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A WebGIS tool for visualizing and exploring socioeconomic vulnerability to dengue fever in Cali, Colombia

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Abstract. WebGIS tools have the potential to disseminate the outputs of spatial vulnerability assessments to a wide range of communities, including public health decision-makers. Based on a previous assessment of socioeconomic vulnerability to dengue fever in Cali, Colombia, we developed and used a WebGIS tool to facilitate the visualization, exploration and dissemination of prevailing vulnerabilities to dengue fever in an interactive online environment. Results show that the tool presented here has distinct implications for policy and decision-making as it facilitates spatial prioritisation, both with respect to the intervention areas and the intervention measures needed to reduce human susceptibility and strengthen resilience to the disease.

Keywords: dengue fever, vulnerability, visualization, WebGIS, decision support, Colombia.

Link: http://www.geospatialhealth.unina.it/vHealth/gh-v8i1-kienberger-01

Background

Dengue fever is a vector-borne viral infection transmitted among humans by the bite of the female *Aedes aegypti* mosquito (Simmons et al., 2012). The presence of dengue fever has recently increased around the world, imposing a heavy burden on vulnerable populations. It is prevalent in many tropical and sub-tropical climates, mostly in urban and sub-urban environments. Current estimates by the World Health Organization (WHO) report 50-100 million dengue infections worldwide every year, making dengue fever a leading cause of morbidity and mortality in the tropics and subtropics (WHO, 2012). Although *A. aegypti* was eliminated from large areas of South America in the 1950s and 1960s as part of an "eradication" campaign initiated by the Pan American Health Organization (PAHO), it reappeared in urban areas in the late 1960s, not only due to lack of political will to implement control measures, but also influenced by the enormous influx of people from rural to urban areas which was often accompanied by overcrowding and poor sanitation (Tapia-Conyer et al., 2009).

Despite sustained efforts to treat infections and reduce exposure to the vector, dengue fever has become a major public health problem in the past decades. There is increasing consensus that, in addition to modelling transmission risk, integrated approaches also need to take into account socioeconomic, demographic, political, cultural and behavioural factors that impact human vulnerability to the disease. Such activities are urgently needed to effectively reduce the burden of vector-borne diseases (VBDs), in particular with regard to those for which there are currently no vaccines, e.g. dengue fever and malaria (Ribera and Hausmann-Muela, 2011; Dickin et al., 2013).

Santiago de Cali (referred to as Cali from here on) has a population of approximately 2.4 million, which makes it the third largest city of Colombia. Dengue fever in Cali follows a temporal pattern generally seen in poor neighbourhoods in the rest of sub-/tropical South America. Rapid population influx to urban landscapes of the rural population, combined with insufficient water infrastructures resulting in an abundance of stagnant water has created optimal environmental conditions for the breeding of *A. aegypti* and the propagation of dengue fever. By the 1990s, *A. aegypti* had returned to the same level of distribution as before the "eradication" programmme of the 1950s, presenting distinct outbreaks in 1995, 2002, 2005 and 2010.

To identify targeted, place-specific intervention measures with the aim of reducing the burden of the disease,

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we have previously modelled relative levels of prevailing socioeconomic vulnerability to dengue fever for 340 neighbourhoods of Cali (Hagenlocher et al., 2013). Based on a conceptual vulnerability framework, we used a set of socioeconomic and demographic indicators derived from census and ancillary geospatial datasets for the construction and visualization of a composite index. As it was realised that purely hazard-mitigating strategies did not lead to the desired reduction of risk, more holistic risk and vulnerability concepts have been developed in recent years. Vulnerability is a component of risk, which is as a function of the hazard (the disease) and the vulnerability of exposed population groups. In this context, vulnerability is defined as the predisposition of the society (here: the population of Cali) to the burden of dengue fever as a result of differences in their socioeconomic characteristics, taking into account differences in their susceptibility and lack of resilience (Hagenlocher et al., 2013). The core objective of any vulnerability assessment is to provide policy-relevant information for the identification of targeted interventions, enabling policy and decision-makers to minimize risk through the identification of who is vulnerable, to which extent at a particular location (Kienberger et al., 2013).

