INTEGRATING LIDAR AND FLOOD SIMULATION MODELS IN DETERMINING EXPOSURE AND VULNERABILITY OF BUILDINGS TO EXTREME RAINFALL-INDUCED FLOOD HAZARDS

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ABSTRACT

LiDAR-derived Digital Terrain and Surface Models (DTM/DSM) and flood simulation models were used to determine exposure and vulnerability of building to various flood hazard scenarios caused by extreme rainfall events in a river basin in Mindanao, Philippines. The methodology consist of (i.) generating a database of buildings from the DTM and DSM; (ii.) generation of flood depth and hazard maps through the use of a flood simulation model; and (iii.) spatial overlay analysis utilizing the building database and flood maps to determine a building's exposure and vulnerability. This study highlights the importance of combining high spatial information from LiDAR with simulation model to generate informative maps showing the exposure and vulnerability of buildings to flooding.

Index Terms—LiDAR, flood hazard, buildings, exposure, vulnerability

1. INTRODUCTION

Flooding is one of the most destructive natural disasters. In the Philippines, flooding due to overflowing of rivers caused by excessive quantity of rainfall brought by tropical storms has caused loss of lives and damages to properties as well as to infrastructures like buildings, roads and bridges [1]. In the advent of climate change which has caused changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events [2], the need to be more prepared for flood disasters is becoming more urgent. Flood simulation models are considered important tools in simulating and assessing in an advance manner the impacts of various flood scenarios [3]. Because simulation models can depict the depth, duration and extent of flooding event, it allows identification of areas or elements exposed or at risk to flooding, estimation of the element's vulnerability, and even calculation of possible economic damages [3], among many other uses. Buildings are the most common element at risk during a flooding situation. When they get inundated, residents are forced to evacuate. Hence, it is crucial to identify in advance the specific buildings that can be affected by an expected flooding scenario in order to prevent casualties through evacuation, or to lessen the impact through conduct of flood mitigation activities. In this situation, the availability of a building database where each building is attributed in terms of type (e.g., residential, commercial, government, educational, etc.), and height (among many other attributes) can make the required hazard exposure and vulnerability assessment fast, efficient and informative.

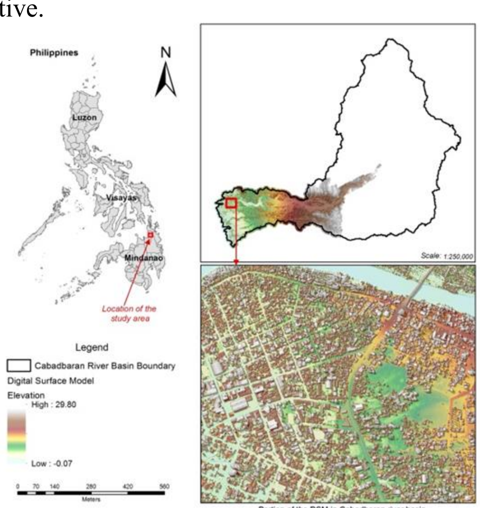

Figure 1. The Cabadbaran River Basin, Agusan del Norte, Philippines, shown here in a Digital Surface Model.

In this paper, we present an approach involving the use of high spatial resolution LiDAR-derived datasets and flood simulation model to assess the impacts of flooding caused by various scenarios of extreme rainfall events, with focus on systematic determination of exposure and vulnerability of building to these hazards. We implemented the approach to the Cabadbaran River Basin (CRB) in Agusan del Norte, Caraga Region, Mindanao, Philippines (Figure 1). With a total area of 238 km^2, this river basin covers an urbanized portion of Cabadbaran City, with the Cabadbaran River traversing the city. Many areas in the city were reported to have been affected by flooding during the onslaught of Tropical Storms Lingling (Local name: *Agaton*) and Jangmi (*Seniang*) in January and December 2014, respectively [4].

The methods and results presented in this work are an update of what we have previously shown in an earlier work [5], where we have discussed building database generation, and hazard and vulnerability determination. In the present work, we present a complete discussion of the methodology which consist of (i.) generating a database of buildings from the DTM and DSM; (ii.) generation of flood depth and hazard maps through the use of a flood simulation model; and (iii.) spatial overlay analysis utilizing the building database and flood maps to determine a buildings' exposure and vulnerability.

