ZIKΛ: A New System to Empower Health Workers and Local Communities to Improve Surveillance Protocols by E-learning and to Forecast Zika Virus in Real Time in Brazil

Juan D. Beltrán
Institute for Risk and Disaster Reduction
University College London, UK juan.beltran@ucl.ac.uk

Andrei Boscor
Institute for Risk and Disaster Reduction
University College London, UK
andrei.boscor.14@ucl.ac.uk

Wellington P. dos Santos
Department of Biomedical Engineering Federal University of Pernambuco Brazil
wellington.santos@ufpe.br

Tiago Massoni
Department of Systems and Computing
Federal University of Campina Grande,
Brazil massoni@computacao.ufcg.edu.br

Patty Kostkova
Institute for Risk and Disaster Reduction University College London,
UK p.kostkova@ucl.ac.uk

ABSTRACT

The devastating consequences of neonates infected with the Zika virus makes it necessary to fight and stop the spread of this virus and its vectors (*Aedes* mosquitoes). An essential part of the fight against mosquitoes is the use of mobile technology to support routine surveillance and risk assessment by community health workers (health agents). In addition, to improve early warning systems, the public health authorities need to forecast more accurately where an outbreak of the virus and its vector is likely to occur. The ZIKΛ system aims to develop a novel comprehensive framework that combines e-learning to empower health agents, community-based participatory surveillance, and forecasting of occurrences and distribution of the Zika virus and its vectors in real time. This system is currently being implemented in Brazil, in the cities of Campina Grande, Recife, Jaboatão dos Guararapes, and Olinda, the State of Pernambuco and Paraiba with the highest prevalence of the Zika virus disease. In this paper, we present the ZIKΛ system which helps health agents to learn new techniques and good practices to improve the surveillance of the virus and offer a real time distribution forecast of the virus and the vector. The forecast model is recalibrated in real time with information coming from health agents, governmental institutions, and weather stations to predict the areas with higher risk of a Zika virus outbreak in an interactive map. This mapping and alert system will help governmental institutions to make fast decisions and use their resources more efficiently to stop the spread of the Zika virus. The ZIKΛ app was developed and built in Ionic which allows for easy cross-platform rendering for both iOS and Android. The system presented in the current paper is one of the first systems combining public health surveillance, citizen-driven participatory reporting and weather data-based prediction. The implementation of the ZIKΛ system will reduce the devastating consequences of Zika virus in neonates and improve the life quality of vulnerable people in Brazil.

CCS CONCEPTS

- **Information systems ~ Location based services**
- **Information systems ~ Geographic information systems**

KEYWORDS

Zika virus; big data; surveillance; forecasting; e-learning

ACM Reference Format

Juan D. Beltrán, Andrei Boscor, Wellington P. dos Santos, Tiago Massoni, Patty Kostkova. 2018. ZIKA: A New System to Empower Health Workers and Local Communities to Improve Surveillance Protocols by E-learning and to Forecast Zika Virus in Real Time in Brazil. In 2018 Digital Health Proceedings, April 23–26, 2018, Lyon, France. ACM, NY, NY, USA, 5 pages. https://doi.org/10.1145/3194658.3194683

1 INTRODUCTION

The Zika virus (ZIKV) has devastating consequences in neonates [1, 2], and its spread has alarmed international organizations [3]. It is critical to fight and stop the spread of the ZIKV and its vectors [4]. The ZIKV is usually spread by *Aedes* mosquitoes [5, 6]. The ZIKV can also be transmitted by transfusions of contaminated blood, via unprotected sex [7] and from mothers to unborn children (perinatal transmission) [8, 9].

The ZIKV is associated with microcephaly and severe deformities in children who have been infected by perinatal transmission [1, 2]. There is no vaccine available at the moment to prevent ZIKV infection. The fact that ZIKV affects the health and

DH'18, April 23–26, 2018, Lyon, France

ACM ISBN 978-1-4503-6493-5/18/04.
https://doi.org/10.1145/3194658.3194683

life quality of newborns makes the ZIKV a public health problem that needs constant surveillance.