Effective intervention planning requires not only information on neighbourhoods of high vulnerability, but also an understanding of the socioeconomic and demographic factors that impact vulnerability in these areas. For example, intervention measures could be targeted at limiting exposure (e.g. through the promotion and distribution of mosquito nets, larviciding, or indoor residual spraying, etc.), reducing susceptibility (e.g. through poverty alleviation measures), and strengthening resilience through better access to health care or warnings of upcoming outbreaks. Vulnerability assessments, as described by de Mattos Almaida et al. (2007) and Hagenlocher et al. (2013) are a powerful means for the prioritisation of intervention areas (vulnerability "hotspots"), and provide policy makers with the required "overview". To identify the optimal set of interventions, regional and local factors contributing to vulnerability are distinguished for each geographical region. This can be achieved by determining the relative contribution of each indicator to the composite vulnerability index, which can then be visualized by means of, for example, pie charts (Hagenlocher et al., 2013). To facilitate a better understanding of the composition and characteristic of prevailing vulnerabilities for each geographical region, the multi-dimensional nature of vulnerability needs to be visualized in an interactive, decomposable manner that also allows the exploration of the single vulnerability indicators. Such a concept was introduced by Kienberger (2012), where the composite vulnerability index is targeted to inform policy makers, whereas for decision-makers in practice (e.g. local public health experts) the decomposability of the composite indicator down to the level of single indicators allows an exploration and possible reasoning of vulnerable areas (Fig. 1).

To increase public awareness of the dangers posed by VBDs, the outcomes of spatial vulnerability assessments should be communicated to public health decision makers and community groups in an adequate way: (i) it should address "user" needs in a dynamic manner; and (ii) make use of explorative tools to estimate the set of appropriate prevention measures for each region.

WebGIS tools provide a suitable platform for such tasks, as they enable the integration of interactive user elements, and allow "unlimited" access to a variety of operations from computers with Internet connection. In the past decade WebGIS tools have become increasingly popular as a result of advances in computer technologies, improved and established geographic standards (e.g. OGC standards) which have helped the dissemination of spatial data to different audiences, and the shift from expert tools to community-based tools that are accessible to a wider range of users, e.g. virtual globes (Stensgaard et al., 2009; Blaschke et al., 2012). Closely related to (simple) web-based GIS tools are spatial decision support systems (SDSS), that are interactive GIS-based platforms, including integrated database management systems designed to support place-based decision making at the various stages of a planning process (Duncombe et al., 2012). For example, Hernández-Ávila et al. (2013) developed a web-based, geographically enabled, dengue surveillance system for the collection, integration, analysis and reporting of geo-referenced epidemiologic, entomologic, and control interventions data in Mexico. A similar system is described by Porcasi et al. (2012), who designed an integrated platform for the surveillance and prediction of risk areas for dengue fever in Argentina using geospatial technology.

In this paper, we used ArcGIS Explorer (AGX) (see Box 2) as a very simple SDSS in a dengue fever context. The goal is to facilitate the visualization and exploration of vulnerability, and its contributing factors, in an interactive way (Fig. 1; also see video).

One of the benefits of AGX is that it inherently provides a well-defined set of exploratory tools which can be easily integrated without any programming skills. We visualize vulnerability in five equidistant classes (low vulnerability (0) to high vulnerability (1)).

