which includes the study area, dengue and severe dengue cases have increased more than expected [10]. Floralia is a residential neighborhood in the north of the city, at approximately 3° 29′ 44.06″ N and 76° 29′ 37.36″ W (figure 1). This neighborhood has 353 storm drains distributed across its area.

Selection of Storm Drains for the Study

The sample size was chosen assuming a 90 % reduction in the mean pupae per storm drain. Further assuming 20 larvae per unmodified storm drain, and a negative binomial distribution with dispersion parameter k of 0.2 [14], a total of 42 storm drains (21 per arm) gave 90 % power for a two-tailed significance level of 5 % [15].

The selection of storm drains was done by assigning a numerical value to each of them on a digital map of the area and allocating them at random, subject to a minimum separation of 70-90 m. Moreover, backup storm drains were identified in case, on visiting the selected location in the field, it did not exist or could not be included for other reasons. However, on one occasion, this backup protocol was not followed, and a replacement drain was selected by convenience, after finding the selected one to be completely sealed. Once identified in the field, the selected storm drains were identified and marked.

Figure 1. Location of the study area-Floralia neighborhood, northern Cali
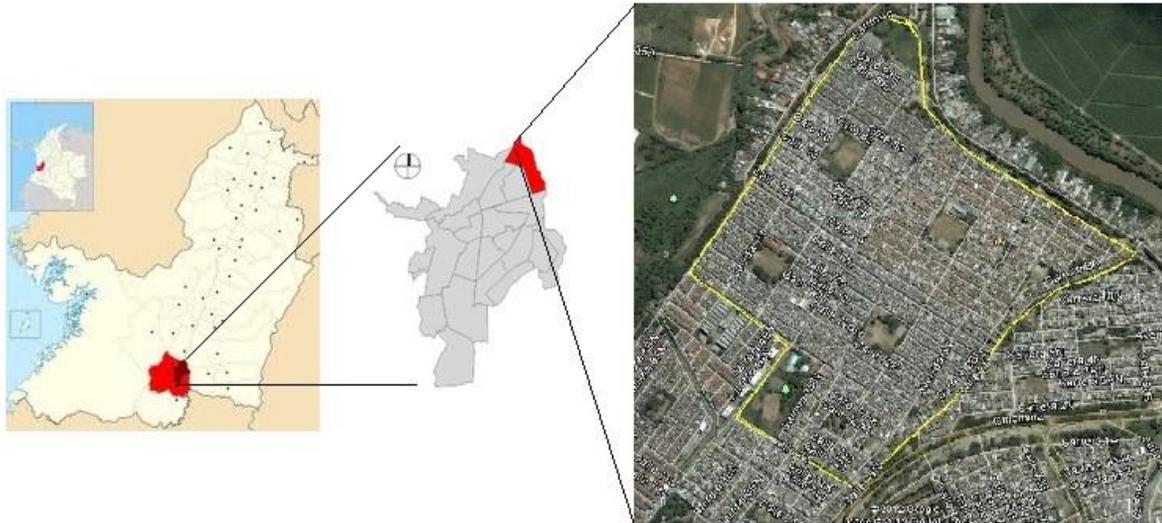
Source: Own elaboration

Modification of the Storm Drains

The modification of the 21 selected storm drains consisted in installing a filter bed in order to avoid accumulation of water in the chamber of the water seal, which works as a mechanism for control of odors of Volatile Organic Compounds (VOCs) released from the sewer. This modification should therefore eliminate the potential of the drain to be a breeding site of the dengue vector *A. aegypti*. The first step was to fix a millimeter ruler in all storm drains, whether modified (M) or unmodified (UM), to determine the water level. For the modification, the overflow screen was drilled at the base, making two rows of holes, each row separated by 10 mm. A total of 15 holes were perforated at a spacing of 30 mm. The diameter of the perforation (15.87 mm) was smaller than the gravel of the filter bed, since the 3/4" gravel at the bottom had an average diameter of 19.05 mm. Once the overflow screen was perforated, geo-textile and hollow bricks were installed at the bottom of the storm drain (figure 2).

