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DengueChat: A Social and Software Platform for Community-based Arbovirus Vector Control

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Abstract. The mosquito *Aedes aegypti* transmits arboviral diseases at extraordinary rates. Dengue alone afflicts 50 to 100 million people each year, with more than 3 billion at risk globally. This indicates that current approaches to prevention and control are inadequate, and that a paradigm shift from one that largely promotes vertical chemical-based control and vaccine development to one that also concentrates on eliminating the mosquito through actions by the communities it plagues is necessary. We have developed a new social and software platform, DengueChat (denguechat.org), to advance community interventions in arbovirus vector control. It is an interactive platform combining open-source digital communication technologies with face-to-face assemblies. It promotes resident participation in evidence collection, reporting, and analysis, and it incorporates pedagogic information, key messaging, and game concepts to motivate communities to implement vector reduction strategies. Using DengueChat, we conducted a 19-month pilot study in five neighborhoods of Managua, Nicaragua. The results strongly suggest that using the software produced value-added features that enhance community engagement. We measured the entomological and behavioral impacts at different time points and relative risk reduction of entomological indices at the end of the study. The entomological results showed significant risk reductions in disease transmission: *Ae. aegypti* larvae and pupae indices were reduced by approximately 44% in neighborhoods using DengueChat during one epidemic year, whereas control neighborhoods experienced an increase of more than 500%. A cluster permutation test determined that the probability of household positivity was significantly reduced in neighborhoods that participated in DengueChat compared with the reference neighborhoods ($P = 0.0265$). Therefore, DengueChat is a promising resource for vector control.

INTRODUCTION

Mosquitoes are the most successful predator of humans on the planet. *Aedes aegypti*, a day-biting mosquito with an extensive global range, transmits dengue, chikungunya, Zika, yellow fever, and other arboviral diseases at increasing rates. It is estimated that dengue alone afflicts 50 to 100 million people each year, with more than 3 billion at risk,[1] thus causing a tremendous worldwide economic burden of more than $9 billion annually.[2,3] There have been two basic approaches to dengue prevention: chemical-based vector control that is "vertically managed" and vaccine development. With chemical-based vector control, government officials focus on reducing mosquito populations through mandatory programs that apply chemicals in and near people's homes without their participation or consent. These programs implement extensive fumigation campaigns, source reduction, and breeding site treatment with larvicides.[4,5] With vaccine development, pharmaceuticals and governments massively invest in the development of vaccines that, despite decades of trials, are difficult to produce effectively and deploy safely. Results of the only licensed dengue vaccine have been disappointing to say the least.[6–8] Although many candidates are in progress, the world still awaits a universal dengue vaccine.

Even where dengue control has been deemed successful, *Ae. aegypti* continues to spread globally and is encouraged by human behaviors and habitats.[9–11] In these circumstances, two types of problems persist. First, the application of larvicides in the most productive breeding containers, the spatial spraying with pyrethroids, and the application of long-lasting insecticides have been inadequate. Mosquitoes have developed increased resistance to these chemicals[12–14]; however, the actual deployment of insecticides is often suboptimal because of budgetary and personnel constraints. Second, our fieldwork data obtained in both Rio de Janeiro and Managua showed that residents frequently do not want government agents inside their homes to apply chemicals, or for any other reason; therefore, they shut them out. Other communities showed decreased community involvement when spraying campaigns were conducted.[15] Both factors lead to failures in prevention. Moreover, failure politicizes arboviral disease and puts governments on the defensive. Therefore, the need for improved *Aedes* surveillance data for better dengue control is a common denominator in most countries battling the disease.[16]

These conditions require a paradigm shift in prevention from one that largely promotes vertical chemical-based control and vaccine development to one that also focuses on eliminating the mosquito through actions by the communities of the residents it affects.[17] Therefore, it is encouraging, that the WHO and Pan American Health Organization (PAHO) recognize that the most sustainable approach to curb arboviral disease is to develop "integrated vector control strategies."[18] These include promising initiatives that focus on the reproductive modification of mosquitoes to inhibit their ability to reproduce or transmit arboviruses.[19–21] They also recommend engaging municipalities for improved environmental management, including refuse and water services and, more importantly, incorporating community mobilization as a key component. In practice, however, despite the early success of strategies like COMBI[22] and Patio Limpio[23] in Latin America, community interventions based on how residents live with mosquitoes have received much less attention and investment during the past decade.[24–26]

Researchers also suggest that new digital communication technologies involving residents could provide significant

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opportunities to reinvent arbovirus control.[17,27,28] To date, these technologies overwhelmingly focus on mapping and reporting. Some also involve the diagnosis of symptoms and transmission modeling. Examples include DengueME (modeling and simulation of outbreaks),[29] Dengue Track (mapping cases and outbreak predictions; www.Breakdengue.org), Kidenga (reporting of cases and mosquito presence and aggregation of information),[30] Premise (heat maps for operationalization of vector control; www.Premise.com), and others. However, none of these solutions mobilizes residents to take charge of the dengue problem in their community or to become the agents of what we call community-based entomology. Moreover, there is little to no evidence that maps by themselves motivate people to take action resulting in the reduction of dengue risk; rather, they seem more useful for policy and planning intervention. Although mapping and reporting are certainly fundamental in any integrated approach and have proven crucial for malaria intervention planning,[31] they do not, by themselves, diminish risk or proactively engage residents in prevention. As a result, the proposed integration of community engagement in vector control strategies has not yet materialized at scale, residents do not participate systematically in risk reduction, and prevention strategies remain unfulfilled.

To advance community engagement in preventing arbovirus disease, the Social Apps Laboratory and the School of Public Health at the University of California, Berkeley, have developed a new resource called DengueChat (denguechat.org) (Figure 1). DengueChat is an interactive social and software platform designed to motivate residents to identify and eliminate mosquito breeding sites. In collaboration with the Sustainable Sciences Institute in Nicaragua, we implemented DengueChat as a pilot study in Managua, Nicaragua, from 2014 to 2016, and obtained remarkable results. This article focuses on the design, implementation, and results of that study. DengueChat combines open-source digital communication technologies (both web and mobile) with face-to-face assemblies. It promotes resident participation in evidence collection, reporting, and analysis, and it incorporates pedagogic information, key messaging, and game concepts to motivate communities to implement arbovirus vector control without the need for pesticides or larvicides. We initially tested DengueChat in Rio de Janeiro (Complexo da Maré), Brazil, in 2013; then, we deployed it as a pilot study in Managua from 2014 to 2016. Since then, several of the intervention neighborhoods in Managua continue to use it systematically to reduce dengue infestation. In addition, its use for dengue control has expanded to Asunción, Paraguay (2017–2019),[32] and it is used for Zika control in Nicaragua (2017–2019).

The fundamental premise of DengueChat is three-fold: reducing entomological indices through sustained community engagement results in significant reduction in arbovirus risk at neighborhood levels; communities affected by arboviral diseases are the best sources of information regarding positive and potential mosquito oviposition sites and, therefore, the best agents for their elimination; and using the software in combination with face-to-face organization significantly enhances community mobilization to eliminate mosquitoes. The first component is based on Camino Verde[33] and Socialization of Evidence for Participatory Action (SEPA)[35] methodologies. Together, the three components constitute an initiative involving residents using DengueChat and becoming essential participants in data collection, analysis, and action. Moreover, DengueChat considers that residents collectively "own" the data they collect. In effect, it approaches arbovirus vector control as a problem of social mobilization and collaborative deliberation. The challenge is to translate residents' knowledge of their neighborhoods into specific data of vector control as a means to motivate them to act.

