A georeferenced and time-indexed data visualization strategy to support decision-making to combat *Aedes aegypti* mosquitoes during Zika, Dengue and Chikungunya Fever outbreaks: An use case from the Northeast of Brazil

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Abstract *Brazil has been faced outbreaks of arbovirus-related infections such as Chicungunya, Zika and Dengue fevers, and some of them have a proven association with neurological disorders in newborns. It triggered a worldwide alert concerning dengue, chikungunya and zika viruses infection, which are transmited by the Aedes sp. mosquitoes. To fight the spread of A. aegypti in Brazil, primary care technicians (ACSs and ACEs) are acting as the main vectors of health surveillance measures. Data gathered in their visits, such as local and time helps public health managers to define to which areas control measures might be taken. We propose a georeferenced and time-indexed visualization strategy of the area covered by technicians, with specific indication of visited homes. Results points to more efficient possibilities to plan control of the A. aegypti reproduction and a clear visualization of areas at risk.*

Introduction

With the recent emergence of arbovirus-related infections (*e.g.* Chikungunya and Zika Virus fevers) in Brazil, the world turned the attention to the neurological disorders in newborns that arose between 2014-2015. Several public health agencies confirmed identified a possible causal association among the Zika Virus (ZIKV) and neurological disorders (*e.g.* Microcephaly), such as the Center for Disease Control (USA) [1], European Center for Disease Prevention and (also) the World Health Organization (WHO) [2]. There was a clear urge on fighting and identifying the causes surrounding ZIKV and neurological disorders.

In Brazil and several other countries, ZIKV is spread through areas where *Aedes sp.* mosquitoes are found such as *Aedes aegypti* and *Aedes africanus* [3]. For instance, *A. aegypti* is (also) described in areas with circulation of Dengue Virus (DENV)[4] and Chikungunya Virus (CHIKV) [5], responsible for Dengue Fever and Chikungunya Fever (respectively). In 2015 and 2016, the three viruses (*i.e.* ZIKV, DENV and CHIKV) were circulating simultaneously in Brazil. From estimations of the Brazilian Ministry of Health, probable infections regarding the spread of DENV, CHIKV and ZIKV accounts for (approximately) 3,7 million cases, see Table 1.

Regarding the neurological disorders, between November 8th 2015 and January 14th 2017, there were 2,829 confirmed cases [6]. Considering these cases are (mostly) associated with the confirmed infection by ZIKV during pregnancy, this accounts for (approximatelly) 2% of the overall estimated ZIKV infections for the period. As the number seems to be small, we have to take into account these neurological events in newborns were (almost) unnoticeable by the Brazilian Ministry of Health.

Table 1: Number of probable infections related with the DENV, CHIKV and ZIKV in Brazil (2015 - 2016)

Manifestation	2015	2016	Total
Dengue Fever	1,688,688	1,487,924	3,176,612
Chikungunya Fever	36,254	263,598	299,852
Zika Fever	-	211,770	211,770
Total	1,724,942	1,963,292	3,688,234

Source: Brazil, Ministry of Health, Health Surveillance Office (2016). [7]

In this scenario, and after several years of successive cuts in budget to fight DENV and *Aedes sp.* spread in Brazil, the Brazilian Government started (January/2016) a nationwide plan to reduce the spread of *Aedes aepypti* (less than 1% of residencies), together with the number of infection cases by DENV, CHIKV and ZIKV[8]. The aim of this plan was to (i)fight the mosquito, *e.g.* decreasing the possibility for its reproduction with field and educational activities; (ii)healthcare, *e.g.* guaranteeing assistance for the one affected though the Unique Health System (Sistema Único de Saúde - SUS); and (iii) tecnological Inovation, Research and Development, *e.g.* developing knowledge and solutions with new ways to fight *Aedes aegypti*, DENV, CHIKV and ZIKV.

To support fighting the mosquito, the technicians from the primary care team were charged with the identification of the water repositories and their removal (when necessary), when visiting families in their residency. This activity, stimulated by the Ministry of Health, was performed without supervision, e.g. the public health managers were not able to identify to which residency the technician (known as *Agente Comunitário de Saúde*, ACS, or Community Health Agent) visited; if there were mosquito repository there; and, the decision taken when mosquito repositories where found.

