Review: Geographical Information Systems for Dengue Surveillance

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Abstract. This review provides details on the role of Geographical Information Systems (GIS) in current dengue surveillance systems and focuses on the application of open access GIS technology to emphasize its importance in developing countries, where the dengue burden is greatest. It also advocates for increased international collaboration in transboundary disease surveillance to confront the emerging global challenge of dengue.

In the last 50 years, dengue incidence has increased 30-fold to more than 50 million cases annually.¹ Approximately 70% of those people at risk of dengue reside in the Asia Pacific region, predominantly in developing countries such as the Philippines, Indonesia, Vietnam, and Thailand.¹ In lieu of a vaccine, dengue prevention is limited to vector control (chemical spraying, biological control, physical removal of breeding sites, and improving infrastructure) and community education. Surveillance is essential to dengue management, because it identifies the number and distribution of cases, virus serotypes, and severity of disease in a population. Geographical Information Systems (GIS) allow further investigation of surveillance data through spatial statistical analyses and visualization of patterns and relationships between disease and the environment.

This paper reviews the role of GIS in current dengue surveillance systems. It identifies ways that GIS can enhance dengue surveillance, and it describes recent technological advances for improved targeting of prevention and control programs. In doing so, this paper advocates for a collaborative approach to dengue management, moving from an autonomous framework to an international model that emphasizes information sharing and program planning at a regional scale.

GIS are databases that can capture, store, analyze, and display data that are linked by a common spatial coordinate system. GIS are most commonly used for data visualization in dengue surveillance, allowing identification of the distribution of disease and changes over time and identification of spatial relationships with risk factors for disease.² Maps for visualization of dengue surveillance data are particularly useful for public health professionals advocating for increased resources, such as vector control or laboratory facilities for serological confirmation of disease, because policy makers respond more positively to maps rather than raw numbers or graphs.³

Mapping the distribution of dengue in a geographic area allows instant visual identification of areas at risk and enables faster mobilization of resources. Figure 1 shows incidence data from the Philippines, where the Cordillera Administrative Region (CAR) had the highest incidence of dengue in 2010. In Nicaragua, Google Earth and ArcGIS were used to map dengue cases and *Aedes* larval infestation and development sites.⁴ These maps were then used by public health

staff to target specific neighborhoods for immediate dengue control measures.

Spatiotemporal mapping using GIS allows visualization of changes over time in a particular geographic area or population. This information is vital to understanding the dynamics of the disease and can influence planning of future control programs. For example, a study in Brazil from 1996 to 2002 showed changes in epidemic zones and identified areas considered spatially vulnerable, which is important information for predictions of future dengue outbreaks.⁵ Furthermore, spatiotemporal analysis of an interior residual spraying (IRS) program in Cairns, Australia, used data from previous dengue outbreaks to show that 90% of dengue cases were located within a 100- to 300-m radius of the index case during the first wave of transmission and that IRS was only effective if 60% or more of houses were treated.⁶ These results informed strategic changes in Cairns dengue control policy and action.

Identifying drivers of dengue is also possible using GIS and is particularly useful in the initial stages of analysis, where relationships between variables can be evaluated visually and linked geographically before rigorous statistical testing is undertaken. For example, older age, low education, and low income were identified as drivers of dengue infection in Brazil.⁷ This information was used to target community-based social mobilization and communication programs. Recent studies using GIS to identify meteorological drivers of dengue infection (rainfall, temperature, and humidity) have progressed methodologically and should now be applied to real-life disease management.^{8–10}

Exploratory applications of GIS can be used to predict outbreak zones. Cluster detection algorithms, such as Kulldorf's spatial and space time scan statistics, implemented with open access software (SaTScan) can be used to detect dengue clusters (a statistically significant excess of cases within a defined geographic location and time period). This application can enable more accurate planning of programs and allocation of resources and timelier, more efficient epidemic responses. One example of an application of the spatial scan statistic has been reported from Thailand.¹¹ The authors suggested that this methodology could be used to identify the most critical clusters at differing geographic scales (i.e., province, neighborhood, and household). Furthermore, low-risk clusters can be identified using SaTScan, allowing reorientation of resources to areas most likely to have an outbreak.^{12,13}

Spatial decision support systems (SDSS) are interactive computer-based systems built on GIS platforms that are designed to enhance decisions at various stages of the planning process to produce the most effective result. Historically,

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FIGURE 1. Dengue incidence by administrative region in the Philippines in 2010. Data sources: National Statistics Office (Philippines) and National Epidemiology Centre, Department of Health (Philippines).

they have been used in environmental management as a planning tool and have recently been applied to infectious diseases such as West Nile virus. Using this technology for dengue could further progress surveillance systems in terms of efficiency and resources.³ Particularly, a dengue SDSS could be automated to regularly undertake statistical data analysis and produce reports and maps accordingly.