2. METHODS

2.1. Building Database Generation

We used 1-meter resolution LiDAR-derived DTM and DSM for extracting the building features within the river basin (Figure 2). Buildings were manually digitized from the LiDAR DSM using ArcGIS 10.1 software. The extracted buildings were saved as a GIS Shapefiles. The heights of the buildings were calculated as the difference between the average of the base elevations and top elevations for each footprint. The base and top elevation values were extracted from the DTM and DSM, respectively. Field surveys, familiarity with the area, and free online web maps such as Wikimapia (http://wikimapia.org/) and Google Map (https://www.google.com.ph/maps) were used as references to identify the type and name (for non-residential types) of the buildings. More details about the procedure can be found in [5].

2.2. Simulation Model Development and Generation of Flood Depth and Hazard Maps

The simulation model consisted of a hydrologic model of the river basin, and a two-dimensional (2D) hydraulic model of the main river and its floodplain. The hydrologic model, based on the Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS) Version 3.5, was used to compute how much volume of water is produced in the river basin during the occurrence of an extreme rainfall event; the hydraulic model (using a trial version of Flood Modeller Pro), was then used to simulate how these volume of water travels in rivers and in various locations within the river basin, including how it overflows from the rivers and floods nearby areas. The reader is referred to [4,6] for more details on how the flood simulations models were developed, including the various geospatial datasets used during the development process as well as its accuracy. For the flood scenario modeling, the hydrologic model was used to generate discharge hydrographs corresponding to 3 hypothetical, extreme rainfall events corresponding to return periods of 25, 50, and 100 years. Each event has 24 hours duration with accumulated rainfall depths of 248 mm (25-year), 279 mm (50-year), and 309 mm (100-year). These rainfall datasets was extracted from Rainfall Intensity Duration Frequency (RIDF) curves generated by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) based on 21 years of record. The 2D model was used to generate hourly flood depth and extent for the 3 extreme rainfall events using the discharge hydrographs computed by the hydrologic model as inputs. Maximum flood depth maps at 1-m spatial resolution were then generated from the result of the 2D simulations. These maps were further transformed into hazard maps by categorizing the flood depths into 3 levels: low (<0.50 m depth), medium (0.50 m – 1.50 m depth), and high (>1.5 m depth).

2.3. Flood Hazard Exposure and Vulnerability Determination

GIS overlay analysis of the building footprints and flood hazard maps was conducted to identify which buildings are exposed to various levels of flood hazards (e.g., low, medium, high). In addition to this, we also compared the building heights with the simulated flood depths in determining their vulnerability using simple criteria. If a building is located in a location where flood depth is less than 0.10 m, then it is coded as "Not vulnerable". If the flood depth at the building's location is 0.1 m to less than 0.25*h (h is building height), then the vulnerability is "Low". On the other hand, if the flood depth is > 0.25h and ≤ 0.5h, then the vulnerability is medium. If the flood depth is > 0.5h, then the vulnerability is high [5].

3. RESULTS AND DISCUSSION

3.1 Buildings Database

A total of 9,086 buildings were extracted from the DSM of the study area. After attribution, 94.71% (or 8,605) of these were found to be residential while the remaining 5% belongs to government, commercial, educational, and other types. The average height of all buildings was computed at 4.10 m.

3.2 Exposure of Buildings to Flood Hazards

The flood hazard maps generated through model simulation are shown in Figure 2. As expected, there is an increase of flooded areas as the rainfall event becomes more extreme (i.e., higher return periods). Figure 3 summarizes the number of buildings exposed to different levels of flood hazards under different extreme rainfall scenarios. An example map showing the locations of these exposed buildings can be found in Figure 4. Statistics show that as the rainfall return period increases (which also means increase in rainfall intensity and duration), the number of buildings affected by flooding also increases. Consequently, the number of

buildings that are not flooded decreases. In all rainfall scenarios considered, majority of the buildings appears to be not flooded. For flood-affected buildings, more buildings are exposed to ‘low’ flood hazard levels than those in ‘medium’ and ‘high’ hazard levels. This result means that majority of areas within the river basin where buildings are located are relatively not prone to flooding; and if there is flooding, the level of hazard is low.