In this way, the Telehealth Center (NUTES) from the Clinics Hospital of the Federal University of Pernambuco (UFPE), together with the Pernambuco State (Northeast, Brazil) Health Secretary, began telemonitoring the primary care technicians activities regarding control of *A. aegypti*. The visit was assisted by a mobile application by which the technician could report his activities, and the public health manager could track to which residency repositories were found and the population in risk. When the technician was unable to use the mobile application, a paper form was made available so the technician could report the activities performed later through a web-based website.

With the visits' records, we were able to identify that to which visit and measures taken, it is possible to georeference and index in time each visit. These simple information enabled us to identify the technician dynamics during their work in the field. This means, from a public health manager perspective (and considering the DENV-CHIKV-ZIKV situation), keeping track of their activities is equivalent to understand in which areas the population is properly covered and not covered; the period necessary to perform the next visit; when the population of a certain area might be at risk again; and several other informations.

In practice, the use of a georeferencing approach for public health matters is a valuable tool for managers in planning and performing health surveillance, as well as enabling prevention and control of non-transmissible and chronic communicable diseases. By means of a simple georeferencing tool, it is possible to carry out disease mapping and environmental risk assessment, linking them to the social determinants of health [9].

In this sense, our aim is to present a use case whether the simple use of a georeferenced and time-indexed record about visits made by primary care technicians to fight *Aedes aegypti*, DENV, CHIKV and ZIKV spread enables timely decision support and identification of areas under risk. We present this work exemplifying the activities performed by 18 technicians from the municipality of Brejinho (Pernambuco, Brazil) that continuously recorded their visits by means of the mobile application between March and December of 2016.

Background

In this section, we describe some background on Dengue, Chikungunya and Zika virus infection. Next, we describe the role of the Brazilian Unified Health System (SUS) towards the health surveillance of arboviruses and the primary care, aiming the population affected by such diseases.

Aedes aegypti, Dengue, Chikungunya and Zika

Aedes aegypti (LINNAEUS, 1762) (Diptera: Culicidae) is the main arthropod vector of DENV, CHIKV and ZIKV. These viruses are the known causative agents of Dengue Fever, Chikungunya Fever and Zika Fever [10, 11, 12, 13]. *A. aegypti* and the arboviruses present active circulation in Brazil.

A. aegypti is an anthropophilic and cosmopolitan mosquito that feed itself with human blood [14]. This mosquito is considered potentially the unique responsible for the arboviruses transmission in Brazil. Diseases caused by the arboviruses infection affects (mostly) tropical and subtropical regions of the globe, where environmental conditions are limited (e.g. the rainfall regime, health conditions, among others) and stimulate the vector proliferation [15].

Dengue is an acute infectious disease transmitted by the mosquito *Aedes aegypti* and it is considered one of the main public health issues. In Brazil, historically, the disease control process is developed with limitations, mainly due to its complex nature. With the Dengue Fever outbreak, the disease control has become even harder, considering that the controlling process requires the intervention of other sectors of society such as basic sanitation, education, among others [16].

At the same time, Chikungunya fever resembles dengue due to both the transmission of the *A. aegypti* and the symptomatology, as well as the prevention and control measures.

Zika Virus (ZIKV), is an Arbovirus, e.g. from a group of RNA virus (Ribonucleic Acid) transmitted by arthropods during blood repast. The first ZIKV-related record is dated 1947, with the detection of ZIKV in primates collected in Zika Forest, Uganda [17]. Until recently, reports of human infection were restricted to African and Asian continents. With identification in other continents, ZIKV is considered an emerging pathogen [18]. In Brazil, the introduction of the Zika virus (ZIKV) occurred (possibly) during the Soccer World Cup (2014) [19]. The first official records are dated May 2015, in patients from the Northeast of the country [20] According to the projections described by the MS, the State of Pernambuco was (among the other states) the 4th place in the estimates of the highest number of individuals infected by ZIKV only in 2015.

The symptomatology of ZIKV infection is similar to infection with Dengue Fever Virus (DENV). It is described the presence of fever, muscular pain, ocular pain, and maculopapular rash. Like DENV, ZIKV promotes antibody-dependence with a possible hemorrhagic (even clinically uncertain) condition. Other effects of ZIKV infection are Guillain-Barré syndrome [21] and recent cases of microcephaly [1, 22] in neonates.