DengueChat makes a case for "integrated vector control" as a community initiative that could be integrated within a toolbox of different strategies. Its contributions include sharing data that communities gather and vector management that they perform. Our view of "integration" does not

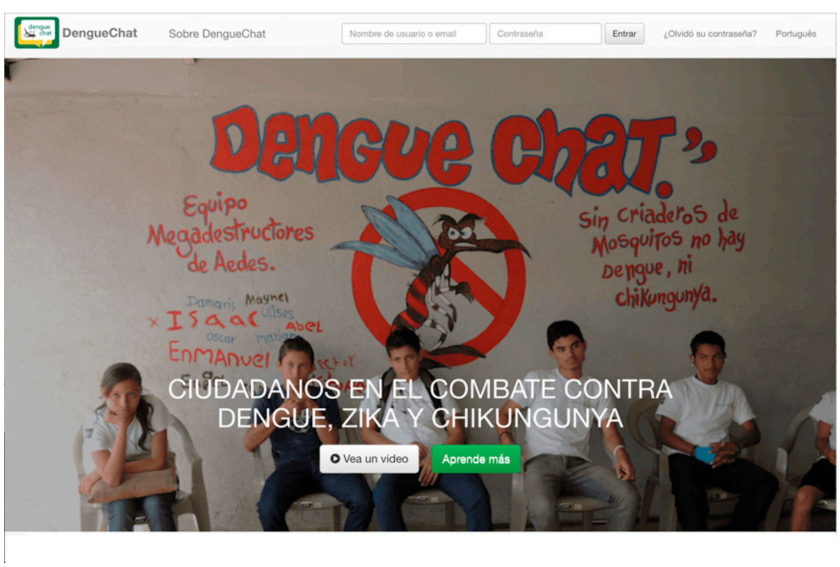

FIGURE 1. Landing page of denguechat.org where users log onto the platform. Brigadistas (shown) participating in the Nicaragua study created the app logo (upper left) and the mural in the background.

presume, for example, that residents will participate in government programs of larvicide application. Instead, DengueChat proposes that residential communities must be integrated in vector control programs as essential, collaborative, and active participants who contribute their own coordinated efforts to dengue prevention that are usually pesticide-free.

Implementing this approach, we conducted a 19-month pilot study of DengueChat in Managua from October 2014 to May 2016, within the existing social framework of community-based volunteer youth brigades for "Health and Life." The pilot established a baseline entomological assessment before the deployment of DengueChat in five intervention neighborhoods and five control neighborhoods without the intervention. Subsequent entomological assessments measured the impact and showed significant risk reductions.

DengueChat combines scientific significance and behavioral impact. Our results suggest that this type of interactive social and software platform has considerable promise for mobilizing people to engage in civic action to address many types of local issues in addition to arbovirus vector control. Here, we present the methods and results of the pilot study in Nicaragua and discuss issues of social mobilization, technology for community engagement and education, sustainability, and scale.

METHODS

DengueChat Platform. The DengueChat platform is both socialware and software. Here, the term "platform" emphasizes the construction of both a structure and an opportunity (as in a platform for public discussion) that incorporates multiple resources for specific purposes. The term "socialware" emphasizes that DengueChat is based on a social model of a particular type and is intended for a particular purpose, namely, to organize the participation of residents in arbovirus vector control.

When constructing DengueChat, we developed five components to guide the articulation of socialware and software based on the experience of Camino Verde, our own research of direct democracy, and our development of social app technology[36]: (1) a social model of community organization that continues to evolve through field collaborations; (2) an intervention plan that emphasizes the participation of residents in data collection, analysis, and action; (3) a software application that articulates the social model and intervention plan and includes an evidence-gathering protocol based on house visits; (4) a commitment to collaboration in research, pedagogy, and development that involves residents and other field associates; and (5) close attention to the politics of implementation.

The software consists of a website, a mobile app, an Application Programming Interface, and a database layer. It features two "sides" that have distinct but related user–interface experiences, each with a main user group in mind. One side, DengueChat Community, engages organized residential groups with the aim of educating and mobilizing community residents in mosquito vector control. It has familiar social network characteristics but includes specific feedback to encourage social behavior change for vector control. It allows individuals and organizations to interact through blog posts, win points earned for vector elimination and container management, and obtain reports of the efficacy of their work to reduce mosquito infestation. The other side, DengueChat Data, stores and organizes the wealth of data that residents collect and makes that data available to researchers, community leaders, and public health officials for analysis and decision-making. It maintains a detailed registry of neighborhoods, house visits and inspections, and the status of individual breeding sites (e.g., barrels and tires) identified and labeled in DengueChat Community. It offers complex search functions with spatial and temporal parameters for inquiries and reports. These two sides interact to produce the software workflow (Figure 2).

The foremost element of the social model is the determination of a form of assembly-making among residents capable of articulating through direct deliberation specific variables regarding the evidence of mosquito infestation and prevention activities aimed at specific locations. Examples of such assemblies include local brigades, youth clubs, school groups, neighborhood associations, religious congregations, and sport teams. Therefore, the implementation of DengueChat requires ethnographic knowledge of the communities that intend to use it and a focus on social organizations, political structures, and cultural values.[37] DengueChat cannot be parachuted into neighborhoods. It is not a scheduling utility, social media, or a reward-based virtual game; however, it has elements of all three. Moreover, it focuses on the digital and face-to-face mobilization of residents. The social modeling derived from knowledge of the locals must orient both facets.

A key element of the social model of DengueChat is talking, in its multiple forms of chatting, conversing, socializing, and reporting about dengue and its mosquitoes among all who participate. This ongoing dialogue occurs both online and offline. Therefore, DengueChat emphasizes talking with residents in their homes about the life cycle of *Ae. aegypti*—of which most know very little as a baseline Knowledge, Attitude, and Practices survey indicated—to establish the link between water, refuse management, and vectors; this key message was established in Camino Verde.[35] It also emphasizes online blog posting. These different types of offline and online talk constitute opportunities for participants to act on speech formulated within, broadcast from, and publicly visible on a platform dedicated to arbovirus disease prevention. It provides a stage where they become the agents of dengue control and are recognized for it.

The significance of "talk" for community-based arbovirus control is evident in the name of the platform itself. Holston originally named it "DengueTorpedo" when he launched it earlier in Rio de Janeiro. "Torpedo" means both "SMS text message" and "torpedo" (a weapon) in Brazilian Portuguese. However, when the project moved to Managua, Nicaraguans did not think "torpedo" was appropriate because, in their Spanish language, it does not mean "text message"; it only means a weapon of war. Therefore, they felt that it contradicted the idea of citizen action for public health and suggested changing the name to "chat," which in their Spanish, means both a conversation and a text message (i.e., both oral and digital speech). Renaming the platform "DengueChat" was one of the first collaborative contributions of the Nicaraguan community partners.

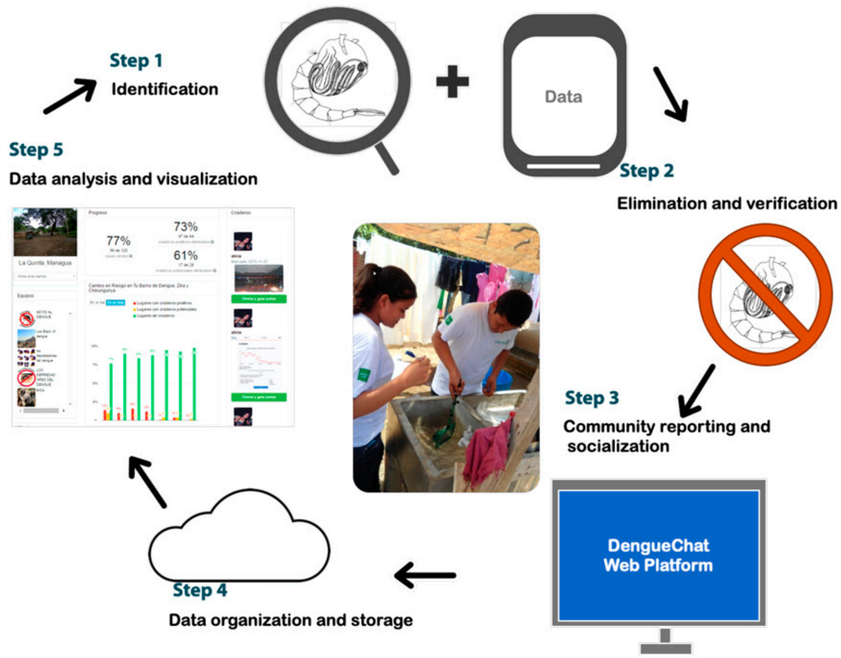

FIGURE 2. DengueChat Workflow. Step 1: Brigadistas identify *Aedes* breeding sites and collect house-level data using smartphones or paper registries. Step 2: Residents eliminate breeding sites that brigadistas verify during house visits. Step 3: Entomological and other data are uploaded to the website and brigadistas use the social platform to chat about their findings. Step 4: DengueChat cloud computing sorts, stores, and processes the community-collected data. Step 5: DengueChat displays the data in color-coded graphs representing neighborhood risk (% of households positive, negative, or potential for *Ae. aegypti*). This figure appears in color at www.ajtmh.org.