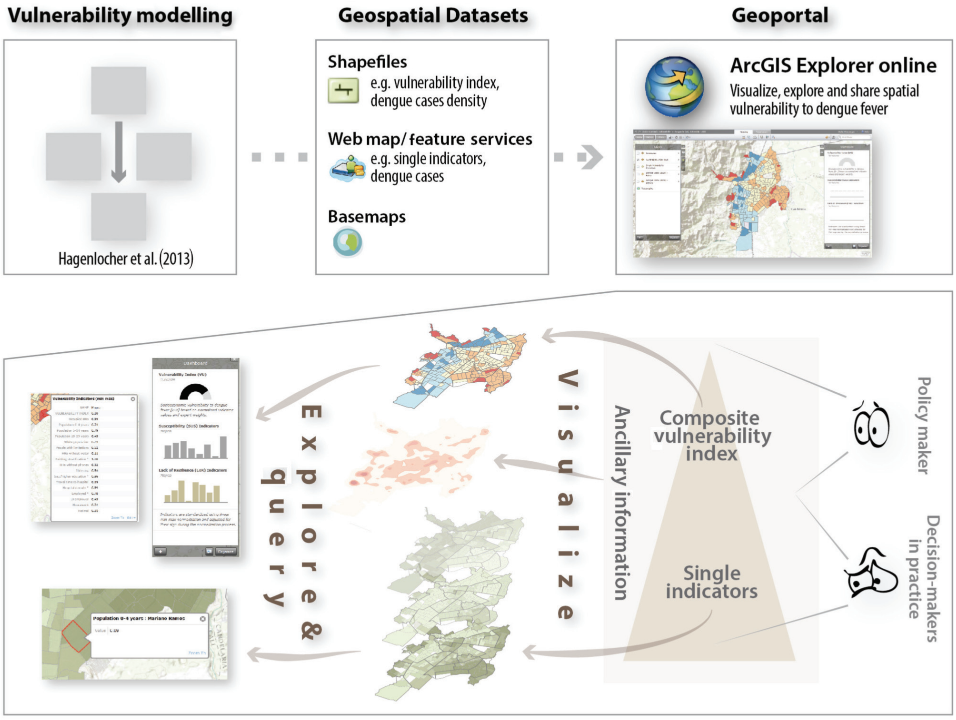

Fig. 1. Concept for the development of a WebGIS tool for the interactive visualization of vulnerability to dengue fever.

Regions of low vulnerability are displayed in shades of blue, while areas of high vulnerability are displayed in shades of red. When selecting a particular geographic unit, the dashboard in AGX provides a gauge with the total vulnerability index (based on a scale that can vary from zero to one). In addition, the normalised values of the single indicators (also according to a scale varying from zero to one) are displayed for their respective domains (i.e. susceptibility and lack of resilience) in the dashboard using bar charts. As such, the application not only provides information at the level of socioeconomic vulnerability (low to high) for each geographic neighbourhood, but also gives additional information on the contribution of each vulnerability indicator. These are visualized using a web map service (WMS); i.e. an OGC standard protocol for serving geo-referenced layers online that are generated by a map server using data from a geospatial database. By selecting a particular neighbourhood, values of the single indicators can be queried. Next to mapping the composite vulnerability index and the single indicators, a gridded density surface representing recent dengue outbreaks (January to December, 2010) is available.

Outlook

WebGIS tools provide necessary capabilities to communicate results of spatial vulnerability assessments to a range of users. AGX is a free online application that allows fast implementation of pre-defined geospatial visualization tools and thus facilitates efficient and cost-effective decision-making. Moving towards a more sophisticated SDSS, however, requires more than the pre-defined solutions provided by AGX. Currently available web-based tools (such as open source and established standards) have an enormous potential for the development of customised geoportals that enable the integration of additional geo-processing capabilities and statistical metrics for exploring and visualizing vulnerability to VBDs. For a successful implementation of vulnerability assessments, adequate tools for visualizing and exploring the multi-dimensional nature of vulnerability are needed, while sound and scientific-grounded assessment methodologies are even more important.

Box 1. Overall aim.

> The overall aim of this paper is to develop and utilise a WebGIS tool for the interactive visualization and exploration of socioeconomic vulnerability to dengue fever in an urban environment in Colombia. The presented tool has distinct implications for policy- and decision making: first, it facilitates the spatial prioritisation of intervention areas, and second, by decomposing vulnerability into its underlying factors, it provides an indication of which factors need to be addressed to reduce existing vulnerabilities in specific areas.

Box 2. Applied software.

ESRI ArcGIS 10.1. ArcGIS Desktop includes a suite of applications, including ArcMap, ArcCatalog and ArcToolbox. The user can perform a wide variety of GIS tasks, including mapping, spatial analysis, data editing and compilation, data management, visualization and geoprocessing. ESRI ArcGIS Explorer Online.

ArcGIS Explorer Online is a free, interactive online mapping tool that is used to explore, visualize and share geospatial information with a worldwide audience. The application runs within the web browser, thus it is not necessary to install any ESRI software to interact with it. Local data can be fused with existing online map services to create custom maps.

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