Application of GIS and Modeling of Dengue Risk Areas in the Hawaiian Islands

M. Napier

Pacific Disaster Center, 590 Lipoa Parkway Suite 259 Kihei, HI 96753 - mnapier@pdc.org

Abstract - Geographic analysis was conducted for the 2001-2002 Dengue Fever (DF) outbreak in the state of Hawaii. A GIS (Geographic Information System) spatial/temporal analysis depicting the spread of the disease and a spatial Dengue Threat Model (DTM) were created. In addition, GIS case clustering and mean/median distance comparison analysis of homes in rural and semi urban areas were conducted. The DTM is primarily a predictor of areas exhibiting the geographical, environmental, and epidemiological characteristics similar to East Maui where the majority of Dengue infection occurred. DTM output is derived via a weighted overlay analysis of the various datasets. This model may be adapted for use as a predictor in other arboviral (arthropod borne) outbreaks in various geographic locals.

Keywords: Hawaii Dengue Fever outbreak, Geographic Information System, Dengue Threat Model, *Aedes albopictus,* Nahiku, Hana.

1. INTRODUCTION

Arthropod borne viruses (Arboviruses) such as Yellow fever, Malaria, encephalitides (eg West Nile Encephalitis), Filariasis, and Dengue Fever are expanding worldwide. In fact, mosquito borne infections rank in the top five death etiologies in the world.

Although DF is rarely fatal, the disease is debilitating in its effects in which patients experience high fever, rash, and severe body pain typically for two to three weeks.

DF is currently spreading at an alarming rate in the Pacific. As DF continues to establish itself as a pandemic, it becomes of paramount importance to study the disease and glean information to help officials make decisions to reduce the incidence and severity of DF outbreaks.

A significant outbreak of Dengue Fever has not occurred in the Hawaiian Islands in nearly fifty years. Historically, Hawaiian Dengue epidemics occurred in 1852, 1856 and 1903, including a major epidemic in Honolulu in 1943. At such time, some 1400 people were infected. Data suggests the uniqueness of the 2001 Hawaii DF outbreak lies in the geographical\ environmental features near foci and the increased incidence of import dengue cases. The 2001 outbreak infected 124 individuals.

Of the four DF serotypes, DEN 1-4, DEN-1 was identified as the Hawaii infection serotype in the 2001 outbreak (Hayes, 3.2). No deaths occurred and no hemorrhagic forms (Dengue Hemorrhagic Fever) of the disease surfaced.

Essentially, the GIS analysis of the outbreak included four components: three phases of data collection, a CDC (Centers for Disease Control and Prevention) study, "SK Factors for Dengue Infection, East Maui DEN-1 Outbreak, Hawaii, 2001", an automated spatial-temporal GIS analysis, and the DTM.

In September 2001, an investigation of the outbreak began. It was essentially comprised of three phases in which a major portion of the data were collected:

The first data collection phase included a cursory investigation to gather geographical and epidemiological outbreak data as well as observe the sociological components of the outbreak.

The second phase involved a random seroepdemiological survey of outbreak foci, and a house-to-house comparison of rural areas vs. semi urban areas. Two points of study were investigated. First, a determination of the environmental, sociological and epidemiological differences applicable to these areas. Secondly, elimination of any possible data gaps due to late DF onset or inconclusive laboratory results.

The third phase involved completion of the positive DF case GPS (Global Positioning System) point dataset and four-wheel drive roads.

2. METHODOLOGY

2.1 Study Area

Although the islands of Maui, Oahu, and Kauai were all affected by the Dengue Fever outbreak, the majority (73.9 %) of the infections occurred on the island of Maui, specifically in the Hana/Nahiku area on the eastern side of the island.

2.2 Initial Study

On September 24, 2001, a small team of individuals from the State of Hawaii Department of Health and the Pacific Disaster Center were deployed to Nahiku, Maui, to determine the locations of the first suspected dengue cases, and extract blood from potentially infected individuals. Observations of the environmental, biological and geographical conditions such as vegetation, mosquito breeding areas, and climate were noted for further study. GIS point and line data were collected using GPS technology for potential cases and other geographic information. In addition, digital photographs were taken of areas and objects harboring mosquito larvae subsuming perennial streams, man-made containers, and vegetation. Utilizing these collected data, the fundamental layers were created for the analysis.