Therefore, DengueChat emerged from conversations about design and a collaborative process of development. Both are based on ethnographic experiments in the field—for example, which names are meaningful, what local organizations are effective, which channels of political power are receptive, how best to collect data, and how to engage residents in discussions about the life cycle of the mosquito. These ethnographic investigations establish the social model and its relation to the digital.

Study Design. We launched an initial 4-month feasibility study in Managua from October 2014 through January 2015. The objective was to implement DengueChat in neighborhoods that exhibited a range of dengue risk, work with resident feedback, and adjust the protocol and platform accordingly. We selected a set of neighborhoods in districts 1, 5, and 6, which were low socio-economic areas heavily affected by dengue, chikungunya, and, later, Zika. Selection was performed in consultation with the staff of the Sustainable Sciences Institute based on their prior work and knowledge of neighborhood organizations that might be interested in the project, local political leaders who might support it, and residents who might become facilitators. The key selection criterion was that neighborhoods actively sustain Brigadas de Salud y Vida (Brigades of Health and Life), which is a legacy of the Sandinista political mobilization in the 1970s and today involves decentralized components of the national government's health model "Modelo de Salud Familiar y Comunitario" instituted in 2007.

We presented DengueChat to the political leadership of four neighborhoods. Three committed to the feasibility study: La Quinta Pacheco (District 6); Francisco Meza (District 1); and Ariel Darce (District 5). Matching control neighborhoods in the same districts (similar geographic location, water service regularity, social organization, size, dengue risk, and others) were selected for impact measurements and comparisons. Each neighborhood in the study had its own resident DengueChat volunteer brigade led by a facilitator hired by the project who invited community residents to join (Supplemental Figure 1). The project supplied basic mobile phones for each brigade member, an Android-enabled mobile phone for each facilitator, and a tablet and smartphone for the project coordinator. It also placed one desktop computer and printer per neighborhood in the home of each facilitator as an "internet café" for community use.

At the conclusion of the feasibility study, two small neighborhoods, Tangaré and Galope, adjacent to La Quinta in District 6 were added, with one brigade. We deployed DengueChat in these five neighborhoods for the next 14 months, from February 2015 through March 2016, encompassing a full epidemic year. Including the feasibility period, the project encompassed two rainy seasons and two dry seasons.

House Visits. DengueChat activities focused on household visits initiated with an evidence-based dialogue between brigadistas and residents that centered around the mosquito life cycle, followed by the identification of key breeding sites and water containers inside and outside the home. We developed the organizational design of the visits with the direct involvement of the coordinator and facilitators and based on the SEPA and Camino Verde models. Each brigade took responsibility for a set of approximately 120 houses in its neighborhood, completed an inspection of each home in search of water containers and receptacles, taught residents how to identify both positive and potential breeding sites and how to eliminate them, and revisited the homes regularly (weekly or bi-weekly) to continue the dialogue and determine if residents had incorporated new specific practices aimed at removing and preventing larval habitats.

Brigade members were deployed in pairs, assigned specific houses in a square block, and instructed to follow a detailed inspection protocol during each visit. At the front door of their assigned houses, they introduced themselves to residents during the initial visits by engaging in a conversation about dengue and especially about the life cycle of *Ae. aegypti*, which was illustrated on the DengueChat t-shirts they wore and on handouts. If possible, demonstrations with live larvae and pupae captured in prior house visits were performed (Supplemental Figure 2). Because they were neighborhood residents themselves—the youth of the community—they encountered little difficulty getting invited inside homes. Their objective was to accompany residents in the process of inspecting water containers for the presence of immature forms of *Ae. aegypti*, especially pupae. Because counting *Ae. aegypti* pupae in the context of demographic surveys is a reliable method of estimating the relative abundance of the adult mosquito populations,[38–40] the entomological inspection largely focused on finding live pupae. Although there are limitations to using pupae indices, especially with small samples because of their sensitivity to sampling error, we chose the presence of pupae because it is clear evidence of the lack of prevention measures for at least 1 week before the emergence of adult mosquitoes.

The intervention protocol of house visits required brigadistas to start in the yards typically found in the front or back of houses and to conduct their accompanied visit as consistently as possible by inspecting in a clockwise manner, checking both high and low places, and then moving inside the home (Supplemental Figure 3). They focused on water storage (especially the ubiquitous and often uncovered 54-gallon barrels), abandoned tires, wash basins, animal feeding dishes, plastic containers, and plant pots. The barrels and tires were found to be the most productive for immature *Aedes* forms. The protocol specified that when they found a larva or pupa, they were to capture it in a hand net, put it in a transparent plastic bag with water, and use the wiggly insect to teach residents about the vector's life cycle. As time went on and residents became more familiar with the work of DengueChat brigades, inspections were completed in less time.

The brigadistas also demonstrated specific control actions to protect water containers and best practices to control or remove other sources of standing water. These methods mostly focused on weekly scrubbing of barrels to remove eggs from their walls, proper sealing of barrels with lids, disposal of plastic and unused containers, and protection of or filling of tires with sand or soil. They supplied free barrel covers that were manufactured locally of mesh or permeable vinyl and asked residents to sign a pledge to use them. Residents assumed responsibility for performing the suggested control actions at least weekly, and the brigadistas verified their activities by conducting regular re-visits at least once per month and often every 2 weeks. The brigadistas earned online points for each visit and for the actions taken by residents, which were automatically added to their DengueChat profile. They earned additional points when homes remained free of positive and potential breeding sites for 2 consecutive months of brigade inspections, achieving "green house" status.

Report, Verification, and Data Upload. The study design provided three ways for brigadistas to collect and record their observational data. With permission from residents, they used their mobile phone cameras to photograph positive and potential breeding sites. The procedure required taking a photograph of either type of container before and after an intervening action to eliminate it, and then taking a follow-up photograph during a subsequent visit. This set of before-and-after photographs constitutes a verification step. As they circulated clockwise through the house, brigadistas marked and noted each barrel and tire inspected with a unique identifier, thus creating a historical registry of the status of these two types of most productive containers that could be followed over time (Supplemental Figure 4). During subsequent visits, brigadistas checked each labeled container and annotated its status.

Brigadistas made their annotations of various data points on a one-page house visit registry form based on research of the local classification of seven types of water containers most at risk for being converted into larval habitats; namely, barrels, tires, pails, wash basins, flower pots/vases, usable plastic receptacles (dog dish, bird feeder), and unusable plastic refuse (empty bottles, caps, etc.) (Supplemental Figure 5). The registry also captured the presence of larvicides applied by the government agency and present at the time of inspection in water containers. We developed the paper-based format because most residents did not have smartphones and WIFI to work with when in the field. Therefore, the brigadistas were to walk through the house, take photographs with their cell phones, and record data on the form. Each house visited had a unique coded registry form with information entered as 0 for no and 1 for yes for ease of completion of data cells that included permission to enter, inspection date, recent cases of dengue and chikungunya (self-reported), type and location of containers with water (each coded and barrels and tires numbered), whether covered, whether chemically treated with larvicide (*abate*), number of larvae, number of pupae, whether photographed, date and photograph of elimination, and comments. At the end of an inspection day, each brigade returned to its facilitator's home or community center, where it conducted a "*socialización*" (socialization) meeting (horizontal dialogue) to discuss the day's work. Volunteers manually uploaded the form data and the photographs to the desktop computer, and then through a batch upload to the DengueChat website through a batch upload (a kind of vertical dialogue). Data uploads were double-checked by the brigade facilitators and later audited by the project coordinators for accuracy.