Despite the difficulties of control, health surveillance activities can be performed by local health managers, such as an analysis of the epidemiological behavior of dengue and other arboviruses. In practice, these activities are potentially adequate, enabling effective changes. However, there is no current framework, focused on the reduction of morbimortality of arboviruses on a Brazilian population, neither considering where and when public health measures were taken.

Unified Health System, Health Surveillance and Primary Care

In Brazil, the public health sector is represented by *Sistema Único de Saúde* (SUS, or Unified Health System). SUS is characterized as a set of activities and services for collective and individual health regarding promotion, prevention and recovery of health. In parallel, as a way to promote universal access to health and to qualify healthcare practices, the Brazilian Ministry of Health has developed a series of programs and initiatives, for example the *Estratégia de Saúde da Família* (ESF, Family Health Strategy) and the *Programa de Agentes Comunitários de Saúde* (PACS, Community Health Agents Program) [23].

ESF, known in the past as *Programa de Saúde da Família* (PSF, Family Health Program), has as main objective to reorganize and improve the basic level of health care, in which the individual and his family work as a unit of work. The actions of the ESF are carried out through the work of the family health teams that are made up of doctors, nurses, nursing technicians and *Agentes Comunitários de Saúde* (ACS, Community Health Agents). In addition, among the various actions carried out by SUS, health surveillance consists of practices to promote the health of citizens and mechanisms for the prevention and control of infectious and non-communicable diseases [24].

Health surveillance is one of the practices of the ESF, developed in the basic attention representing actions of prevention, diseases and injuries. By considering the territory environment as a dynamic space of health-disease-care process, targeted surveillance in the fight against *A. aegypti* makes it possible to interfere in the transmission chain of dengue and other arboviruses. The ACS is a professional who resides in the community, being a link between the family health team and the population assigned to the ESF.

Likewise, the *Agente de Combate à Endemias* (ACE, Endemic Diseases Agent) is another key element, such as the ACS, to combat endemics. ACEs enables the integration of epidemiological, sanitary and environmental surveillance [6]. In the context of fighting dengue, zika and chikungunya, the ACS and the ACE inspect households and peridomiciliary areas to identify potential breeding grounds or other situations that require the use of larvicide. In the later, ACS should request the ACE of their area [25, 26].

The integration of these two professionals in the same territorial base is considered fundamental for the success in the control of endemics, since the responsibility and consequent integration of activities potentiate the preventive work and optimize actions that, although distinct, are complementary. Healthcare services are the main sources of suspected cases detection, playing an important role for the surveillance services. Thus, the timely collection of data and the data quality are essential for beginning the control and prevention actions at local level.

In these situations, certain vector control actions are adopted, as [26]:

- Geographical recognition, e.g. the identification and numbering of blocks, as well as locating and specifying the type of property within each block;
- Home visit, e.g. a fundamental activity to verify the presence of breeding sites, guide the residents about the elimination of breeding sites and preventive measures, identification of focus and treatment (biological, chemical, mechanical, etc.). It is also used to survey infestation rates;
- Record of the visit, e.g. record of activity on paper or digital form containing from the date record, the address to the procedures adopted during the inspection of the property;
- Strategic point, e.g. places where there is deposit concentration for the spawning of the female *Aedes aegypti* or especially vulnerable to the introduction of the vector. Activities at these locations should be held every fortnight; and
- Delimitation of focus, e.g. for each focus found, larval research activities and focal treatment are performed on 100% of the houses included within a 300m radius, opening new rays for each focus detected.

Material and Methods

Next, we describe the material used as exemplification, and the methods performed to explore the georeferenced and time-indexed records taken from ACSs and ACEs field work.

Local description and relevance

Among the 185 municipalities of Pernambuco State, each of which enabled to use the mobile application, the municipality of Brejinho was chosen one. Between March 2016 to December 2016, ACSs and ACEs from this municipality continuously submitted their reports on vector control. This period was also chosen for exemplification.

