FLOOD DEPTH AND VELOCITY IMPACT ASSESSMENT OF HISTORICAL FLOODING EVENTS USING LIDAR AND 2D NUMERICAL MODELING

Jennifer T. Marqueso, Arthur M. Amora, Jojene R. Santillan, Meriam Makinano-Santillan, Amor L. Gingo, Linbert C. Cutamora, Jesiree L. Serviano, Ronald M. Makinano

CSU Phil-LiDAR 1 Project, Caraga Center for Geo-Informatics,
College of Engineering and Information Technology, Caraga State University,
Ampayon, Butuan City, 8600, Philippines
E-mail: jennifer.marqueso@gmail.com

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ABSTRACT: This paper applies a framework that integrates LiDAR data with hydrologic and 2-dimensional (2D) hydraulic modeling to generate detailed information of flood depths and velocities that are often needed for planning and mitigating the effects of flooding. Both the flood depth and velocity are important considerations whenever flooding occurs and can be a vital input in determining safe evacuation centers and routes. The models primarily utilize the 1-m spatial resolution LiDAR-derived Digital Elevation Models as source of elevation data associated with roughness coefficients derived from generated land cover map and recorded rainfall data. The approach was applied to the Tago River Basin in Mindanao, Philippines, primarily as a wayt to reconstruct and generate flood depth and velocity information during tropical storms Lingling (local name: Agaton) and Jangmi (local name: Seniang) in the year 2014. The framework also allows GIS-based impact assessment wherein the number of structures and area of land cover that were affected were quantified based on the simulated flood depths and velocities.

1. INTRODUCTION

Flood hazard maps are important sources of information for flood preparedness as well as for planning and implementation of flood mitigation strategies, including vulnerability assessment of affected communities (FEMA, 2012). Vetere-Arellano (2003) stated that estimates of the impacts caused by flooding can be used by a number of stakeholders for different purposes. These includes decision-making and risk management, emergency preparedness and response, spatial land use planning, emergency preparedness and response, disaster relief and recovery, construction, insurance and damage estimation practice and research. Different parameters are usually considered in flood hazard maps generation, and these includes flood extent, water depth, flood velocity, duration and the rate at which water rises (de Moel et al, 2009). Maps depicting flood depths and velocities are particularly useful for future planning and for increasing public awareness of flood hazard risks in areas identified as susceptible to high flood water velocities

In this paper, we focus mainly on a methodology utilizing the LiDAR data to assess the impacts of flood depth and flood velocity by reconstructing the historical flooding events through numerical model simulations. The results of numerical model simulation were used to determine and estimate the impacts of flood depth and flood velocity by assessing the number of structures and area of each land cover classes affected. This application provides insights on what areas that should be avoided and possibly be flooded when heavy rains occurs. It is also an important consideration in formulating evacuation procedures of the concerned local government units (LGUs).

1.1 Study Area

We selected as a case study area the Tago River Basin in Surigao del Sur, Mindanao Philippines. It has a drainage area of approximately 1, 444 km^2 (see Figure 1). This area was reported as one of the areas affected by the tropical storm *Agaton* (International name: Lingling) and *Seniang* (International name: Jangmi) that affected the area last January 2014 and December 2014, respectively. Such catastrophe caused widespread flooding and fatalities in many areas (NDRRMC, 2014; 2015).