Despite the usefulness of GIS technology, there are a number of challenges to implementation, including the lack of reliable epidemiological, entomological, serological, and geographical data, the computational demands of some applications, and the cost of purchasing and maintaining the software and training staff.⁴ Improving data is a process that is particularly time consuming; however, the recent develop-

ment of open access data management tools may assist the process.¹⁴ Furthermore, advances in open access applications have made GIS widely accessible and easier to use, and public health experts advocate for these programs in underresourced countries. For example, Quantum GIS and GeoDa are robust open access applications that can be downloaded from the internet. A dedicated website (www.opensourcegis.org) has been established as a central repository for all open access GIS applications.

Currently, international collaboration in dengue surveillance is limited. Given that dengue transcends international borders, collaboration at the regional and global level is imperative. The World Health Organization has established DengueNet, a website that aims to provide standardized data

to compare disease burden between countries. Unfortunately, data are incomplete and unreliable. The development of enhanced international relationships and collaborations could help improve surveillance at subnational, country, and regional levels, increasing the ability of programs such as DengueNet to be used for global disease management planning.¹⁵

The advancement of GIS technology has the potential to greatly assist dengue prevention and control. Open access applications enable all countries to use this technology, including those nations with limited resources. Advances in open access GIS technologies should be viewed as a catalyst for increased global collaboration, where information sharing and public health planning are prioritized to achieve common goals. By improving surveillance and control and identifying where resources would be best directed, dengue transmission will be restricted, and ultimately, incidence and mortality will be reduced.

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REFERENCES

1. World Health Organization, 2009. *Dengue Guidelines for Diagnosis, Treatment, Prevention and Control*. Available at: http://whqlibdoc.who.int/publications/2009/9789241547871_eng.pdf. Accessed July 13, 2011.
2. Eisen L, Lozano-Fuentes S, 2009. Use of mapping and spatial and space-time modeling approaches in operational control of *Aedes aegypti* and dengue. *PLoS Negl Trop Dis* 3: e411.
3. Fisher FP, Myers BA, 2011. Free and simple GIS as appropriate for health mapping in a low resource setting: a case study in eastern Indonesia. *Int J Health Geogr* 10: 15.
4. Chang AY, Parrales ME, Jimenez J, Sobieszczek ME, Hammer SM, Copenhaver DJ, Kulkarni RP, 2009. Combining Google Earth and GIS mapping technologies in a dengue surveillance system for developing countries. *Int J Health Geogr* 8: 49.
5. deMattos Almeida MC, Caiaffa WT, Assunção RM, Proietti FA, 2007. Spatial vulnerability to dengue in a Brazilian urban area during a 7-year surveillance. *J Urban Health* 84: 334–345.
6. Vazquez-Prokopec GM, Kitron U, Montgomery B, Horne P, Ritchie SA, 2010. Quantifying the spatial dimension of dengue virus epidemic spread within a tropical urban environment. *PLoS Negl Trop Dis* 4: e920.
7. Siquiera JB, Celina M, Martelli T, Maciel IJ, Oliveira RM, Ribeiro MG, Amorim FP, Moreira BC, Cardoso DDP, Souza WV, Andrade ALSS, 2004. Household survey of dengue infection in central Brazil: spatial point pattern analysis and risk factors assessment. *Am J Trop Med Hyg* 71: 646–651.
8. Nakhapakorn K, Tripathi NK, 2005. An information value based analysis of physical and climatic factors affecting dengue fever and dengue haemorrhagic fever incidence. *Int J Health Geogr* 4: 13.
9. Ferreira GS, Schmit AM, 2006. Spatial modelling of the relative risk of dengue fever in Rio de Janeiro for the epidemic period between 2001 and 2002. *Braz J Prob Stat* 20: 29–47.
10. Hu W, Clements A, Williams G, Shilu T, 2009. Climate variability and dengue fever infections in Queensland, Australia. *Epidemiology* 20: S27–S28.
11. Jeefoo P, Tripathi NK, Souris M, 2011. Spatio-temporal diffusion pattern and hotspot detection of dengue in Chachoengsao Province, Thailand. *Int J Environ Res Public Health* 8: 51–74.
12. Tran A, Deparis X, Dussart P, Morvan J, Rabarison P, Remy F, Polidori L, Gardon J, 2004. Dengue spatial and temporal patterns, French Guiana, 2001. *Emerg Infect Dis* 10: 615–621.
13. Mammen MP Jr, Pimgate C, Koenraadt CJM, Rothman AL, Aldstadt J, 2008. Spatial and temporal clustering of dengue virus transmission in Thai villages. *PLoS Med* 5: 1605–1616.
14. Eisen L, Coleman M, Lozano-Fuentes S, McEachen N, Orlans M, Coleman M, 2011. Multi-disease data management system platform for vector-borne diseases. *PLoS Negl Trop Dis* 5: e1016.
15. Derraik JGB, Slaney D, Nye ER, Weinstein P, 2009. Vector-borne disease prevention: the need for a joint South Pacific approach. *N Z Med J* 122: 7–12.