Uploading distributes the data into various pages on the website. Some provided tabulations and visualizations only to coordinators, facilitators, and other researchers with login permissions (DengueChat Data), and others provided access to all users (DengueChat Community). For each container with water (potential larval or breeding site), all users saw a report that displayed a thumbnail photograph of the brigadista responsible for the home where it was identified. This photograph linked to their profile page, and its type, description, date of inspection, photograph, and status as potential (orange), positive (red), or eliminated (green). The status section in each report lists changes chronologically by date and color so that it is easy to see at a glance the history of each breeding site and to know, for example, if a positive container has been eliminated and if it has become potential or positive again. Reported breeding sites were linked to the neighborhood page where infection risk was assessed statistically (Figure 3).

Entomological Assessments. Four entomological surveys—one at baseline and three for monitoring and impact measurement—were conducted by professional entomologists trained by the Ministry of Health. Each included approximately 100 households per neighborhood and assessed stegomyia *Ae. aegypti* indices. During the surveys, the entomologists collected larvae and pupae samples, determined and classified species, counted numbers, and annotated the immature forms. They calculated the classic Breteau, container, house, pupae per household, and pupae per container indices. They obtained information regarding the presence of Temephos in barrels and the frequency of visits by government campaigns. They also gathered information regarding some social issues, such as knowledge about the life cycle of *Ae. aegypti*, technology use, and dengue transmission. The baseline measurement occurred in October 2014 during the rainy season before beginning DengueChat activities in the three districts. After the feasibility phase, another entomological assessment was performed in March 2015 (dry season) in each of the five DengueChat and five control neighborhoods. Baseline entomological measurements were used to determine the most productive containers in households and yards, which were understood as those that contain the greatest number of immature *Aedes* forms. These containers (plastic refuse, abandoned tires, and especially uncovered clean water storage barrels) became the focus of DengueChat activities.

After 1 year of intervention, in March 2016, a third entomological impact survey was conducted in all 10 participating and control neighborhoods. The study ended officially after this measurement, and payments to the project coordinator and facilitators stopped. However, they and the community health brigades continued to use DengueChat in three of the five intervention neighborhoods for at least the next 9 months with similar intensity. A fourth and final entomological survey including adult mosquito collections was conducted in November–December 2016 during the next rainy season in these three neighborhoods to assess poststudy impact sustainability.

Statistical Analysis. We measured the effect of using DengueChat at 18 months after the initiation of activities. We estimated the relative risk reduction (1-relative risk) for the intervention group as compared with the reference group for all the entomological indices calculated from larval and pupal counts. Following the Camino Verde approach for estimatimg its impact on household positivity per neighborhood, we performed two statistical tests to estimate the effect of DengueChat at the household level, accounting for neighborhood. First, we performed a cluster t test to determine the difference in household index positivity between the intervention and control with the neighborhood as the unit of analysis. We included weights in the t test to account for differences of households measured in each cluster at the time of the entomological survey. Second, we performed a clustered permutation test to evaluate the effect of the intervention on household positivity. We performed the analysis with the cptest function in the cvcrand package in R.[41] We accounted for variables previously identified by Andersson et al.[42] to independently affect household entomological status. The variables included were number of houses evaluated in each neighborhood, water access, *abate*, and community organization. For the permutation test, we compared

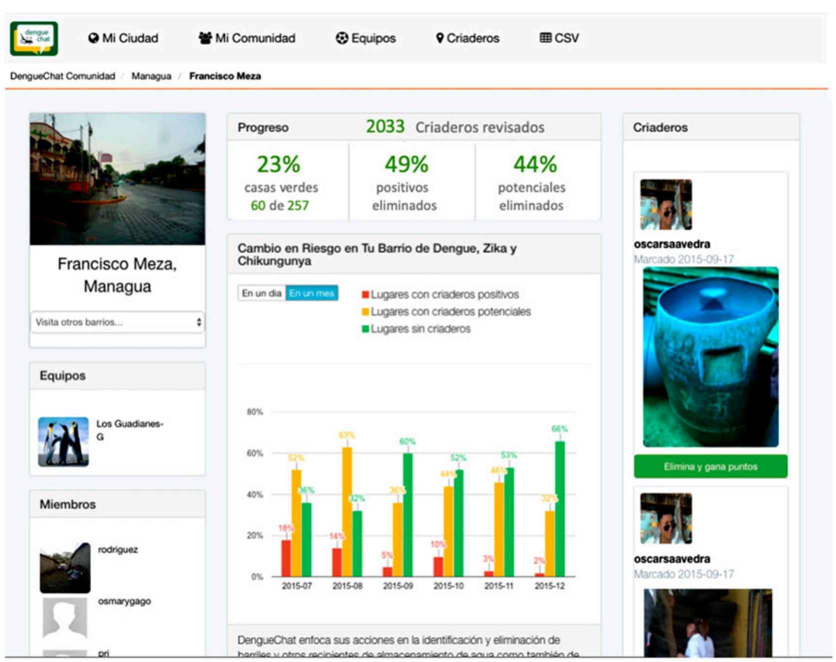

FIGURE 3. DengueChat assesses entomological risk in two ways, as shown for a study neighborhood. A bar graph displays percentages of homes that are positive (red), potential (yellow), and green for each house visit. Progress in community prevention is shown as percentages of green houses achieved and positive and potential breeding sites eliminated. The total number of container inspections is also provided. In addition, the page shows team members and blogs.

the final randomization scheme selected for intervention and control to the null distribution composed of randomization schemes with a similar balance of the covariates known to affect outcomes independently.

Human Subjects. Most of DengueChat technology development and implementation are exempt from human subjects review. However, the relevant components of this project that included human subjects research such as household Knowledge, Attitude, and Practices surveys and focus group interviews received approval from Committee for the Protection of Human Subjects (CPHS) at UC Berkeley (under protocols CPHS# 2010-05-1596 and CPHS# 2016-09-9137), as well as from the Nicaraguan Committee for Human Subjects Research of the Ministry of Health (CIRE) (under protocol #CIRE-28/09/18-094.Ver1).

RESULTS

During the 19 months of deployment, the pilot study reached approximately 4,000 residents in five neighborhoods and regularly monitored 3,200 water barrels, hundreds of tires, and thousands of other containers during 7,300 house visits. The data gathered by brigadistas captured consolidated neighborhood information focusing on the entomological status of inspected containers, with an emphasis on water storage barrels and tires and the actions taken to control or remove them. The following analysis of results considered social factors of mobilization, the value added by the software, collaborative design, entomological impact, validation of community data, and sustainability.

Socialization and Motivation. The development of the DengueChat platform—both its social and software—provoked and responded to four kinds of considerations among participants: the socialization of evidence, motivation, collaborative design, and the value of using the software for all three. We used the SEPA concept of "socialization of evidence for participatory action" to emphasize the importance of evidence-based discussions to motivate residents to take actions regarding vector control.[35,42,43] These discussions consisted of various forms of "chat" that residents have with each other and with nonparticipants (e.g., health officials and politicians) about the evidence of mosquito infestation that the brigadistas find. Participants used the term *socialización* for the in-person assembly they conducted after each session of house visits (Supplemental Figure 6). During the assembly, brigade members reported to each other what they found, how they related to residents, what problems they encountered, their assessment of neighborhood risk, and other information. It is important to highlight that DengueChat added online socialization of evidence to SEPA's traditional in-person assembly because brigadistas also provided these reports to a much larger audience in their blog posts.