State health officials were hesitant to publicly announce the presence of DF as suspect cases were not CDC confirmed at this time. Positive confirmation for DF required the extracted bloods to be sent via airline to the CDC Puerto Rico Dengue laboratory for analysis.

Due to the terrorism events on September 11th, DF confirmation was delayed for a few weeks as a result of the worldwide air travel moratorium.

In the meantime, suspect cases and environmental attributes were concurrently studied in anticipation of a DF outbreak affirmation. Following positive Dengue confirmation, CDC officials augmented the study with Dengue experts, biologists, and entomologists. Field studies involving extraction of mosquito larvae from streams, man-made containers and vegetation were conducted to determine the DF transmission vector. The vector was identified as the *Aedes albopictus* mosquito. Of the two Dengue vectors, *Aedes aegypti* and *Aedes albopictus* mosquitos, *aegypti* mosquitos are much more aggressive disease transmission vector. It is speculated if the *Aedes aegypti* mosquito were the DF transmission vector in the 2001 Hawaii outbreak, the rate and incidence of disease spread would have been much higher. Additionally, the concurrent aggressive eradication campaign carried out by the Hawaii State and County Vector Control departments encouraged a rapid reduction of Dengue transmission.

2.3 Second Phase - Seroepidemiological Study

October 27-29, 2001
Upon CDC confirmation of DF, a team of approximately sixty individuals comprised of CDC officials, State of Hawaii Health Department employees, Pacific Disaster Center personnel, Maui County Health Department personnel, Hana High School faculty, and Hana area residents conducted a seroepidemiological survey.

The group was divided into two teams in order to survey two geographic area types: the rural village of Nahiku and the semi-urban Hana Subdivision. The survey entailed randomly extracting bloods from area residents and administration of pre-written hardcopy epidemiological questionnaires. Vector hardcopy maps identifying roads and houses targeted for the survey were distributed to designate team members prior to field deployment. Small reconnaissance teams were dispatched into the field prior to the seroepidemiological survey to verify and enhance existing maps.

Map creation involved digitizing house rooftops from high-resolution air photos with associated unique identification numbers. The Unique ID numbers constituted the link for the database to GIS. GPS data was gathered for undetected points (homes) on the air photos then integrated into the database. GIS maps of each area were produced prior to team deployment, printed in hardcopy format and distributed to team members for identification of the Unique Identification codes to attach to the GIS.

Bloods were subsequently sent to the San Juan Laboratories, Dengue Branch, National Center for Infectious Diseases, Center for Disease Control and Prevention (CDC) Puerto Rico, for positive Dengue Case confirmation using the ELISA method. The data were transmitted to the Hawaii DOH and PDC for integration into the GIS and DOH databases. Laboratory results from this particular survey comprise approximately half of the DF case point data attribution.

2.4 Final Data Collection Phase -

November 10-12, 2001
A two-person team from the State of Hawaii DOH and PDC were deployed to collect GPS coordinates for any remaining or new positive Dengue cases in Nahiku.

2.5 General Data Sources

All tabular case data from the various entities (State DOH, Maui County DOH, CDC, and PDC) were compiled into Excel spreadsheets using individual patient unique ID numbers associated to GPS coordinates. Specific CDC confirmed case data were collected in the field utilizing a customized database in conjunction with mapping software allowing immediate case geocoding and verification.

GIS field data collection was conducted utilizing a Trimble Pro XRS GPS system connected to specialized weatherproof field computer (VIA Computer Systems belt worn PC). The collected data was verified in real time to previously rectified USGS DRGs (digital raster graphics) in addition to road and stream vector data. Geographically rectified high-resolution air photographs were especially useful in locating households in rural areas. Actual GPS positioning was simultaneously observed, verified and collected with aerial photographs overlayed on the previously mentioned data layers. GPS technology proved to be a crucial capability in the analysis. Virtually no other method existed to geocode potential cases in these remote areas as street addresses are virtually non-existent in many rural areas of East Maui. Case households not accessible in the field were identified on high-resolution air photos with assistance from the Hana Public Health nursing staff, exemplifying the value of local knowledge in similiar situations.