Two types of gravel, with a 19.05 and a 9.5 mm diameter, were used. The first type of gravel was placed at the bottom half of the storm drains, according to the height of the overflow screen which varied between 0.50 and 1.20 m, depending on the storm drain. After this, a diamond extruded plastic mesh was installed to separate the next layer of gravel with 9.5 mm in diameter (3/4") and a height of 0.12 m. This process was done in order to provide a filter media and avoid the accumulation of water by allowing a continuous flow of water and at the same time retaining solids inside the storm drain (figure 2).

Storm drain Cleaning

Before performing the physical modification of the 21 storm drains, all 42 selected storm drains were completely cleaned, removing floating solids (e. g., dry leaves, sticks, and solid waste), supernatant water, and accumulated sludge. The drains were then pressure-washed to remove excess grime and any eggs of *A. aegypti* or other insects adhering to the walls.

Figure 2. Storm drain modification process. (a) Screen perforation, (b) Installation of brick and gravel 9.5 mm diameter (3/4"), (c) Installation of the diamond mesh d. Modified storm drain

Source: Own elaboration

Evaluation

The evaluation consisted of the following two components:

1. Presence of standing water in the storm drains
2. Entomological inspection in search of viable *A. aegypti* larvae

This evaluation was to be made after a strong rainfall event (rain intensity greater than 100 mm/hr with a duration greater than 15 min). This took place at the end of March 2013 and the evaluation was carried out in the first week of April 2013, approximately 8 days after the rain event, since full larval development takes 5-7 days in the pertaining temperatures [5], [6] and [16].

Entomological inspections were performed using a larval dipper with a volume of 70 cm^3. Ten samples were extracted from each drain with water, for a total of 700 cm^3/storm drain. Each sample was poured into a plastic tray to facilitate the identification of any mosquito larval stages. A plastic dropper was used to transfer them to Ziploc® plastic bags containing 200 cm^3 of 70 % ethyl alcohol. These bags were sealed and labelled with the date and number of the storm drain evaluated (figure 3).

Figure 3. Collection of larvae and pupae from the evaluated storm drains

Source: Own elaboration

Sample Processing and Species Determination

After sampling, the material was transported to the Entomology Laboratory of the Universidad del Valle, where it was quantified and identified to the species level following the taxonomic keys of Forattini [17] y Gonzales and Carrejo [8]. Finally, for each treatment, the Aedic Index (AI) was calculated, expressed as the number of storm drains positive for immature stages over the number of sampled storm drains (equation 1).

$$AI = \frac{\#\ positive\ storm\ drains}{\#\ sampled\ storm\ drains} \qquad (1)$$

According to the sample size calculation, negative binomial regression was used to analyze the main response variable of larvae per storm drain. The residual deviance was used to assess the fit of the model.

Cost Estimate

Costs of materials, instruments, and labor per modified storm drain were measured and extrapolated to the total cost of modifying all the storm drains in the study area (n = 353). Maintenance costs were not included.

Results

Figure 4 shows that, of the 42 storm drains evaluated, 24 had standing water, and 15 of these were positive for *A. aegypti*. Among modified storm drains, the numbers with standing water and larvae were 5 and 2, respectively. By contrast, the numbers of unmodified storm drains with standing water and larvae were 19 and 13, respectively (figure 4).