Brejinho, is a city located in the countryside of Pernambuco 400 km from the capital (Recife); and, has a little more than 7 thousand inhabitants in about 106,297 km^2 of area [IBGE]. It has a tropical climate with a dry season, classified as AW according to the Köppen-Geiger Climate Classification [27]. Brejinho's climate is characterized by high temperatures and low rainfall regime. Even with this climatic characteristic, the local population's need to store water in most part of the year, what increases the concern about the existence of possible outbreaks of *A.aegypti*. This reinforces the need for efficient strategies for analyzing areas covered by the work of ACSs and ACEs.

Data gathering

Data used as example were taken from a mobile application for telemonitoring in health surveillance [28], between March 2nd 2016 and December 31st 2016. Such data are collected by ACSs and ACEs in several municipalities of Pernambuco State, as an strategy to identify where *A. aegypti* repositories were found.

Figure 1: City of Brejinho, Pernambuco, Brazil

Source:Wikipedia

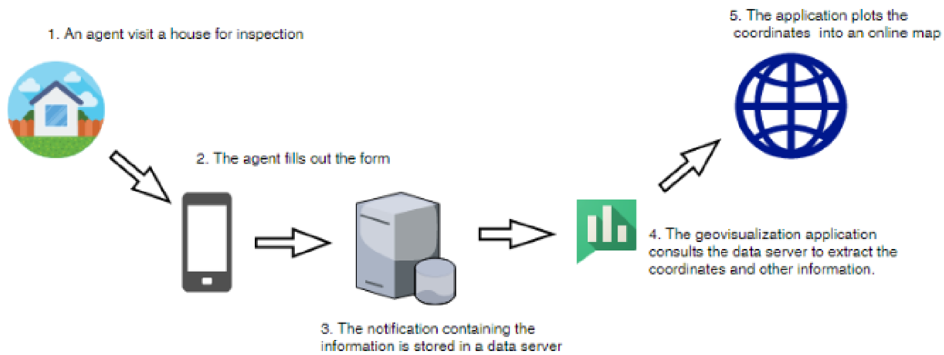
In the telemonitoring application, ACSs and ACEs answer (during each visit) a digital (smartphone or tablet) or a paper form during residency visits. These forms (which are equal) were created by the Pernambuco State Health Secretary. Each form includes several fields, among which we selected the ones related to the technician id, residency visited, and time stamps. For instance, each record used here was composed mainly of:

- Technician ID, *e.g.* technician's personal identifier;
- Visit date, *e.g.* day, month and year of the visit;
- Latitude and Longitude, *e.g.* collected through Global Positioning System (GPS) by means of the ACS and ACE smartphone;
- City, *e.g.* city where the technician is visiting.
- Address, *e.g.* street where the technician is visiting;
- Residency number, *e.g.* house's number where the technician is visiting; and
- Neighborhood, *e.g.* area where the technician is visiting.

All data were stored in a server for future analysis. With these fields, we were able to identify who was the technician that performed the activity, where the technician went to visit a residency (with GPS coordinates, when available), the proper residency location, mosquito repositories site identification, and procedures regarding control and repositories elimination.

Below, the description regarding how geovisualization and time data was processed. The whole process is summarized in Figure 2.

Figure 2: A fluxogram of the data acquisition and publication



Geovisualization strategy

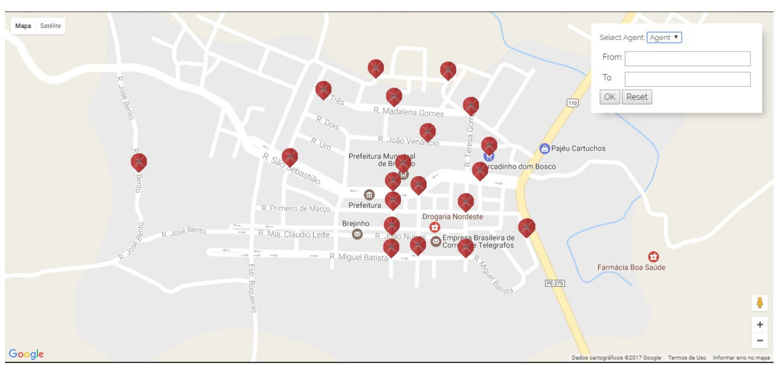
Most GPS coordinates were taken from the application server directly, e.g. when recorded with the support of smartphones or tablets with such capabilities. Otherwise, address data were taken from the address form, entered manually by ACSs and ACEs. Nowadays, this kind of information can be retrieved programmatically with the support of scripts, broadly available in the internet.