3. ANALYSIS/HYPOTHESIS

3.1 GIS Analysis – Hana/Nahiku Spatial Home Analysis Methodology

3.1a Study Area- The areas of the Hana subdivision and Nahiku village on the Eastern shore of Maui were chosen as study areas due to 1) The majority of DF cases occurred in these areas and, 2) A serepidemiological analysis was conducted in these areas by the Hawaii State Department of Health, Pacific Disaster Center, CDC, and Maui County Health Department.
A mean and median distance analysis of homes in a CDC designated polygon area was conducted on each area. These data were then incorporated into the CDC "SK Factors for Dengue Infection, East Maui DEN-1 Outbreak, Hawaii, 2001" study. (Hayes, 3.1)

3.1b Unique Data Sources- Vector maps were created utilizing high-resolution raster air photos (Air Survey Hawaii, 2000) and USGS DRG's (United States Geological Survey Digital Raster Graphics) vector coastline files, roads and stream data.

3.1c Methodology- Two separate ESRI .shp (shape) files were created for homes in a CDC predetermined study area in Arcview 3.2a. The shapefiles were then converted into ARCINFO coverages in ARCGIS 8.1 ARCINFO Toolbox . The house- to - house (for each consecutive house) distances were then calculated using the Proximity Application in ARCGIS 8.1 ARCINFO Toolbox. The coverages were converted into a .dbf file, imported into Microsoft Excel, and the mean and median calculations were executed using the statistical function tool.

3.1d Results
HANA
Mean distance between homes in selected polygon area*: 158.83 meters
Median distance between homes in selected polygon area*: 144.26 meters
*Study area = 6154.16 m2 or 1.5 acres perimeter of study area=109.67 m
NAHIKU
Mean distance between homes*: 1072.22 meters
Median distance between homes*: 1072.57 meters
*Study area = 25,713.9 m2 or 63 acres perimeter of study area 7027.10 meters

3.2 GIS Analysis-Spatial/Temporal Animation Analysis

3.2a Data- DF CDC confirmed case data and vector coastline files of the entire state of Hawaii.

3.2b Methods- A custom script was created using Avenue programming language enabling an automated visualization of the DF outbreak based on temporal characteristics of the event.
3.2c Results- The automation illustrates the movement of DF cases radiating from East Maui to more populated areas of the island. From Maui, the disease spreads to the island of Kauai, and finally Oahu. One would assume the transmission occurred through inter-island autochthonous infection, but data suggests the statewide manifestation of DF resulted from an abnormally high amount of imported DF cases in 2001. Typically, Hawaii has on average four to five import cases of DF annually. By contrast, the state of Hawaii was invaded with some thirty-six imported DF cases in 2001. (Effler, Ayers, 3.3)

3.3 Dengue Threat Model

3.3a Study Area- The six main islands of Kauai, Oahu, Maui, Molokai, Lanai, and Hawaii were included in the model.

3.3b Methodology
Precipitation- Individual polygons were created from each contour line. Data were then converted to GRID format using both ARCGIS 8.1 and Arcview 3.2a. Rain polygons were created from isohyet line data then converted to grids. Isohyet data were obtained from the Rainfall Atlas of Hawaii (State of Hawaii Department of Land and Natural Resources, Division of Water and Land Development.
Vegetation- Data downloaded from the National Oceanic and Atmospheric Administration, Coastal Service Center. Individual island images were then mosiaced and reprojected as one large file. A grid was then created using ERDAS Imagine 8.2 software.
Dengue Cases- the majority of clustering CDC confirmed positive cases were geographically located using GPS (global positioning system), although some were obtained via locating the household on air-photos with the assistance of the Hana Public Nursing staff. Some case points were derived via address geocoding.

Elevation- USGS DEM (Digital elevation model)
Aedes albopictus mosquito density - Hardcopy ovi trap data were obtained from the State of Hawaii Department of Land and Natural Resources. Data were transferred to a GIS via geocoding traps to place names to individual ovi traps.

