Quest Journals
Journal of Medical and Dental Science Research
Volume 3~ Issue 12 (2017) pp: 26-28
ISSN(Online) : 2394-076X ISSN (Print):2394-0751
www.questjournals.org

Research Paper

Identifying Likely Invasion Sites of Zika Virus Infected Mosquitoes through Air and Sea Ports in Mumbai, India

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Received; 20 Jan 2017 Accepted; 31 January 2017; © The author(s) 2017. Published with open access at **www.questjournals.org**

ABSTRACT: *Several mosquito species are capable of invading new geographic regions and exploiting niches that are similar to their natural home ranges where they may introduce, or reintroduce, pathogens. In addition to initial invasion, introduction of new genotypes into established populations may also occur. Zika virus is spreading throughout the world, posing a significant health risk to human populations, particularly for pregnant women and their infants. Mumbai, India currently has active dengue and chikungunya virus circulating in the mosquito and human populations. The BioTEMS TIGER model was used to analyze abiotic and biotic factors influencing potentially Zika infected Aedes species, should they enter through the air and sea ports in Mumbai. The model has been validated by overlaying documented and suspected concurrent Zika cases and comparing published high risk areas for Zika virus in Florida and Brazil. Zika introduction/invasion zones were identified and output indicates surveillance and mosquito management should be conducted in larger zones than local authorities may be considering. Surveillance sites at ports should be identified and prioritized for pathogen and vector control to reduce the import of mosquitoes infected with Zika virus. Providing higher resolution predictive maps may assist local public health officials in reducing the threat of Zika virus invasion into Mumbai.*

Keywords: *Aedes, arbovirus, invasive species, port security, biological agents, India*

I. INTRODUCTION

Zika virus (ZIKAV) continues to spread across the globe. Establishing patterns of invasion and spread into new geographic areas is critical for protecting the public health of naïve human populations. Recently, several publications on the nature and the spread of ZIKAV in geographic regions have been published. The principle factor responsible for the introduction of disease vectors is air and ship transport (Tatem et. al. 2006; Meyerson and Mooney, 2007). In addition to the import of infected mosquitoes, introduction of ZIKAV into the a new geographic area can occur when local mosquitoes bite infected travelers and become infector or when people become infected through contaminated blood or through sex (Hills et. al. 2016). Many of the models published are of low resolution, and although excellent models for looking at global information, they provide little insight into the spread of ZIKAV in local communities. Mosquito-borne diseases pose a significant health risk to the population in India, as well as imposing an economic burden on the government for mosquito surveillance, control and health care (Shepard et al 2014). *Aedes aegypti* and *Ae.albopictus* are the primary vectors of dengue, chikungunya and ZIKAV and understanding risk of invasion of these two species is critical.

A survey of *Aedes* mosquito species was conducted in Mumbai in 2010 in the housing and operational sites in the Mumbai Port Trust area (Kumar et. al. 2104). *Aedes aegypti* was found primarily breeding in fire buckets in the port area; also found was a high level of insecticide resistance to temephos and fenthion. How mosquito-borne pathogens might spread from the port area in Mumbai through suitable vectors is not known. Because of the number of mosquitoes around the airport in Mumbai during 2016, public health officials conducted surveillance and control measures at a radius of 400 m surrounding the airport. However, this distance for control may not be adequate. The Bioagent Transport and Environmental Modeling System (BioTEMS) was used to provide information should ZIKAV invade through the maritime port and airport in Mumbai. Public health officials at the local level in Mumbai may benefit from information concerning sites of possible invasion of ZIKAV infected mosquitoes or humans and sites for expanded areas of integrated mosquito management (IMM), including surveillance and control, and to prevent the establishment or reduce the risk of ZIKAV in the community.

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II. MATERIALS AND METHODS

ArcGIS geospatial analysis software, Statistica statistical software and BioTEMS were used to analyze geographic information and conduct data analysis. BioTEMS utilizes up to several hundred abiotic and biotic factors to produce risk and vulnerability assessments for biological agents and infectious diseases. Examples of biotic and biotic factors include; pathogen strain, vector/host relationship, vectorial capacity, host/vector physiology, colonization ability, population dynamics of hosts and vectors, soil, shade, and weather conditions, such as wind, temperature, precipitation, shade. Analytical methods within BioTEMS includes; artificial intelligence, fuzzy logic, niche analysis, random forests and general additive regression and statistics. As the former Epidemiologist of the USAR Consequence Management Unit and as the Brigade Surgeon for the 415th Chemical Brigade, BioTEMS was used in risk analysis and vulnerability assessment for biological weapons of mass destruction, including; *Bacillus anthracis, Francisella tularensis, Yersinia pestis*, and Crimean-Congo hemorrhagic fever virus. These assessments were used during consequence management planning for military facilities in the U.S. and internationally, government facilities and during presidential/national events. BioTEMS has also been used with HPAC to analyze bioagent information and to optimize placement of Biological Integrated Detection Systems. In addition to applications for biological weapons defense, BioTEMS has been used for infectious disease modeling and planning.