The time dimension, required for distinguishing was gathered together with the address form, by means of system records submission logs. After converting records from server as comma separated files, and supported by a script written in JavaScript, geo and time data were plotted directly in the project website (http://geotimeaedes.github.io) using Google Maps API[1]. The project website also includes anonymized data and scripts used as exemplification.

Results

The main result of this study is an online application which provides an overview of every visited home in a date interval in Brejinho (Pernambuco, Brazil). This application enables the user to have a macro view of the areas covered by the technicians.

Figure 3: Screenshot of the online application

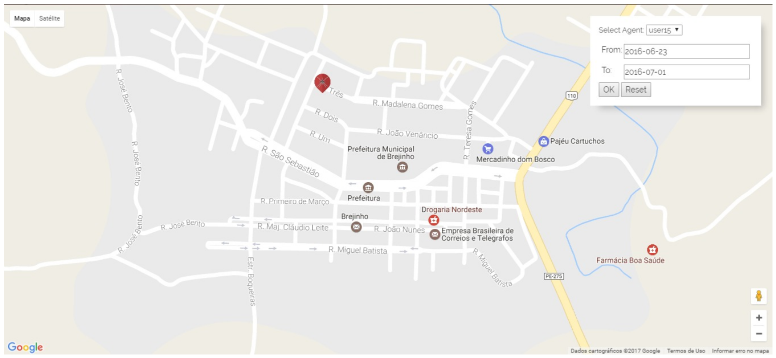


In the context of geovisualization strategy, the application contains some filters to provide specific information regarding the notifications sent. In this first version, the filters are divided into two categories: Date Interval: Necessary to establish a time interval Agent: Used to determine the notifications sent by one specific technician or a group of technicians.

[1]https://developers.google.com/maps

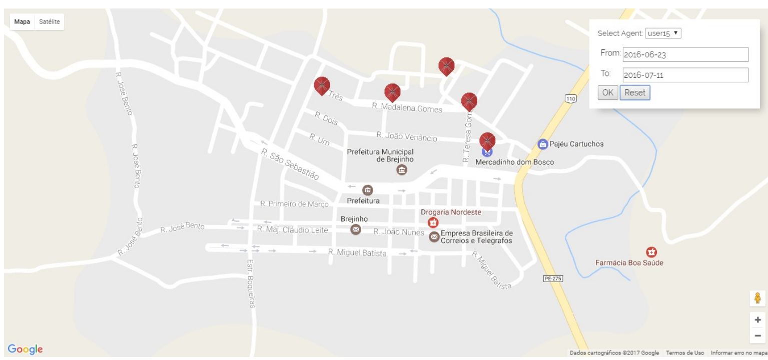
The Figure 3 above shows the map containing some highlighted points characterized by red diagrams. These points are visited homes whose notifications are according to the parameters set in the filters.

Figure 4: Visualization of a single notification from a random technician



The Figure 4 above demonstrates a simple notification sent by one random technician between 23th june 2016 and 1st july 2016.

Figure 5: Visualization of more than one notification of a random technician



The Figure 5 above shows another overview of notifications sent by the same technician of the figure B but in a later time interval.

A comparison between Figure 4 and Figure 5 shows that Figure 5 contains the same point seen in the Figure 4 plus other notifications that this technician sent after the last day set in the date interval of the Figure 4. Beyond having a good visualization about the covered area (which can be used to either monitor the technician's work and measure the visited area), this feature makes it possible to identify if there have been susceptive visits, which sounds valuable in cases of potential breeding spots for the mosquito.

Discussion

Since the worldwide alerts regarding the spread of Zika virus infections and the neurological defects in newborns, the Brazilian engaged all health assistance levels to support the ongoing outbreaks. Pernambuco was the first state to notify the Brazilian Government about the microcephaly outbreak. At the same time (in Brazil), Dengue and Chikungunya infection rates were increasing. Among several measures taken by the Brazilian government, control and elimination of the arthropod vector was the main one. Primary Care technicians (ACSs and ACEs), which are closer to the population, started visiting residencies throughout the Brazilian municipalities to eliminate possible mosquitoes repositories.