Figure 4. Evaluation of storm drains (M: modified and UM: unmodified)
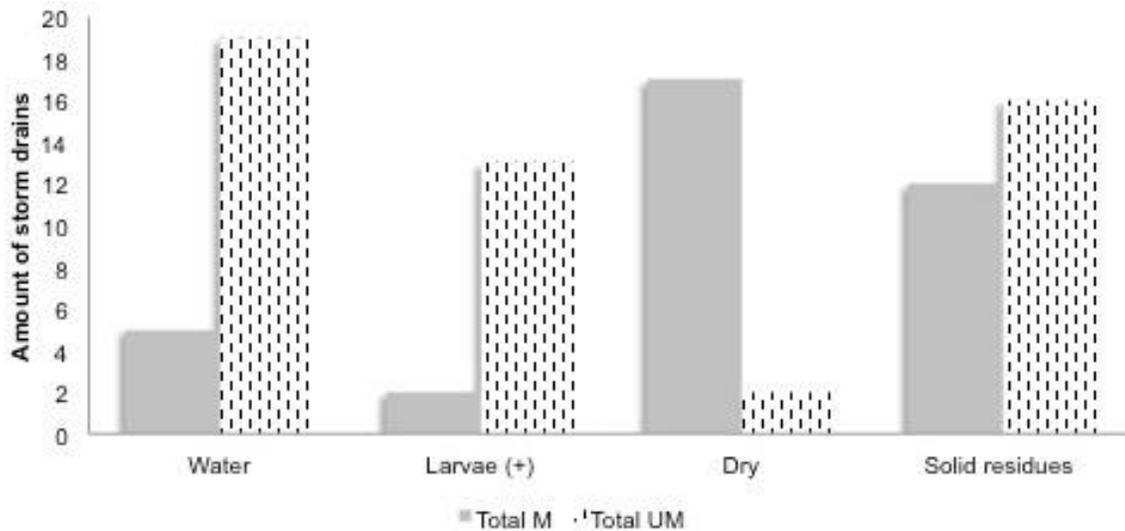
Source: Own elaboration

Modified Storm Drains

Of the 5 modified storm drains with water, two were positive for larvae of *A. aegypti*. In the first one, 38 individuals were found: 14 third stage larvae, 10 fourth stage larvae, and 14 pupae. In addition, 40 larvae of *Culex quinquefasciatus* were found. In the second storm drain, 43 *A. aegypti* larvae were found: 37 second stage and 6 third stage. The remaining 16 storm drains were dry (table 2). For this treatment, the AI was equal to 5 %.

Unmodified or Control Storm Drains

Of the 21 unmodified (control) storm drains, 19 were found to have standing water. Of these, 13 were positive for immature stages of *A. aegypti*. In one of these, 380 individuals were found, representing 56.8 % of the total juveniles found in UM storm drains. For this case, all individuals were in the second larval stage. Densities below 100 individuals were found in the other storm drains. An ecological niche overlap between *A. aegypti* and *Culex quinquefasciatus* was observed, with 6 and 14 individuals present in a single storm drain, respectively. Of the two dry storm drains, one had accumulated a large amount of sand, flushed from nearby construction sites, and the other had been manually cleaned. For UM storm drains, the AI was 62 %.

Table 2. *A. aegypti* found in modified and unmodified storm drains in Floralia

Type of storm drain	Storm drain number	Larvae		Pupae		Total	
Modified (2 positive out of 21)	2	24		14		38	
	16	43		0		43	
	Subtotal	**67**	**(9.1 %)**	**14**	**(60.9 %)**	**81**	**(10.7 %)**
Unmodified (13 positive out of 21)	3	73		0		73	
	6	4		0		4	
	7	380		0		380	
	8	6		0		6	
	11	6		0		6	
	12	10		7		17	
	14	6		2		8	
	15	56		0		56	
	16	52		0		52	
	17	22		0		22	
	19	21		0		21	
	20	8		0		8	
	21	25		0		25	
	Subtotal	**669**	**(90.9 %)**	**9**	**(39.1 %)**	**678**	**(89.3 %)**
	Total	**736**	**(100 %)**	**23**	**(100 %)**	**759**	**(100 %)**

Source: Own elaboration

Statistical Analyses

The average number of larvae per storm drain, including those with zero, was 3.2 in the modified ones, one tenth of the value of the unmodified ones (31.9), that is, a ratio of 0.10 or a reduction of 90 %. Using negative binomial regression, the 95 % confidence interval of the 0.10 ratio is 0.014 to 0.74 (a reduction between 98.6 and 26 %), with a *p-value* of 0.016. The residual deviance was 29.7, which is less than the degrees of freedom of 40, indicating a good fit of the model. This ratio of 0.10 corresponds to the 9.1 % of larvae in the intervention arm shown in table 2: (67/669) / (1 + (67/669)). The 95 % confidence interval for this percentage is from 1.3 to 42.5 %. This indicates that this intervention reduced the proliferation of the dengue mosquito vector *A. aegypti*.