The latest outbreak occurred in the Americas, when in 2015 the Brazilian Ministry of Health confirmed autochthonous infections in the Bahia region [10, 11]. However, phylogenetic analyses of the DNA of the virus suggested that it was introduced in 2013 [12]. Since then, the virus has spread to countries in South and Central America and tropical territories of the US, perhaps associated with the El Niño effect in 2015-2016 [13].

In Brazil more than 1.5 million cases have been reported and this is the largest outbreak of ZIKV [14]. In Brazil other viruses are co-occurring such as Dengue virus (DENV) and Chikungunya virus (CHIKV). In February 2016 the World Health Organization declared the ZIKV a public health emergency and a matter of international concern [3].

In order to fight the ZIKV it is necessary to implement a surveillance protocol which empowers local communities to avoid bad practices to decrease the prevalence of ZIKV. In addition, it is necessary to understand the population dynamics of the vector in real time (*Aedes* mosquitoes; in particular *A. aegypti*) to alert governmental institutions to allocate resources in areas with higher risk. The present study is focused on Brazil (in particular in the cities of Campina Grande, Recife, Jaboatão dos Guararapes, and Olinda, the State of Pernambuco and Paraiba) because Brazil is the country with the highest number of reported ZIKV cases in the world.

The elimination of the vector requires cooperation of governments and healthcare agencies setting the disease control strategies with general population. However, in Brazil the situation is more complex: the local "community health workers" (health agents) volunteers deliver care alongside professional healthcare workers but are often disregarded when it comes to engagement and training which makes combating vectors very challenging. How can community health agents in primary care, who are often geographically dispersed in poor and hard to reach regions, better fight the mosquito outbreaks?

Considering the potential of engagement of games like Pokemon Go©, gamified applications like Waze©, and the popularization of smartphones among individuals of all social classes in Brazil, there is a great potential to train health agents in practical knowledge using medical training apps and serious games. In this paper we propose the development of a gamified system to engage community health workers to help in the surveillance of ZIKV in the States of Pernambuco and Paraiba.

2 MONITORING THE DISTRIBUTION OF MOSQUITOES AND ZIKV IN REAL-TIME

Understanding the location of the most vulnerable areas for the ZIKV infections in real time is a priority for early warning and rapid response. The use of real-time spatial-temporal big data is needed to model and to predict the distribution of the virus and its vector. The most recent literature concerning the potential distribution of the ZIKV and its vectors have focused on a global scale using historical data [9]. For example, the potential distribution of the ZIKV, DENG and their vectors have been assessed using Random Forest and Artificial Neural Networks [9, 15, 16]. The global scale and the temporal scale that the previous studies used make it difficult to draw any inference at regional, local scale or real time, where the governmental institutions have to make decisions to allocate their resources efficiently to fight the virus.

The potential distribution and prediction of the ZIKV vectors and the ZIKV in the cities of Campina Grande, Recife, Jaboatão dos Guararapes, and Olinda require the use of finer-scale variables (such as, the use of daily weather variations, vectors population density, and presence-absence ZIKV data). These variables are relatively easy to obtain using mobile devices and can establish critical information such as ZIKV suspected, potential and confirmed cases, based on the surveillance protocol established by the WHO in 2016.

Other applications such as Mosquito Alert© have focused on reporting the presence of mosquitos in real time. Mosquito Alert© has been used mainly in Spain and has not been used much in the Americas where the most recent ZIKV outbreak has occurred. Monitoring mosquitoes is a very important part of the surveillance process. However, in order to evaluate the risk of infection in a geographical context it is necessary to model both mosquitoes and the presence of the virus in the States of Pernambuco and Paraiba in Brazil.

3 ZIKΛ SYSTEM - THE THEORETICAL FRAMEWORK

This paper proposes a novel surveillance system using a medical app to train (e-learning) health agents improving the surveillance of ZIKV in Brazil. In addition, by using other sources of data (governmental institutions, weather and climatic data, laboratory records, among others) the system can establish the potential areas of the ZIKV and its vectors. With that information is possible to assess the risk of the localities in the cities mentioned in section 2. The databases described in Fig. 1 improve the e- learning platform which helps health agents to identify mosquitoes' species and where the help is most critically needed, and good practices to reduce the spread of the virus. In addition, it will help to build and recalibrate the forecasting of ZIKV in real time.