The BioTEMS TIGER model was developed to assist in identifying areas at highest risk for invasive mosquito species and pathogens and to optimize surveillance and control efforts (Kollars et. al. 2016). Within the BioTEMS TIGER model; Transport- identifies the point of origin, method and rate of transport to a locality, Introduction- point of initial introduction/immigrant haplotypes and preliminary spread into a locality, Gap- determines the area where vector/pathogen initially spreads once it has gained a foothold, Escalade- incorporates abiotic and biotic resistance to invasion, and Residence and recruitment - incorporates factors and area where vector/pathogen adds to genetic diversity or becomes endemic and recruits con-specifics. The BioTEMS model has been used to identify areas at risk for ZIKAV and identify areas for integrated mosquito management in maritime ports in Miami, Tampa, Mayport Naval Port in Florida, and the ports of Rio de Janeiro and Fortaleza, in Brazil (Kollars and Kollars, 2016; Kollars, 2017). Areas at risk of Zika virus and IMM zones were developed based on the BioTEMS TIGER model should Zika virus be introduced through the air and sea ports in Mumbai. BioTEMS and ArcView were used to produce output into Google Earth.

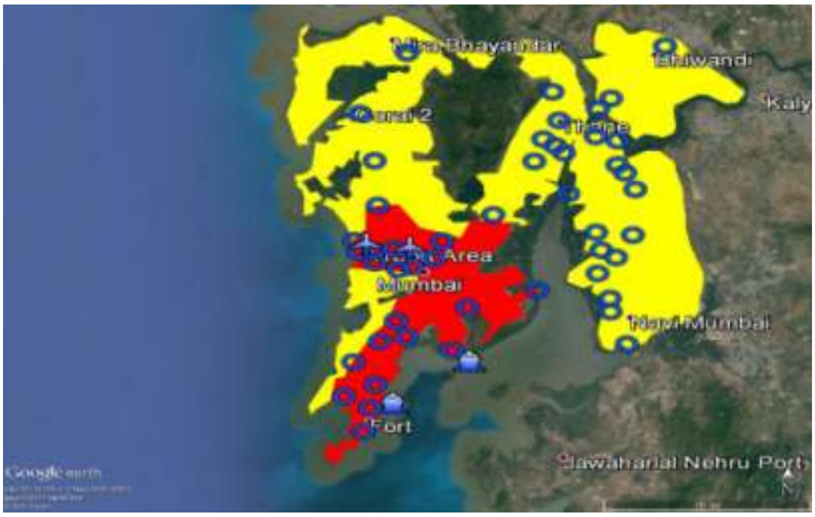
III. RESULTS AND DISCUSSION

Four sites principal sites were identified and analyzed using BioTEMS for import of ZIKAV into Mumbai, two airport areas and two maritime port areas (Figure 1). Approximately 150 km^2 of Mumbai is at risk for introduction and spread of ZIKAV during the initial invasion of the virus through mosquitoes or humans in the port areas infecting local *Aedes* mosquitoes. Approximately 634 km^2 of Mumbai and its surrounding area, is at risk for Gap infiltration of ZIKAV infected mosquitoes. Surveillance sites around the ports as well as throughout the greater Mumbai area were identified to assist in surveillance of ZIKAV as in other ports, e.g. Miami (Florida), United Arab Emirates, Hong Kong, Malaysia, Republic of Georgia, Honduras and Brazil. Import of ZIKAV into Mumbai and other ports in India is of high probability if ZIKAV is endemic at the port of origin or infected mosquitoes or personnel are in transit. BioTEMS predicted that if ZIKAV was imported into the Mumbai air and maritime ports, it would rapidly spread through the mosquito population, endangering the human population.

Due to the resistance of temephos and fenthion in *Aedes* vectors in Mumbai, alternative pesticides must be sought. Recently a new pesticide was tested which has both adulticidal and larvacidal activity (Yalwala et al. 2016). The pesticide is non-toxic and has been tested in port areas and when used in applicators such as the ProVector Tube, the pesticide remains active up to 3 months (Kollars et al. 2016). The technology used in the ProVector allows for the adult mosquito to ingest the pesticide and then transport the pesticide to larval breeding sites. In approximately 7 days the adult mosquito dies and if the mosquito lands in water, the larval mosquitoes die as well. The ProVector may provide a useful tool in killing larva mosquitoes in various breeding sites, including the fire buckets. The ProVector tube can be hung from structures in air and maritime ports as well as on ships to help reduce the risk of ZIKAV infected mosquitoes from being imported into Mumbai. In the event an infected traveler infects local mosquitoes, the presence of ProVector applicators, or other long lasting environmentally safe pesticides, can reduce the mosquito population and reduce the risk of ZIKAV spreading.

In conclusion, caution should be taken when identifying control and surveillance sites for *Aedes* mosquitoes. Reports of the flight ranges of *Ae. aegypti* range from 150 to over 3,000 m and 200 to 800 m for *Ae. albopictus* (Reiter et al 1995; Liew and Curtis 2004). The flight range and habitats of *Aedes* mosquitoes should be identified in Mumbai to assist authorities in better controlling these medically important species. In the assessment for ZIKAV, seaports should be considered as they often play a critical role in the invasion of *Aedes* mosquitoes; this includes recruitment of new haplotypes (Futami et. al. 2015). Identifying the correct pesticide to avoid resistance or environmental contamination is an important aspect if IMM. The possible invasion of arboviruses through ports, both aviation and maritime, is not a new concept (Gardner and Sarkar, 2015). Focusing control efforts primarily on travelers and not including ports of entry may do a disservice to the population to whom public health officials are trying to protect. Integrated mosquito management plans should be put into place before ZIKAV arrives ashore through infected mosquitoes or infected humans.

Figure 1. Areas in the Greater Mumbai area at high risk for the introduction of Zika virus (red) and recommended integrated mosquito management (yellow) should Zika virus be introduced through the air and sea ports. Recommended surveillance sites for mosquito surveillance (blue circles).



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