Other forms of online and offline socialization were also important. They included discussions among facilitators and brigadistas about the science of arboviral disease and control practices, as well as the informatics of the software platform and its management of data. Both occurred during the assemblies and in the blog posts, and both the science and the informatics retained the attention and commitment of the adolescent brigadistas, male and female, some of whom stepped forward to become reliable spokespersons about these twin aspects of DengueChat. In addition, the facilitators hosted periodic community events for all the brigades during which brigadistas created vignettes, dances, *piñatas*, and posters, and residents and community leaders talked about what they had learned. Throughout the Managua study, brigadistas made videos and different kinds of artwork from murals to rap to graphic novellas, some of which were posted to the website where they generated more conversation (Figure 1). We found that these online and offline socializations of evidence gave residents confidence to learn about arbovirus disease and fight the mosquito with particular actions. This realization transformed them from victims of disease into proud agents of prevention who could achieve source reduction with their own resources.

Additionally, DengueChat deployed a number of socialization strategies to motivate residents that are specific to the software and demonstrate its merits. A crucial one is to display the results of residents' efforts as quickly and directly as possible. Therefore, the DengueChat website shows this "return on investment" by providing easy-to-interpret graphic representations of infection risk in a neighborhood. These are based on the number of houses with positive (red) and potential (yellow) breeding sites and the number of green houses without either for more than 2 consecutive months, which each brigade found during a session of house visits. A positive breeding site is one that has either larvae or pupae at the time of inspection; a potential breeding site has water and is not protected at the time of inspection. Using this "traffic light" color scheme, the results of a day's work are visualized in real time. As these data are uploaded, DengueChat generates two kinds of graphic risk analysis: "change in risk over time in your neighborhood for dengue, Zika, and chikungunya" and "progress" (Figure 3).

The first is based on the classical entomological "house index" with bar plots either by month or by day of the number of houses with positive or with potential breeding sites, with each bar also giving additional information about prevention efforts. The second assessment of risk, "progress," displays the following variables: the percentage of breeding sites eliminated that, at any time in the past, had been identified as positive or potential in relation to the total number of positive or potential breeding sites discovered; and the number of green houses among the total number of houses assigned to the brigades in a neighborhood.

These real-time website assessments of risk became the focus of considerable community interest and conversation because residents turned to them to demonstrate the efficacy of their efforts. They provided snapshots over time of the entomological risk that the brigades found in the neighborhoods and houses they visited. They did not presume to do more, for example, to address epidemiological conditions in the city or indicate the entomological risk for areas greater than the neighborhoods defined by the blocks and houses assigned to the brigades. Because "red" does not mark or identify individual houses on the website, but rather a community problem, we did not find any stigma attributable to DengueChat among community members who the brigadistas documented to have positive sites. To the contrary, we found that the identification and broadcast by the website of a community problem increased solidarity to focus collective action.

In the absence of smartphones and WIFI sync, the uploading of collected data was the most labor-intensive aspect of the protocol during the pilot study. Nevertheless, the volunteers always seemed eager to work on the computer, and their job became much easier after we perfected batch uploading of the house visit forms. Processing the photographs, however, remained laborious, and eventually the brigadistas fell behind uploading the photographs with their associated data forms. During approximately the fifth month of the pilot, we discussed the problem with all facilitators and unanimously decided that the form data on each container provided sufficient verification of its status and that, therefore, we could eliminate the requirement to upload the before-and-after sequence of photographs. Brigadistas still took many photographs, but they mostly uploaded them to their blog posts and less often to the "Breeding Sites" page of the website. We continue to think that this decision was justified because the data on the paper forms were detailed and reliable and because data entry—probably the greatest source of error—was regularly double-checked. Using a smartphone app with embedded digitized forms to record both photographs and data points and using WIFI autosync with the website database would make these aspects of data collection and reporting easy to accomplish. Developing such an app was not possible at the time of the pilot because of the lack of smartphones and WIFI in Managua. However, we have since developed an app and deployed it during the Asunción, Paraguay study.[32]

Although laborious, the manual collection and reporting of the data remained viable, reliable, and systematic throughout the Managua study. The protocol mobilized residents for face-to-face interactions and for using the software, both of which engaged them with evidence, education, and documentation. As a result, these two components of the DengueChat platform functioned as intended to mobilize community members for vector control. Moreover, the software component significantly amplified these results. DengueChat Community engaged social conversations and actions about dengue, chikungunya, and, later, Zika, reported other activities in the neighborhoods, and served to recruit new users. DengueChat Data captured information about the status of inspected containers and the actions taken at both the detailed house level and the consolidated neighborhood level.

The software promoted two additional strategies to motivate participants: certain kinds of "gamification" and Internet recognition. We found both to be effective, especially among younger participants. Opportunities to earn fame as a "dengue warrior" or "mosquito killer" (or whatever other denominations participants invented) are internal to the website and occur through three features: blog posts, green houses, and individual profiles (Supplemental Figure 7). The blog posts and their threads of comments appear prominently on the city and neighborhood homepages. One look reveals that participants of all ages among the brigadistas, facilitators, and coordinators used them enthusiastically for both social and data communication. They used them as social media to communicate about many subjects through text and photograph, such as birthdays, hangouts, social relationships, brigade activities, neighborhood stories, and barbecues, all of which promoted social cohesion in the brigades. They also used the blog posts to communicate about data collection and dengue risk. They reported house visits, enumerated findings, illustrated with photographs, identified problems, discussed remedies, and commented on the "work ethic" of making neighborhood rounds. The posts manifest the pervasive pride that the bloggers shared in being brigade members engaged in a community project of disease prevention. They also showed a keen sense of individual accomplishment because bloggers associated with many posts become prominent names in the world of DengueChat.

The website promotes this recognition by displaying on the homepage of each city where residents are using DengueChat a profile photograph of the top 10 brigadistas as measured by the number of green houses they have each maintained. The display shows the points earned (200 points per green house) and a bar graph of the total number of green houses by week over several months. We found a strong sense of competition among the participants to win points for maintaining green houses, and we found that this competition increased not only their motivation but also their proficiency of participation. We measured motivation by tracking an individual's involvement in brigade activities, number of posts to the website, and green house "acquisitions." We measured proficiency by the number of breeding sites identified and eliminated as well as the more subjective sense of involvement in the citizen science of dengue prevention.

Brigadistas also developed an unexpected aspect of the software: they used the tabulations of green houses to make comparisons between neighborhoods. The green house rates became easy to recognize as a measure of where the brigades had been successful and where they needed to redouble their efforts. For example, in November 2016, the small neighborhood of Galope had 45 green houses out of 52 houses visited (87%), with a total of 191 breeding sites eliminated. By contrast, Francisco Meza—the largest of the five neighborhoods—had 60 green houses out of 257 (23%) with 2,033 sites inspected (Figure 3). The numbers of Francisco Meza confirmed what residents suspected; namely, that it presents much greater risk than the other neighborhoods. Because the effort of that neighborhood's brigade seemed similar to others with regard to the number of green houses, the greater risk there was probably due to well-known environment factors. Francisco Mesa has longer periods without water service; therefore, most homes have more than one barrel for water storage. It also has significant accumulations of garbage at several sites.

Importantly, residents notified local officials about the problems in Francisco Meza and in other communities of the study that the DengueChat data had pinpointed. Unexpectedly, the municipality responded with a number of interventions, such as trash collection, piped water, and fumigation, which were attributed to DengueChat by the residents. This response was unprecedented. For example, for the first time ever, the municipal government provided money from its emergency fund (FISE) directly to the community of La Quinta, distributing it to the coordinator and facilitators of the DengueChat pilot to execute potable water and sewage sanitation projects. As a result, La Quinta now has both kinds of infrastructure where none existed before. Needless to say, community residents experienced extraordinary empowerment that they attributed to their participation in DengueChat and to the presentation of data on its website.

Value of the Software. Our pilot study demonstrated the great merit of combining software and socialware for effective community-based entomology. While building on the accomplishments of Camino Verde, the DengueChat combination achieved reductions in dengue risk significantly greater than those achieved with traditional methods of face-to-face community engagement and education. Adding the software is clearly crucial to the production of these results, precisely because it vastly increases the possibilities for key aspects of community-based vector control—namely, mobilization, pedagogy, sustainability, and integration with other prevention strategies—and especially because its technology engages and promotes young residents who are vital to all of these aspects. Although a fully controlled comparison using the same study design with only the socialware, with only the software, and with both was beyond the scope of the pilot study, comparisons with Camino Verde reveal the inherent worth of using the software technology.