Whereas control activities were under action, keeping track of: which residency was visited, when the visit took place, and when the next one should take place was problematic. To overcome such limitation, NUTES developed a mobile and web-based application as a partnership with the Pernambuco State Health Secretary. The outcome was a database filled with measures taken for A. aegypti control in Pernambuco.

In this work, we presented a simple strategy on how to gather, process and display data about the dimensions where and when the A. aegypti control measures happened. Brejinho (Pernambuco, Brazil) was the municipality chosen, as the local ACSs and ACEs engaged on keeping track of their activities and notify State and Federal public health offices. We were able to demonstrate the usefulness of georeferenced and time indexed data for tracking primary care technicians field work. In practice, this kind of information should support public health managers, health care professionals and the population on where health surveillance activities took place, in which areas the population are at risk, or even when an additional visit is required.

Several technologies have been created as possibilities for *Aedes Aegypti* mosquito control, using multiple intervention mechanisms, such as social measures (health education), dispersion of insecticides, new chemical and biological control agents and others. In this experiment, we used the risk mapping process as a promising strategy developed to analyze and identify potential areas of arbovirus transmission, using the georeferencing tool for public health problems [29].

Health geoprocessing is a common practice in organization of health services, however, in the scope of basic health care it emerges as a valuable instrument, which can be directed to actions of spatial surveillance of communicable diseases in less structured territories, allowing managers : (I) registration of useful information for the planning, implementation and evaluation of health actions, (II) and monitoring of *Aedes Aegypti* control practices. In addition, it is through this tool that it is possible to identify in real time and earlier the situations of environmental risks to health, characterizing, therefore, as a fundamental instrument of subsidies for health surveillance practices at SUS [9].

Nevertheless, its application for monitoring primary care field work is quite recent in Brazil [30]. Sa et al. described a web and mobile application to give structure to paper forms for the Brazilian *Sistema de Informação da Atenção Básica* (SIAB, Primary Care Information Systems) Brazil. One of their main results was the ability to plot where non-communicable diseases were found in community.

In current work, we highlighted a different aspect (e.g.) the usefulness for health surveillance and to keep track of activities performed for control and elimination of A. aegypti repositories. Additionally, we demonstrate that with time indexed data, we are able to identify when the ACS and ACE performed their activities, and not only where the data were collected.

Other work from [31] et al. described an approach with ovitraps, installed in 44 different locations of an urban residential area in Divinopolis, Brazil from May 2011 to May 2012. The number of eggs counted was used to calculate the rate of infestation and they were georeferenced with a Global Positioning System (GPS) [31]. In practice, the work of [31] et al. may be considered complementary to the one presented in current paper.

Identifying until where the mosquitoes can reach and when this information was gathared, together to when and where the ACS or ACE visited might give the public health manager the areas control measures are being effective or not. For instance, if a ACS visit a residency and remove all mosquito repositories, it might be expected that the number of eggs laid in the ovitraps decreases with time.

Even though its potential of supporting decision-making in the process of fighting the mosquito, there are some issues that limits the application impact. The conscientization and training of ACSs and ACEs about the use of the digital form to send the notifications is a challenge, especially for those who lives in remote areas and, in some cases, do not even have a mobile device to work with. Another issue is the poor quality of the internet connection in some countryside areas (some of them do not even have internet connection) but it has been improved by some brazilian programs that aims to provide internet connection to remote areas [32].

It must be highlighted that the application itself is a result of data processing from the notifications sent by the technicians and this processing is an important achieve to publish information that will directly help the public health systems to reach its purpose in promoting universal health.

Conclusion

We presented a use case whether the simple use of a georeferenced and time-indexed record about visits made by primary care technicians to fight Aedes aegypti, DENV, CHIKV and ZIKV spread enables timely decision support and identification of areas under risk. With current approach, we enable public health managers, health care practitioners and population to properly identify to which place activities for control and elimination of A. aegypti are taking place. Nevertheless, real-time georeferencing might still be a challenge for current Brazilian health care situation, considering limited resources are available to support ACSs and ACEs work.

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