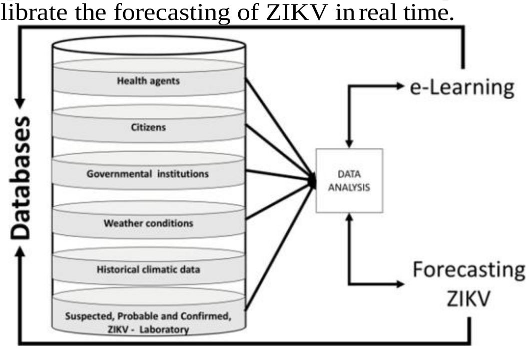


Figure 1. Schematic representation of the different databases and the construction of the forecasting of ZIKV and the e-learning app. Some datasets are updated every day and therefore the forecasting and the e-learning algorithms are recalibrating based on the ZIKV forecasting.

The distribution model of the virus and the vector is currently under construction and validation. The first model to assess both distributions only took into account historical climatic data and the scale is ~30 arc-sec (1 km^2). That model is used as an *a priori* model to build the most robust model (ZIVK Model).

The ZIVK Model integrates the databases from the health workers, governmental institutions, weather daily conditions and laboratory records (Fig. 2). The ZIKV Model is in constant recalibration, on a daily basis, from the databases described in Fig. 1. Health agents have been actively collecting data by visiting houses or other properties in vulnerable neighborhoods and uploading new data to the distribution model of the ZIKV and its vectors. The ZIKV Model uses georeferenced information provided by the health agent in combination with weather conditions associated with the georeferenced location of the health agent.

The output of the ZIKV Model is based on two distribution models (the virus and the vector) mapped in a geographical context, giving an associated risk index (Fig. 2). Random forest and Artificial Neural Networks have been used to model the species distributions of the genus Aedes [15, 16]. In the ZIKΛ system the models are still under construction and evaluation. The output of the ZIKV Model can be visualized by health agents and governmental institutions. To incentive the active participation of the health agent, a series of electronic rewards are included (this part of the app is still under construction).

The proposed system is unique because it combines healthcare surveillance and big data prediction in a single system. The system will empower local communities in the cities of Recife, Jaboatão dos Guararapes, and Olinda and give tools to governmental institutions to act more precisely by attending more vulnerable areas.

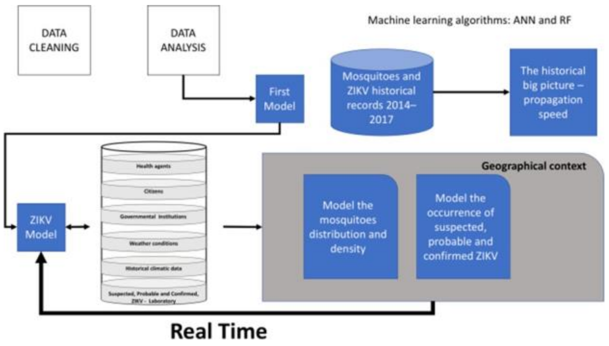


Figure 2. Schematic representation of the construction of the First Model and ZIKV Model.

4 ZIKΛ APP ARCHITECTURE AND IMPLEMENTATION

The ZIKΛ app was built in Ionic which allows for easy cross-platform rendering for both iOS and Android. The code was written in Angular and then compiled into iOS and Android apps. This allows for easy testing as code is written only once. Any platform-specific wrappers are added by Ionic automatically.

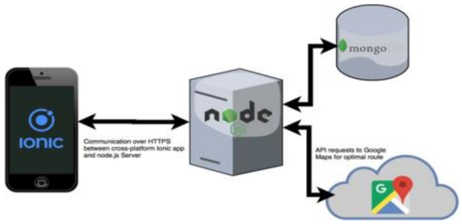


Figure 3. ZIKΛ app architecture showing the Google Maps API and the connection with the databases stored in MongoDB.