The principle of SEPA informed both Camino Verde and DengueChat, but the software component of the latter created differences that were especially significant for the engagement of youth. Interest in the technology drew young residents to the initiative and focused brigade formation around them. Informatics, blog posts, gamification (especially competition to achieve green houses), rapid display of results, and Internet fame increased not only individual motivation but also solidarity within the brigades and between the youth brigades and the adult community. Moreover, the online socialization of evidence broadcast the efforts and results of community vector control to a wide and potentially enormous audience, demonstrating that it is possible to scale-up community-based interventions. We noticed over the course of the pilot study that this solidarity and publicity made the young participants feel "special" in the sense of important and respected, not only among their peers but also by the community. The brigades attained such solidarity that facilitators told us that they were functioning as important extrafamiliar support structures. We learned that in several cases of family abuse, for example, young members turned to the brigades and facilitators to cope. The technology was not merely incidental to this solidarity; it was foundational.

The software also enabled a vast expansion in the range and reach of the project's educational component. It made it possible to embed many links to sources of information in various formats about arboviral disease and citizen science. It allowed us to teach about data processing. This pedagogy builds on the enthusiasm and aptitude of youth for digital technology, motivating them to become engaged and remain committed. Therefore, there is little doubt that the software technology increases the sustainability of DengueChat as an initiative in vector control because it improves the chances of recruiting a new cohort of young people as older participants cycle out.

It is worth adding that the software also enabled effective and secure data management for participants, researchers, and policy-makers. For example, it automated the storage of input data based on standard templates, creating long-term and detailed registries of breeding containers for each house inspected and enabling their retrieval and tabulation for many purposes. Furthermore, the display of changes to these containers by date and color made it easy to see the history of each site at a glance.

Collaborative Design. Throughout the pilot study, we remained committed to collaborating with participants to identify changes and improvements to both socialware and software, using focus groups, daily conversations, and periodic assessments. A few additional examples are revealing. The first model of DengueChat developed in Brazil required users to send information about breeding sites they found to the website using SMS text messaging. Although a Brazilian corporation (Rede Trel) generously agreed to donate SMS recharges, users in Managua were quick to argue that this method of documentation and notification was not sustainable for several reasons, including real cost, unreliable signal, and problems of scale. We agreed. In Managua, we discarded the SMS and instead developed the house registry paper form for residents with basic phones that was based on their collaborative work regarding its design, organization, and substance.

Also developed for the initial project in Rio de Janeiro, DengueChat featured gamification with external rewards in the form of incentives of merchandise donated by local merchants and show tickets donated by the municipal government. This system of reward not only proved ineffective in Rio but also generated suspicions about fraud. Users assumed that some would try to game the system to obtain prizes and insisted that we develop additional online ways to verify the data posted. Although the procedures we implemented seemed to satisfy the naysayers, they proved, as we anticipated, cumbersome to execute and, in practice, they were not followed.

The problems of verification were resolved when Managuans rejected the entire idea of external rewards as "corrupting." Neighborhood leaders argued that residents should and would be motivated to use DengueChat by virtue of their commitments to "community solidarity" as the means to achieve a "collective [health] good," and that external rewards would "corrupt" that spirit of collective participation and create friction among residents (Field Notes). They did, however, approve of internal rewards (e.g., virtual points) as a means to recognize participation publicly, both for identifying and eliminating breeding sites and especially for maintaining green houses. When we eliminated the external rewards concept and developed the house registry protocol, the problem of potential fraud disappeared. No one was concerned about it, essentially because only the brigadistas won virtual points by taking responsibility for specific houses and because they verified the elimination of breeding sites by residents on the registry forms through regular inspections.

In fact, the brigadistas developed the concept of the green houses for the website, specifying their definition and suggesting how and what to display. The brigades also developed the protocol of assigning specific houses to pairs of participants. They suggested, moreover, that we organize occasional public events to recognize their efforts in vector control that would feature both artistic performances about DengueChat and the award of prizes that, in such circumstances, they considered appropriate.

Entomological Impact. The results of the seasonal entomological surveys showed that neighborhoods where DengueChat was deployed had reductions in all entomological indices (house, Breteau, and container) at all time points measured with regard to the matched control neighborhoods. (Supplemental Table 1). In previous analyses, we found that three variables were significant predictors of vector density: use of *abate* during the past 30 days, regularity of water access, and participation in organizations.[34,44] We attempted to balance these variables between our intervention and control neighborhoods, as well as neighborhood size. Therefore, we measured the level of each variable at 18 months in all neighborhoods. There was no significant difference in water access ($P = 0.7262$) and participant organization ($P = 0.442$). There was a significant difference in rate of Temephos larvicide administration during the past 30 days, but it was higher in the reference group (94%) than in the intervention group (89%) ($P = 0.007523$). This indicated that there was higher institutional abatement for the reference compared with the intervention neighborhoods, potentially affecting the results in the direction of a reduced effect of the intervention (Supplemental Table 2).

We measured the effects of the intervention with DengueChat between March 2015 and March 2016, and found significant reductions in the productivity of containers used as breeding sites by *Ae. aegypti* (Supplemental Table 3). We used classical entomological surveys conducted in approximately 100 households per neighborhood (total 818 houses) to determine total larval and pupal counts. Larval and pupal counts had significant reductions during the 19 months of the pilot study from baseline levels (October rainy season) to exit levels (March dry season) in both the intervention and the control neighborhoods. The reduction was greater in the DengueChat neighborhoods (95%) than in the control neighborhoods (86%). A remarkable change occurred, however, during the 12 months between March 2015 and 2016. During this period, larval plus pupal indices were dramatically reduced by 44% in the DengueChat neighborhoods whereas the control neighborhoods had an increase of 507% (Supplemental Table 3). One control neighborhood in District 5 contributed to most of the risk observed, with an explosive increase of 733% in the total number of immature forms compared with what was measured 1 year prior. The matched study neighborhood also had high entomological indices at baseline. However, after the deployment of DengueChat in this neighborhood, its larval plus pupal counts declined by 80% during the study period.

To determine the significance of these observations, we estimated the relative risk reduction (RRR) (1−relative risk) for the intervention group as compared with the reference groups (Figure 4). The RRR of the house index was 71% (95% CI, 51–83%), the RRR of the Breteau index was 75% (95% CI, 60–85%), and the RRR of the container index was 83% (95% CI, 73–90%). Notably, the pupae per container index, which is an indicator of productivity of breeding sites, was reduced to levels unlikely to sustain transmission of arbovirus, that is, to less than 0.1 pupae per 100 containers in intervention neighborhoods. The RRR of pupae per container was 99% (95% CI, 97–100%), and pupae per house had an RRR of 99% (95% CI, 96–100%).

We also performed two statistical tests to estimate the effects of the intervention at the household level, accounting for neighborhood. First, we conducted a weighted *t* test comparing the percent of household positivity for each neighborhood, weighted for the number of houses measured for each neighborhood, between the intervention and reference. The *t* test was significant ($P = 0.02577101$), with an average difference of 10.821% between the intervention (4.187%) and reference (15.008%).

Second, a clustered permutation test showed that the estimated *P* value with the cptest function in the cvcrand package in R was 0.0265, indicating that the probability of household positivity was significantly reduced in neighborhoods that participated in DengueChat compared with the reference neighborhoods.

Validation of Community Data. Many public health professionals and government officials assume that community-derived data are of questionable integrity and validity. As a result, they treat residents as mere observers of scientific processes who need to accept what authorities tell them. DengueChat challenges these assumptions by empowering communities to generate their own data by facilitating analyses and interpretation regarding risk. To validate the crowd-sourced data in DengueChat that residents collected, we compared the entomological indices represented in DengueChat as a percent of households positive for larvae or pupae in District 6 to the values obtained by professional external entomological inspections at baseline for the rainy season, two dry season measurements, and a final poststudy rainy season measurement (Figure 5). These external measurements demonstrated that the community-derived entomological indices represented in DengueChat (house index) coincided with the actual house index measured by professional entomologists during equivalent time points. Therefore, the data residents collected in DengueChat have both scientific significance and validity.