Economic Evaluation

Based on information collected on the costs of materials, tools, and labor per storm drain, an estimate was made of the cost per inhabitant of Floralia (table 1) should the modification be implemented in all the storm drains in the neighborhood (n = 353), the result being USD 1.28 (table 3).

Table 3. Cost estimate for storm drain modification (representative exchange rate of 2013)

Cost	USD
Per modified storm drain	$174.36
Projected cost for all storm drains in the neighborhood (353)	$61,551
Per inhabitant (48,151)	$1.28

Source: Own elaboration

Discussion

The physical modification reduced the potential risk of an outbreak caused by *A. aegypti*, since their Aedic Index does not exceed 4 % [18], indicating that the physical modification is effective to control the breeding sites of the dengue vector and other viruses circulating in the environment (i. e., zika and chikungunya).

The physical changes had a significant effectiveness (p-value 0.016) with respect to unmodified storm drains, reducing standing water events and the presence of the dengue vector mosquito *A. aegypti*, by 80 % and 90 %, respectively. However, an accumulation of solid waste such as leaves and branches was observed in UM storm drains. In this area a large amount of waste is discarded onto the roads, and then swept away by rainwater. This could affect the effectiveness of the filter bed in modified storm drains, due to clogging (figure 4). It was this accumulation of solid waste what possibly influenced the 5 modified storm drains that presented standing water.

In contrast, the unmodified storm drains had a mosquito occurrence of 62 %, since they offer favorable conditions for oviposition and development of the mosquito and are one of the most important sources of mosquitoes in this and nearby towns [9], [19]. The niche overlap between the *Aedes* and *Culex* genera has been previously reported. Carrieri et al. [20] reported competition for food at the larval level between *A. albopictus* and *Culex pipiens*, with the former prevailing. Although two different species are reported in this

research, overlap occurs between these genera, establishing a niche competition that may affect the density of the species involved.

Meanwhile, the local community reported that, due to the high occurrence of mosquitoes, some members of the same community are paid to clean the storm drains. This activity is mainly done during the rainy season when mosquito abundance increases. This explains the presence of a dry storm drain in the UM group, with evidence that it had been manually cleaned.

In the case of unmodified storm drains, the potential risk of a dengue outbreak was high [18], reaching a 65 % probability of occurrence based on the number of larvae found in the storm drains with standing water, which favors mosquito breeding [7], [19].

The economic evaluation showed great potential for the intervention, given the relatively low cost. The cost per inhabitant was relatively low at USD 1.28, which is approximately 2400 Colombian pesos (at the representative exchange rate of the year 2013). However, this only includes the modifications, not maintenance, although the *per capita* total cost would not exceed USD $6 per year.

Conclusions

The physical modification of storm drains with a filter media decreased the larval density of the dengue mosquito vector *A. aegypti* by 90 %, constituting an affordable, environmentally friendly, and sustainable strategy to control one of its main breeding sites.

The modification of the storm drains with respect to the controls yielded an Aedic Index of 4 % compared with the controls with 65 %, indicating that this intervention may be able to reduce dengue transmission and hence possibly also reduce the incidence of dengue cases.

Acknowledgment

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INGENIERÍA Y UNIVERSIDAD: ENGINEERING FOR DEVELOPMENT | COLOMBIA | V. 24 | 2020 | ISSN: 0123-2126 /2011-2769 | Pág. 14