The server is built with Express.js, a node.js framework that allows the creation of a RESTful API by defining routes and running specific functions for the routes. This allows us to create protected paths that require an authentication token. This ensures that our database cannot become corrupted by anyone abusing the API. This also ensures that the user can only modify the specific database objects that they have access to. The ZIKΛ app architecture is represented in Fig. 3.

5 DATABASE MODELS

The ZIKΛ app uses email as the username and requires it to be unique within the database. Furthermore, instead of storing the actual password of the user, the ZIKΛ app only stores the hashed version. In terms of security, if the database is hacked, no sensitive information is leaked.

The activities are created with latitude, longitude, address and a photo as well as a list of assigned health agents to that property. This effectively allows managers to link individual properties to agents. This also allows for a very efficient lookup time by using MongoDB object IDs.

The forms that the health agents are required to fill out are stored as separate MongoDB objects with references to the ObjectID of the user as well as references to the ObjectID of the Property (Activity) they belong to. In this sense, it is very efficient to create functions that gives us information regarding the number of forms filed by an agent or the number of forms belonging to a property.

6 AUTHENTICATION AND SECURITY

The username and password are sent to the API endpoint 'auth/login'. This is done over HTTPS and the login function in the back-end will return two tokens. The first is a long-lived refresh token and the second is an authentication token. The second token is short lived, with a life span of 10 minutes. The second token is used to authenticate the user at every request. It does not hold any sensitive information and is signed with a secret only known to the server. When it has expired, the front- end requests a new authentication token using the refresh token. If this fails, the user is asked to authenticate again. The refresh token is kept within the database and can be invalidated and regenerated at any time. Furthermore, the tokens are JSON web tokens which are self-contained and are signed with a secret only available to the back-end server to ensure that they have not been tampered.

7 RELEASE, TESTING AND CONTINUOUS INTEGRATION

The Ionic app was compiled and bundled into an '.apk' file for Android and an '.ipa' file for iOS. Any future improvements require an update to these files.

The back-end Node.js server is hosted on Heroku and is using continuous integration testing to ensure that only a stable version is being served to the users at all times.

In order to test the code of both the app and the back-end we used the following: Mocha, Karma, and Chai.

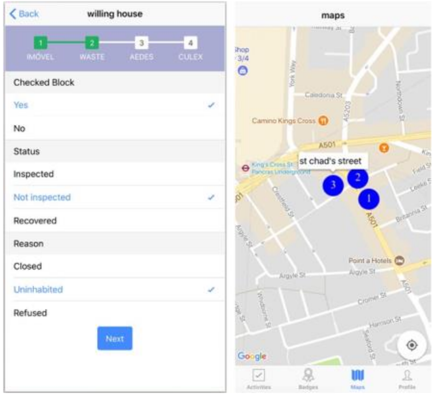
These allowed us to test all functions within both the front-end and back-end with assertions. This method ran the tests multiple times and in different browsers to ensure stability.

8 ZIKΛ APP DESIGN AND FLOW

At the moment, the workflow of the health agents is to visit as many properties as they can each day. From our observations before the implementation of the ZIKΛ app, we noticed that the process without the app was very inefficient. Health agents often communicated over telephone and wrote the reports of visited properties on paper which were later digitized manually. Therefore, the vision of the app is for this process to be automated (reducing the burden on health agents).

The setup process is as follows: health agents register on the app and managers will then be able to assign properties to individual agents by simply linking the address with the health agent's name.

All the properties a particular agent should visit are shown as cards, ordered by the Google Maps API based on their current location. This allows for the agent to visit more properties than before as the routes are now optimized. They can then add information about the property by simply clicking the "+" button. This might be modified taking into account the risk of areas where the properties are located.



Checked Block
Yes ✓
No

Status
Inspected
Not inspected ✓
Recovered

Reason
Closed
Uninhabited ✓
Refused

Figure 4. Multi-step form to be completed by health agents. The previous paper forms are now electronic, and each form could be completed during the inspection. An optimized route is given to visit properties by the health agent based on relative closeness and priority.

As seen in Fig. 4, the form is now multi-step with a progress bar and selectable options. This allows the agents to quickly complete the form and submit the information about the property they are visiting. The form is sent and stored in the database of health agents.