Sustainability. We finalized the pilot study in March 2016, when funding ended. However, brigadistas in District 6 continued to use DengueChat to conduct home inspections and report their status for more than 1 year. During this period, sewage work in these neighborhoods increased the risk because of exposed water pools and building materials. However, residents had enough proof of DengueChat's efficacy during the pilot study to motivate them to continue using it to eliminate active and potential breeding sites. Moreover, when Zika became a critical health issue in Nicaragua, communities deploying DengueChat were more prepared to act and, in fact, controlled their entomological risk. Two entomological measurements in District 6 at the end of 2016 (Figure 6) and in mid-2017 (data not shown) as part of a United States Agency for International Development-funded project to engage communities against Zika[45] demonstrated these results. The three neighborhoods in District 6 that had implemented DengueChat had significantly less mosquito infestation than other neighborhoods. Adult mosquito collections were also performed in the three study neighborhoods of District 6 and the matched control sites. The percent of households with adult *Ae. aegypti* mosquitoes was higher in reference neighborhoods than in intervention neighborhoods (38% vs. 18%; $p = 0.045$). The average number of mosquitoes in the reference neighborhoods was double that of the study neighborhoods (average 0.6 vs. 0.3 mosquitoes; $p = 0.04$). However, when households were positive for mosquitoes, both intervention and control

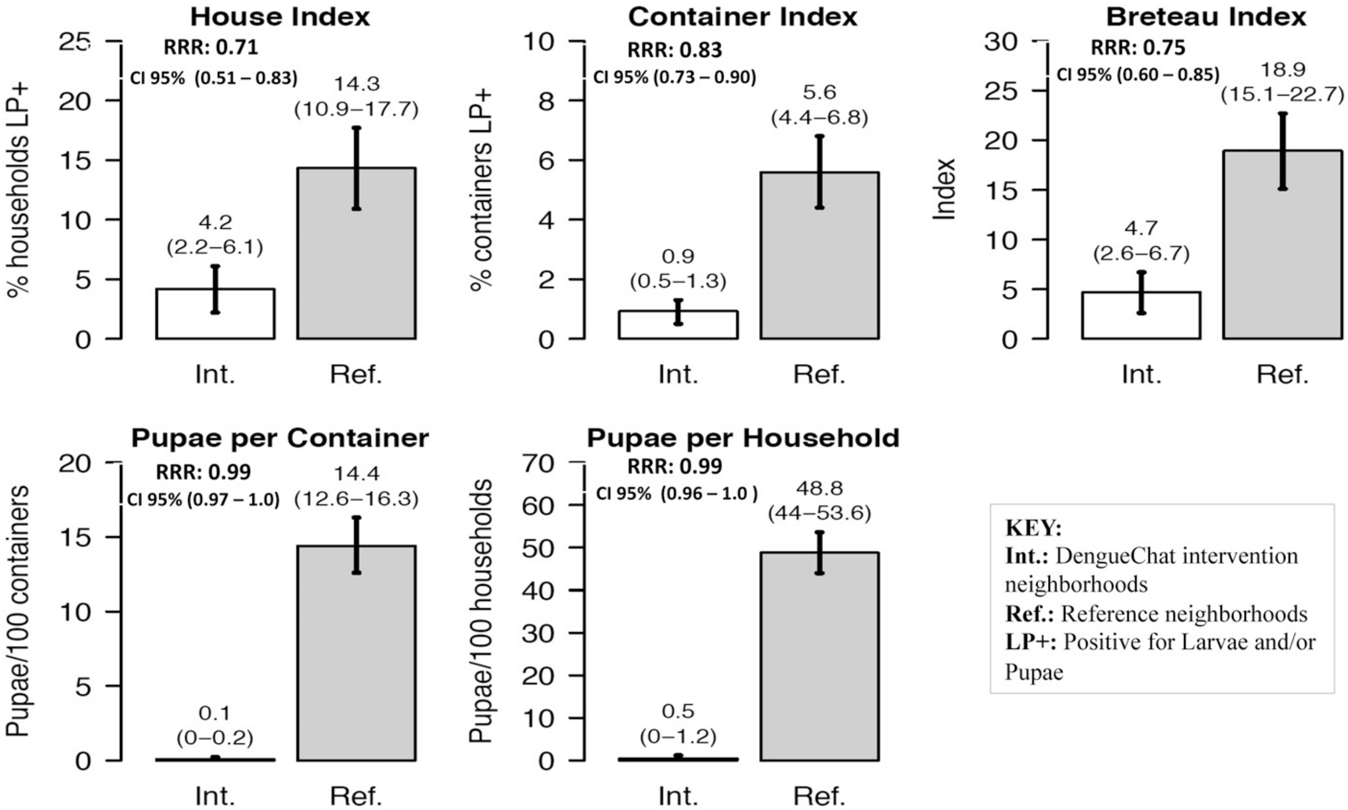

FIGURE 4. Relative risk reduction of entomological indices measured after 18 months of DengueChat activities (March 2016) in five neighborhoods of Managua. Overall, the house index was reduced by 71%, the container index was reduced by 83%, the Breteau index was reduced by 75%, the pupae per container was reduced by 99%, and the pupae per household was reduced by 99%. All had significance at 95% Confidence Interval (CI) in relation to control neighborhoods as shown.

households had equivalent average numbers of mosquitoes (1.78 vs 1.63; $p = 0.498$). Therefore, the greatest impact of DengueChat is at the neighborhood level. These neighborhood reductions continued to be documented in the context of a Zika study at least 15 months after the DengueChat pilot officially ended (field notes). These results suggest that DengueChat can be sustained in a community even with little external management or incentive. Therefore, one of its main achievements is to sustain behavioral change and reduce risk at neighborhood levels.

Furthermore, the software is designed for the local development of features for site-specific needs within a general framework. Therefore, local organizations or governments can easily assume server maintenance by hiring local

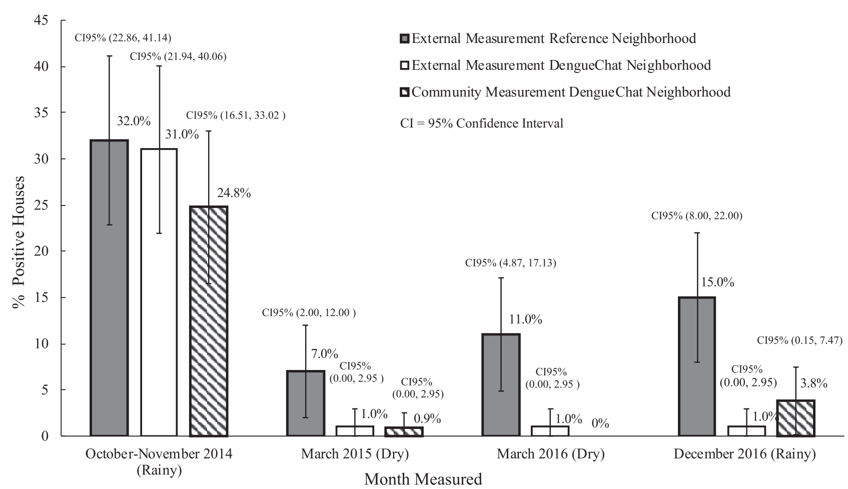

FIGURE 5. Comparison between community-generated data uploaded to DengueChat and data from entomological surveys performed by professionals during the same period for one neighborhood in District 6 of Managua. Graphs show percent of households positive for larvae and/or pupae during two rainy and two dry seasons. The status of the matched reference neighborhood is also shown for comparison. Note that the first community measurement in the study neighborhood was performed approximately 1 month after the external baseline, and the last community measurement was performed almost 8 months after the study ended.

