Quantifying the Impact of Flood Adaptation on Dengue Fever with Geospatial Analysis: a Case Study in Pasig-Marikina-Laguna Lake Watershed, the Philippines

The Philippines is one of the world's most vulnerable countries to floods resulting from increased and intensifying extreme weather events[1]. This study aims to understand the country's historical adaptation responses to floods that can be improved to prevent adverse health outcomes from vector-borne diseases such as dengue, especially in vulnerable, low-income communities within the vicinity of the flood detention basin of Laguna Lake.

Background/Context: The Pasig-Marikina-Laguna Lake Watershed, is composed of approximately 3,600 km^2 of watershed and 870 km^2 of lake areas, covering the Metro Manila and National Capital Region, portions of the province of Bulacan, and the provinces of Rizal, Laguna, and portions of Cavite and Batangas, involving about 80 municipalities or cities (as shown in Figure 1a). Flowing through urbanized and densely populated Metro Manila and the National Capital Region, the Pasig River is vulnerable to flooding in times of extreme rainfall, with the Marikina River tributary as the main source of the floodwater[2,3]. To avoid serious flooding in Metro Manila, the **Manggahan Floodway** was constructed to divert excess floodwater from the Marikina River into the Laguna Lake, which serves as a detention basin to store flood water temporarily. The originally conceptualized outlet spillway for flood waters to escape Laguna Lake and flow into the ocean was never pursued. Excess water in Laguna Lake now drains only through the Napindan Channel of Pasig River, regulated by the repurposed **Nandan Hydraulic Control Structure (NHCS)**. Figure 1b presents surrounding rivers and flood diversion facilities.

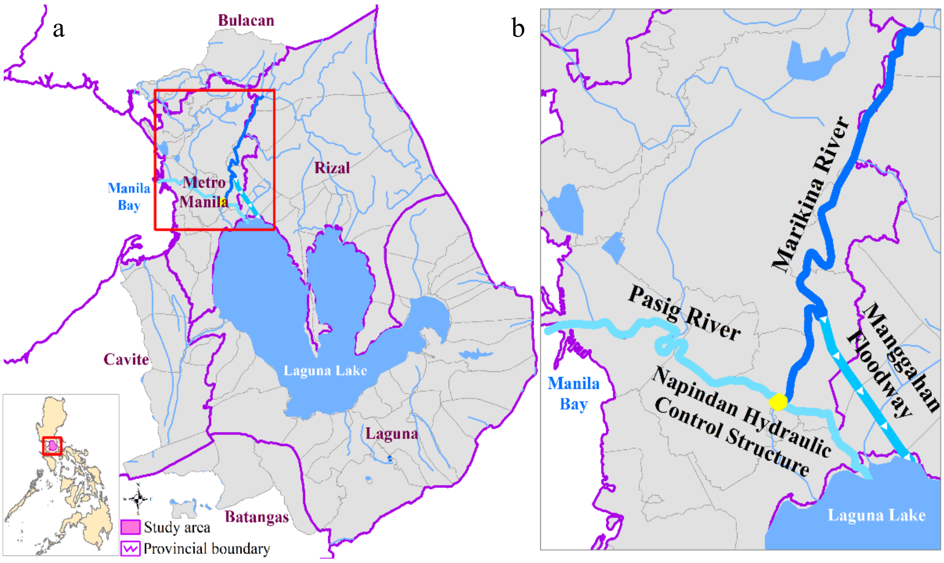

Figure 1. Study area

The studied population includes communities living in the low-lying lakeshore areas oftentimes utilized for floodwater detention. The recent high population growth rate in these areas is attributed to rapid and unregulated migration and informal settlement resulting mainly from the perceived economic opportunities in proximity to Manila. Many communities living in these areas are vulnerable and marginalized. For example, the Manggahan Floodway is a densely populated area that is home to approximately 40,000 individuals. Approximately 57% of the identified labor force in the area are employed as craft and related trade workers (20%), service and sale workers (19%), elementary occupations (17%), and plant and machine operators (11%)[4]. Professionals comprise only 2% of the identified labor force, significantly lower than the provincial average of 8%. A recent survey by the Philippine Statistics Authority reveals the poverty incidence in the Laguna Lake area has been increasing, from 3.8% in 2015 to 6.9% in 2021[5].

Adaptation strategy and health impact: The adaptation responses are composed of various flood management measures developed and operated by a diverse group of decision-makers including national and regional authorities and many local government units[6], sharing inadequate and asymmetric information, and utilizing a set of incomplete, outdated, and repurposed flood management infrastructures. Such adaptation responses are developed without paying attention to preventing habitat production for disease-carrying mosquitoes and other vectors. The temperature during the flooding season and the presence of water in the flood area play significant roles in the spread of dengue virus-carrying mosquitos[7], *Aedes Aegypti*. Stagnant flood water containing household, industrial, and medical waste is an excellent breeding ground for this type of mosquito, which proliferates in crowded areas. Spikes in dengue cases are observed during the rainy season and after large flooding events[8]. However, the quantitative estimation of the impact of these flood adaptations on dengue fever remains unclear, which we aim to address in this case study.