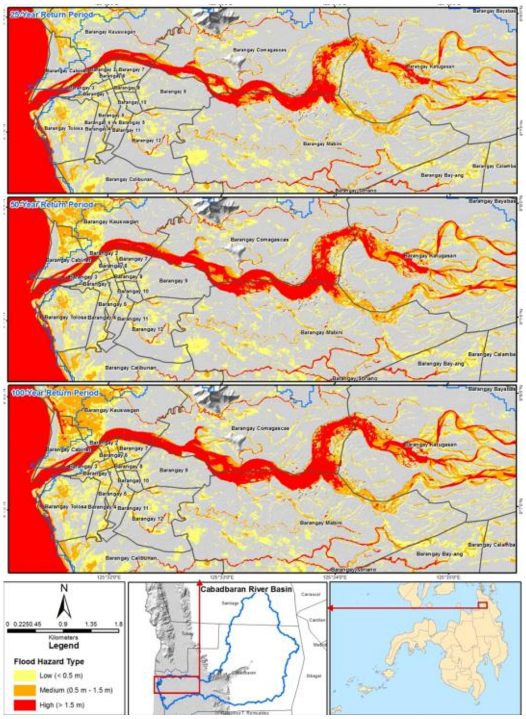

Figure 2. Flood hazard maps of Cabadbaran River Basin for 25-, 50-, & 100-year rainfall return periods.

3.3 Vulnerability of Buildings to Flood Hazards

Figure 5 shows the number of buildings that were categorized according to their vulnerability to flooding caused by rainfall events of different return periods. The locations of these vulnerable buildings are shown in Figures 6. It was observed that more than 40% of the buildings are not vulnerable to flooding. For flood affected buildings, more buildings are in ‘low’ vulnerabilities, with increasing number as the rainfall return period increases. The generated statistics also show that buildings exposed to medium and high flood hazard levels does necessarily mean they will also have medium and low vulnerability. Looking at the graphs (Figures 3 and 5), the total number of buildings under medium and high hazard exposure are higher than the total number of buildings in medium and high vulnerabilities. This implies that even if a building’s location has medium or high flood hazard levels, a building’s vulnerability can be lesser if its height is much higher than the depth of flooding. All of these results, however, only used height as basis for assessing a building’s vulnerability. The type of building material and other factors were not considered.

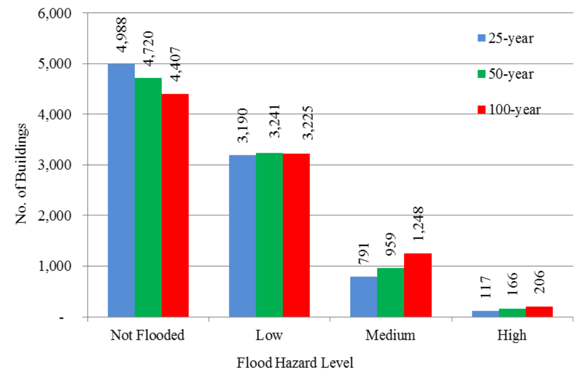

Figure 3. Number of buildings exposed to different levels of flood hazards under different extreme rainfall scenarios.

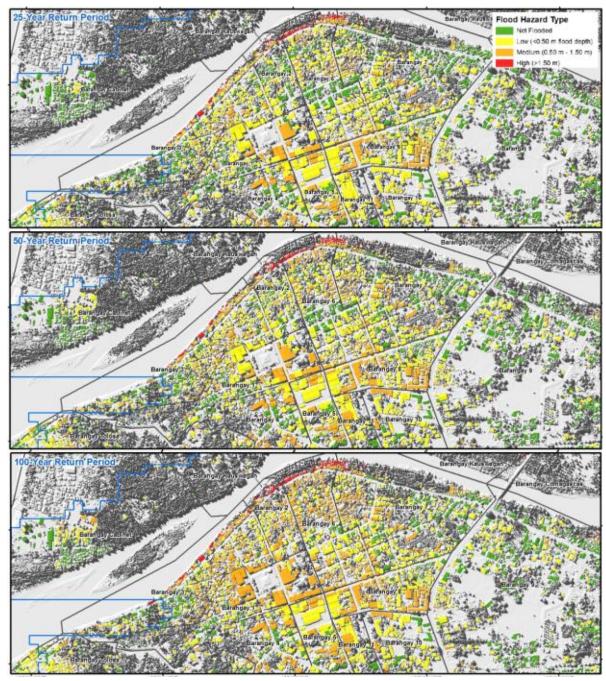

Figure 4. Example map of Cabadbaran City proper showing exposure of buildings to flood hazards.