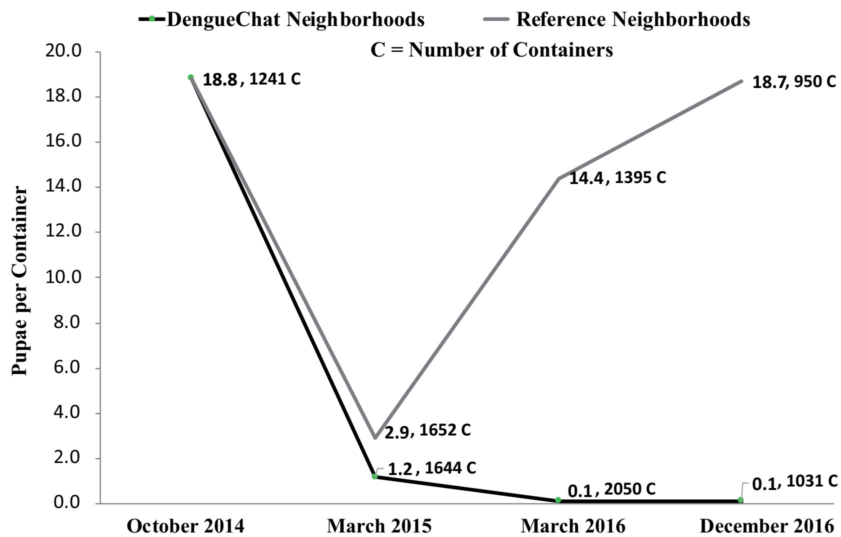

FIGURE 6. Pupae per container counts at baseline and during each of the external entomological measurements. Although the study ended in March 2016, a final measurement performed in December 2016 showed that communities maintained their low entomological levels on their own compared with control neighborhoods, where pupal and Breteau indices (not shown) returned to baseline levels during the wet season.

programmers to customize their deployment. This kind of local development of the platform occurred with its implementation in Asunción, which added not only an interactive mapping function but also a cellphone app. Because the DengueChat software is open-source, other instances can use these new features.

DISCUSSION

Our pilot study demonstrated that combining software and socialware significantly improved mobilization (especially among youth), socialization, pedagogy, and sustainability, and, therefore, substantially increased the efficacy of community-based participation in reducing *Aedes* entomological indices. We realize that there are a number of potential limitations to broader conclusions, including that the study size was relatively small, that dengue infection was not an outcome specifically measured, and that the study was not a randomized controlled trial. However, we are certain of the impact of DengueChat on rapidly mobilizing communities to reduce *Aedes* indices in their neighborhoods. At all measurement points, DengueChat reduced the entomological risk to optimal and either below or just at the transmission threshold for the entire study period. By contrast, the control neighborhoods remained at either emergency or alarming levels of risk.

We found that DengueChat's online and offline socialization of evidence showed residents—both youth and adults who, for different reasons, had little formal education—that they can learn about arbovirus transmission and use that knowledge to fight the mosquito with specific actions. This realization increased their self-respect. Moreover, it mobilized them to accomplish a fundamental goal in dengue control, namely, that of transforming residents from victims or, worse, supposed agents of disease transmission into agents of prevention. Our entomological surveys consistently showed that in relation to dengue transmission, poor residents are often made to feel "dirty"; that is, social stigmatization and misguided government campaigns make them feel that they are responsible for the disease because their homes are "unclean" (without exactly knowing in what sense), and even that dengue is a disease spread by their bodies.

By contrast, residents reiterated in our discussions that DengueChat's online and offline pedagogy led them to realize that dengue and its cognates are caused by viruses transmitted by a particular mosquito that bites rich and poor alike, spread by both mosquito vectors and human movement, and controlled with considerable success by simple nontoxic and inexpensive (if not free) measures that they can apply in their homes, neighborhoods, and daily lives. Moreover, using DengueChat shifts the power structure of vector control from government agencies to the neighborhood households where residents can achieve source reduction within their properties and with their own resources. We consider these realizations to constitute an important advance in the enabling conditions that contribute effectively to disease prevention.

Several studies indicate that community action to prevent dengue must be efficiently combined with other vector control approaches.[46–51] However, for this to happen at scale, there must be more support from local governments and municipalities for community efforts to prevent dengue and for the implementation of software such as DengueChat that engages them at scale and with intersectoral coordination beyond Ministries of Health. In the latter sense, it is obvious that *Aedes* infestation is often the result of failures in services (water, trash collection, recycling) and of reliance on suboptimal use of pesticides and larvicides. With DengueChat, communities can have an essential role in collaborating with other initiatives. They mobilize their neighborhoods, families, and homes to minimize the entomological burden. They also use DengueChat's digital data to inform and impress policy-makers, who may make better decisions as a result, as illustrated by our example of infrastructural improvements in La

Quinta that were based on data gathered by residents and shared with health authorities. In that example, DengueChat became integrated with a government intervention through collaborative action without being absorbed or replaced by it.

Thus DengueChat's combination of socialware and software generates a collaboration of two types of resources. It strengthens the community arm of vector control through scalable data-based mobilization and sustainable teams of citizen entomologists. It also provides a data-rich resource for researchers conducting large-scale entomological studies or randomized control trials[52] and for decision-makers planning to deploy interventions into priority areas. Although our study was performed in parallel to other interventions (e.g., fumigation), it showed that DengueChat could be integrated as shared data and conditions of risk management into a toolbox of control and research strategies that health agencies coordinate.

A great challenge for any social mobilization is motivating people to act and keeping them engaged. To do so constitutes a real change in social behavior. We found that residents were highly motivated to see the results of their prevention work and to show it to others when the data they gathered were displayed rapidly as indicators of risk. The software made this rapid display possible. Furthermore, some residents commented that they had never before seen a public demonstration that their efforts—the specific efforts of marginalized communities—make a difference. DengueChat's strategies of vector control and its combination of socialware and software increased participants' sense of accomplishment and their interest in continuing to contribute. In effect, we could say that DengueChat showed them that an active local citizenship could improve their own living conditions directly.

Therefore, the pilot study in Managua suggested that DengueChat is sustainable and generalizable. Its costs are minimal compared to fumigation, for example, because volunteers perform most of the work, its social model is adaptable to any organized group, its digital technology engages youth and is likely to attract new cohorts of participants, its pedagogy fosters citizen science that may be linked to other education and civic initiatives, it may be integrated with other interventions to scale-up and maintain, and it can be maintained by public or private organizations. DengueChat is sustainable in these terms, and it is also generalizable because its model and methods are based on local knowledge and organization. This conclusion is not contradictory. Rather than trying to impose a uniform platform that denies the specificities that inevitably define community-based action, DengueChat's design and deployment depend on identifying those aspects of local life that can best sustain the efforts of community mobilization.

We emphasize neighborhood groups because they are generally the most committed organizations to the kinds of home-directed initiatives that *Ae. aegypti* vector control requires because their memberships are based on local residence. In this sense, residents perceive DengueChat as an initiative in local association—in effect, in residentially based citizenship—and therefore as congruent with other local groups to which they often already belong. Most important, DengueChat is based on respect for the capabilities of residents. Participants are motivated to remain committed because they find compelling its thesis that users are essential contributors who own and manage the data they collect, its engagement of young people through technology, and its proven results of lowering the disease risk.

The pilot study in Managua demonstrates that a combination of socialware and software mobilized residents to produce community crowd-sourced data about arboviral disease that are scientifically valid, abundant, historically deep, and crucial for both preventive and predictive policies of arbovirus control. It enabled residents to significantly reduce entomological indices of *Ae. aegypti* infestation and disease risk. This mobilization constitutes an important change in the agency of residents and their community organizations. The challenge of DengueChat is achieving these results at a larger scale. If it cannot leverage the Internet to engage extensive populations and territories at modest costs, then its scientific merit and political significance are limited. However, if, as the pilot study suggests, it can achieve mobilization at a large scale, then its significance for disease prevention, scientific research, and civic action is considerable.

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