Proposed Analysis: Dengue fever is the most well-known and feared tropical disease in the Philippines[9]. Its transmission risk is highly related to flood areas due to increased mosquito habitats and thus high mosquito density[10-13]. Therefore, to evaluate the impact of flood adaptation on dengue fever epidemics, we are going to quantify the impact of flood areas caused by flood adaptation on dengue epidemics. Figure 2 illustrates the study design. The analysis will combine the approaches of Geographic Information Science (GIS), Remote Sensing (RS), Hydrological modeling, and Geospatial Analysis to produce quantitative evaluations. Specifically, the analysis includes four steps:

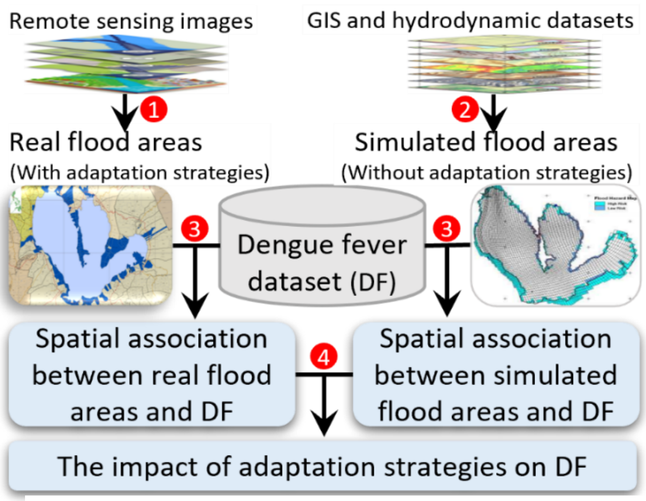

Figure 2. Analysis design

1) ***Identifying real flood areas with remote sensing images***: RS is the process of detecting and monitoring the physical characteristics of an area typically by satellite or aircraft. It provides important data sources to objectively monitor the features and changes of an area in an efficient way. In this study, multi-source satellite data will be integrated to map and monitor the flood areas using the Google Earth engine and deep learning-based methods (e.g., CNN/U-net[14]). Areas identified based on RS images reflected the real-world flood areas considering the flood adaptation.
2) ***Modeling simulated flood areas with hydrological models*****:** Hydrological models are used to analyze the spatiotemporal distribution of flood areas under the scenario without flood adaptation. We will simulate the hydrologic processes of dendritic watersheds using the Hydrologic Modeling System (HEC-HMS)[15,16], and based on the collected environmental and field, the Hydrologic Engineering Center's River Analysis System (HEC-RAS) model[17] will be used to simulate the potential extent of flooding. Differences between the spatiotemporal distribution of real-world flood areas and that of the simulated flood areas are due to flood adaptation.
3) ***Constructing the spatial association between flood areas and dengue epidemics*****:** the Geographically Weighted Regression (GWR) model[18,19] is utilized to detect spatial associations between flood areas and dengue occurrence, in both real-world and simulated scenarios. The associations can be detected comprehensively by studying different spatial scales (e.g., the city and village levels), and flood areas can be quantified by different measures, such as area/size and landscape ecological metrics.
4) ***Quantifying the impact of flood management strategies on dengue epidemics*****:** Since flood areas extracted from RS images represent real-world results due to flood adaptation, while the simulated flood areas represent natural results without flood adaptation, the difference between their quantitative associations with dengue occurrence will reflect the impact of flood adaptation on dengue epidemics.

Data Sources: Our team has accumulated the primary data to be used in the study. The data includes **1) dengue fever data**. We have obtained dengue cases and incidence by year, setting, sector, place, and severity during 2000-2020 from the Philippine national and regional dengue surveillance systems. **2) Population data**: population count and population density data during 2000-2020 have been obtained from WorldPop, which are in raster format with 100-m spatial resolution. **3) Remote sensing data**: we have obtained long-time Landsat data (spatial resolution = 30m and temporal resolution = 16 days), Moderate Resolution Imaging Spectroradiometer (MODIS) data (spatial resolution = 250 m and temporal resolution = 1 day), and Synthetic Aperture Radar (SAR) data provided by the European Union's Copernicus Program (spatial resolution = 5 m and temporal resolution = 6-12 day). **4) Environmental and field data**, including Digital Elevation Models (DEM) data and climate data (e.g., precipitation and temperature), streamflow, and river geometry data which are prepared for hydrological and hydraulic models.

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