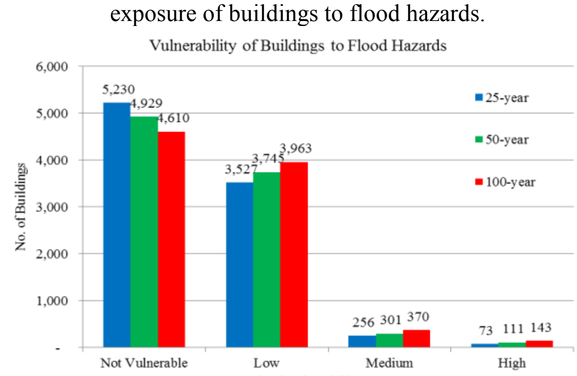

Figure 5. Number of buildings exposed to different flood vulnerability levels under different extreme rainfall scenarios.

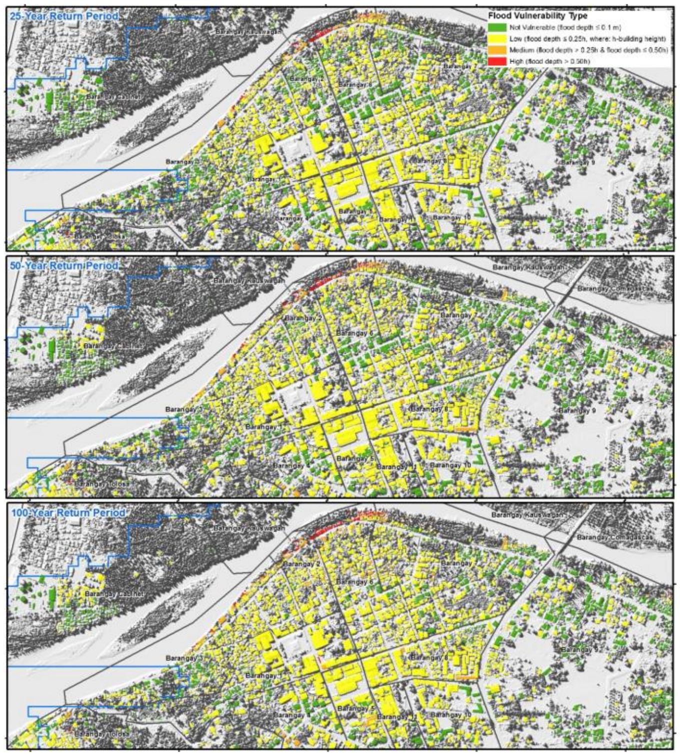

Figure 6. Example map of Cabadbaran City proper showing vulnerability of buildings to flood hazards.

4. CONCLUSIONS

This study highlights the importance of combining high spatial information from LiDAR DTM and DSM with flood simulation model to generate informative maps showing the exposure and vulnerability of buildings to flooding. The results of this case study made for Cabadbaran River Basin highlights the use of a building database extracted from LiDAR data (with each building attributed in terms of type and height) to generate statistics as well as in creating maps that can show the spatial distribution of buildings exposed to low, medium and high hazard levels of flooding caused by extreme rainfall events with return periods of 25, 50 and 100 years. The height information derived for each building also allowed fast generation of statistics and maps showing the building's vulnerability to flooding.

Although the vulnerability assessment was purely based on the building height, the information generated from the analysis can be very useful in flood disaster preparedness and mitigation. One practical application would be identifying those buildings (and informing their occupants) that are at risk of flooding when a particular rainfall event of specific return period is expected to occur. Since the maps and statistics of those buildings exposed and vulnerable to flooding were already generated according to rainfall return period, it is already easy to identify those locations and conduct appropriate measures such as early evacuation to prevent casualties if an extreme rainfall event is expected to occur.

5. ACKNOWLEDGEMENT

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