Temperature- Data for each station weather station was downloaded from the Western regional Climate Center. Raw files were processed in a text editor, then imported into Arcview GIS 3.2a as .dbf files, processed as shapefiles, and geographically rectified to the rain gage files downloaded from the State Hawaii GIS website. Data were also acquired from the National Climate Data Center and processed in the same manner.

Population- Landscan 2000 census data were used as the demographic layer.

Streams- Streams were collected in the field Penmap data collection software in conjunction with GPS. Other streams data were obtained from the Hawaii State GIS website.

Roads- Four Wheel Drive Roads and DF cases were simultaneously collected.

Successive model runs indicate DF concentrating in areas exhibiting characteristics of rainfall in the 1500-5000 mm range per year, tropical rainforest with adjacent grassland, rural demographic types, and high mosquito populations. At this time, a variety of datasets are being incorporated into the model in anticipation of additional threat maps for the state of Hawaii.

The model may be used as a predictor in future DF outbreaks, as well as other health related outbreaks and may help officials make decisions to contain and possibly eliminate the disease before catastrophic spread occurs.

3.4 Climatological Hypothesis
DF outbreaks occurred in 1852, 1856, 1903, 1943 and 2001. Interestingly, these years coincide on or near El Nino years. El Nino events in Hawaii are normally associated with drought during the winter months in Hawaii, especially particular locations on Maui. Additionally, historical thirty-year average rainfall totals are lowest and thirty-year average temperature averages are the highest during the month of September. Thus, in relative terms, high temperature and low precipitation values existed both seasonally and climatologically in the peak of the 2001 outbreak.
Lack of stream flow as a result of lower precipitation values typically results in water pooling and stagnation in East Maui perennial streams. Furthermore, many East Maui stream gauging stations divert stream-flow during drought periods to central Maui sugar cane irrigation systems, rendering many streams in East Maui without flowing water. Field observations in East Maui verify an overabundance of mosquito larvae in stream pools during these periods, although currently no conclusive excessive eclosion (hatching) data have been identified. As a result, a correlation of higher than normal mosquito densities may be attributed to water pooling in streams during drought periods.
In addition, higher temperature values often result in higher ovi production. (Barry M. Alto and Steven A. Juliano, 3.2) Research indicates higher ovi production and increased eclosion rates in the *aedes albopictus* species in similar conditions experienced in East Maui. (Barry M. Alto and Steven A. Juliano, 3.2)
Tropical vegetation may also contribute significantly to the overall mosquito population as numerous tropical plant species found in East Maui possess modified stems allowing water accumulation between leaf axils. Some plants regularly hold 10-

20ml of rainwater in each leaf node. Each leaf node or "tank" typically hosts several mosquito larvae (as many as ten) as observed in the Nahiku study by the CDC/PDC team. Coupled with stream-flow disruption and higher climatologic temperatures, the enormous tropical biomass adds another multiplier to the total ovi-production equation. Successive generations under these conditions may very well equate to maximum mosquito population densities over time, setting the stage for arbroviral outbreaks.

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Authors and Affiliations:
1. Hayes JM, (1) Dengue Branch, Division of Vector-Borne Infectious
Diseases, National Center for Infectious Diseases (NCID), Centers for
Disease Control and Prevention (CDC), San Juan, PR
2. Rigau JG (1)
3. Reiter P (1)
4. Effler P, (2) State of Hawaii Department of Health, Honolulu, HI
5. Pang L, (2)
6. Vorndam V, (1)
7. Hinten S, (3) Division of Vector-Borne Infectious Diseases, NCID, CDC,
Fort Collins, CO
8. Mark K, (4) Epidemiology Program Office, CDC, Atlanta, GA
9. Myers M, (4)
10. Street K, (2)
11. Bergau L, (2)
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13. Amador A, (1)
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Paul V. Effler
M.D., M.P.H.
State Epidemiologist
Epidemiology Branch Chief
Hawaii State Department of Health

Tracy L. Ayers
Influenza Surveillance Coordinator/GIS Analyst
Hawaii State Department of Health

Dr. John M. Hayes
Epidemiologist
Centers for Disease Control and Prevention

Kathleen Street
Public Health Nurse
Hawaii State Department of Health

Delores (Loli) Bergau
Public Health Nurse
Hawaii State Department of Health

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