After selection of critical areas and to increase route optimization, the properties to visit are shown as numbered markers on the map. The users can then click on the map and add information about the property or redirect them to Google Maps for directions. This visualization allows health agents to quickly decide where to go to next. Additionally, the health agents can modify their information at any time easily and it will be updated in the database.

9 DISCUSSION AND FUTURE WORK

It is necessary to characterize the data streams given the great diversity of data sources [17]. The variety of data sources raises issues relating to high noise in real-time datasets, especially, including issues in public health such as swine flu, vaccines rumors, and even social media issues related with ZIKV [18-24].

The health agent's database is obtained by the daily use of the application by the health agents. The whole app has been designed to share their data in an automatic way. All reports from the health agents are georeferenced and validated using Google Maps API. The e-learning and gamified environment ensure that the data collection is situation-aware. All data collected by the app is structured. The health agents' reports are essential to validate the ZIKV Model described in Fig. 2.

One of the key innovations of the present system is the integration of citizens' data (collected by health agents) and official data in order to improve the current ZIKV surveillance and to forecast the occurrence of ZIKV. The governmental data includes density of citizens, number of hospitals per locality and also the official records of confirmed ZIKV outbreaks. Data offered by governmental institutions is sometimes outdated but contains the historical true positives of ZIKV and is therefore important to be included in the ZIKV Model.

Another key innovation of the present system is the combination of weather data to predict in real time the distribution of the ZIKV and mosquitoes. The timeliness of the weather data is perhaps the most finer scale database. The system uses the API from GlobalWeather.com to associate weather conditions for each report. The weather database is georeferenced and structured.

Perhaps one of the most fundamental parts of validating the models is to corroborate whether a suspected or a probable ZIKV case will be confirmed. To establish that condition it is necessary to conduct laboratory tests to find the ZIKV traces in the blood. This task takes several days. To improve that step we propose the use of a cost-effective and portable graphene-enabled biosensor described recently by the heath agents [25]; this issue is still under consideration by the government institutions. The use of this portable sensor will help to reach remote areas that could be in high risk.

Part of the validation of the model is to establish ZIKV presence when the citizens have been preventing the infection by avoiding bad practices. To do that, samples of water in high risk areas have been taken to analyze the presence of the virus in the larvae of the mosquitoes.

The ZIKV Model is currently under construction and evaluation and will be recalibrated on a daily basis given the new true positives, the true negatives, the changes in weather and the reports from the health agents and citizens. Combining the big data analysis and the gamified applications we could empower the local communities and health agents to fight and stop the spread of ZIKV using the ZIKΛ app.

10 CONCLUSIONS

This paper presents the ZIKΛ system which combines public health surveillance, citizen-driven participatory reporting with weather data-based prediction. The main characteristic of the system is to empower health agents by a gamified app that will also be a platform to share data and to visualize the output of the forecasting. The engagement of different actors to build robust forecasting and improve surveillance will help to stop the spread of the ZIKV. This will reduce the devastating consequences of ZIKV in neonates and improve the life quality of vulnerable people in Brazil.

ACKNOWLEDGMENTS

This work was supported by the British Council Newton Fund No. 280860230.

REFERENCES

[1] Martines RB, Bhatnagar J, Keating MK, Silva-Flannery L. Notes from the field: evidence of Zika virus infection in brain and placental tissues from two congenitally infected newborns and two fetal losses-Brazil, 2015. MMWR Morb Mortal Wkly Rep. 2016; 65:159–60.

[2] Oliveira Melo AS, Malinger G, Ximenes R, Szejnfeld PO. Zika virus intrauterine infection causes fetal brain abnormality and microcephaly: tip of the iceberg? Ultrasound Obstet Gynecol. 2016; 47:6–7.

[3] Gulland A. WHO urges countries in dengue belt to look out for Zika. BMJ. 2016; 352:i595.

[4] Attar N. Zika virus circulates in new regions. Nature Rev Microbiol. 2016; 14: 62.

[5] Javed F, Manzoor KN, Ali M, Haq IU, Khan AA, Zaib A, Manzoor S. Zika virus: What we need to know? J Basic Microbiol. 2017; 2017:3–16

[6] Fauci AS, Morens DM. Zika virus in the Americas—yet another arbovirus threat. N Engl J Med. 2016; 374: 601–604

[7] Musso D, Roche C, Robin E, Nhan T. Potential sexual transmission of Zika virus. Emerg Infect Dis. 2015; 21:359–61.

[8] Alam A, Imam N, Farooqui A, Ali S. Recent trends in ZikV research: a step away from cure. Biomed Pharmacother. 2017; 91:1152–9.

[9] Carlson CJ, Dougherty ER, Getz W. An Ecological Assessment of the Pandemic Threat of Zika Virus. 2016. PLoS Negl Trop Dis. 10:e0004968.

[10] Campos GS, Bandeira AC, Sardi SI. Zika virus outbreak, Bahia, Brazil. Emerg Infect Dis. 2015; 21:1885–6.

[11] Zanluca C, Melo VC, Mosimann AL, Santos GI. First report of autochthonous transmission of Zika virus in Brazil. Mem Inst Oswaldo Cruz. 2015; 110:569– 72.

[12] Faria NR, Azevedo RSS, Kraemer MUG, Souza R, Cunha MS, Hill SC, Thézé J, Bonsall MB, Bowden TA, Rissanen I, Rocco IM. Zika virus in the Americas: Early epidemiological and genetic findings. Science. 2016; 352: 345–349.

[13] Paz S, Semenza JC. El Niño and climate change–contributing factors in the dispersal of Zika virus in the Americas? Lancet. 2016; 387: 745.

[14] Kindhauser MK, Allen T, Frank V, Santhana RS. Zika: the origin and spread of a mosquito-borne virus. Bull World Health Organ. 2016; 94:86–67

[15] Messina JP, Kraemer MUG, Brady OJ, Pigott DM, Shearer FM, Weiss DJ, Golding N, Ruktanonchai CW, Gething PW, Cohn E, Brownstein JS. Mapping global environmental suitability for Zika virus. eLife. 2016; 5: e15272.

[16] Samy AM, Thomas SM, El Wahed AA, Cohoon KP, Peterson AT. Mapping the global geographic potential of Zika virus spread. Mem Inst Oswaldo Cruz. 2016; 111:559–560.

[17] Kostkova P. A roadmap to integrated digital public health surveillance: the vision and the challenges. ACM Proceedings of the 22nd International Conference on World Wide Web 2013. 2013; 1:687–694.

[18] Szomszor M, Kostkova P, De Quincey E. # Swineflu: Twitter predicts swine flu outbreak in 2009. International Conference on Electronic Healthcare 2010. 2010; 1:18–26.

[19] De Quincey E, Kostkova P. Early warning and outbreak detection using social networking websites: The potential of twitter. International Conference on Electronic Healthcare 2009. 2009; 1:21–24.

[20] Kostkova P. Grand challenges in digital health. Frontiers in Public Health. 2015; 3:134.

[21] Barata G, Shores K, Alperin JP. Local chatter or international buzz? Language differences on posts about Zika research on Twitter and Facebook. PLoS ONE. 2008; 13: e0190482.

[22] McGough SF, Brownstein JS, Hawkins JB, Santillana M, Simeone R, Hills S. Forecasting Zika incidence in the 2016 Latin America outbreak combining traditional disease surveillance with search, social media, and news report data. PLoS Negl Trop Dis. 2017;11: e0005295.

[23] Kostkova P, Szomszor M, St Louis C. #swineflu: The use of Twitter as an early warning tool and for risk communication in the 2009 swine flu pandemic. ACM Transactions on Management Information Systems. 2014; 5: 8.

[24] Kostkova P, Mano V, Larson HJ, Schulz WS. Who is Spreading Rumours about Vaccines?: Influential User Impact Modelling in Social Networks. ACM Proceedings of Digital Health 2017. 2017; 1: 48–52.8

[25] Afsahi S, Lerner MB, Goldstein JM, Lee J, Tang X, Bagarozzi Jr DA, Pan D, Locascio L, Walker A, Barron F, Goldsmith BR. Novel graphene-based biosensor for early detection of Zika virus infection. Biosensors and Bioelectronics. 2018:15:85–8.