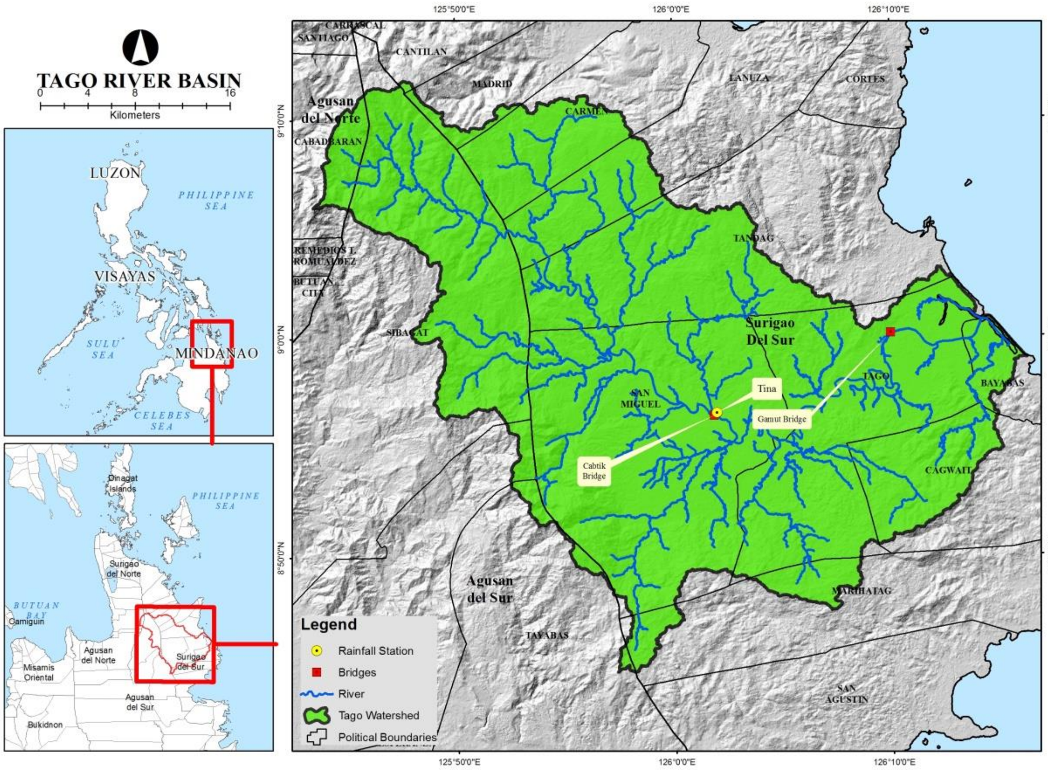

Figure 1. Map of the Tago River Basin.

2. METHODOLGY

2.1 Overview

This work is a continuation of a previous study entitled "Assessing the Impacts of Flooding Caused by Extreme Rainfall Events through a Combined Geospatial and Numerical Modeling Approach" (Santillan et al., 2016). The integrated geospatial datasets utilized in this study are the LiDAR datasets and land cover map derived from downloaded satellite images. The flow information used in 2D-hydraulic modeling were the flow hydrographs of the hypothetical rainfall events with return periods of 2, 5, 10, 25, and 100 Years computed by the hydrologic model to generate flood maps corresponding to different return periods. These maps are then utilized in together with the extracted exposure datasets to assess the impacts of flooding brought by different hypothetical scenarios. As a continuation of the study, the same datasets and methodology were used in assessing the impacts of flooding caused by historical flooding events. The only difference is the flow information used in 2D-hydraulic model was the historical rainfall data recorded by the rain gauge station of Advanced Science and Technology Institute of the Department of Science and Technology (ASTI-DOST). Additional information such as flood velocity are also added in this study, thereby taking advantage of the 2D-hydarulic model's capability to produce such output.

2.2 Exposure Datasets

The procedures for generation of land cover map and extraction buildings features information are reported in an earlier work (Santillan et al., 2016). Land cover information was extracted from Landsat 8 OLI and Landsat 7 ETM+ images through the use of Maximum Likelihood classification algorithm with an overall classification accuracy of 92%. There were seven land classes identified in analysis (see Table 1). This land cover map was converted to roughness map and runoff potential which are required parameters in developing hydrologic and hydraulic modeling (Figure 2). On the other hand, the feature extraction which utilized LiDAR datasets resulted to 12, 830 buildings within the floodplain areas of the study area.

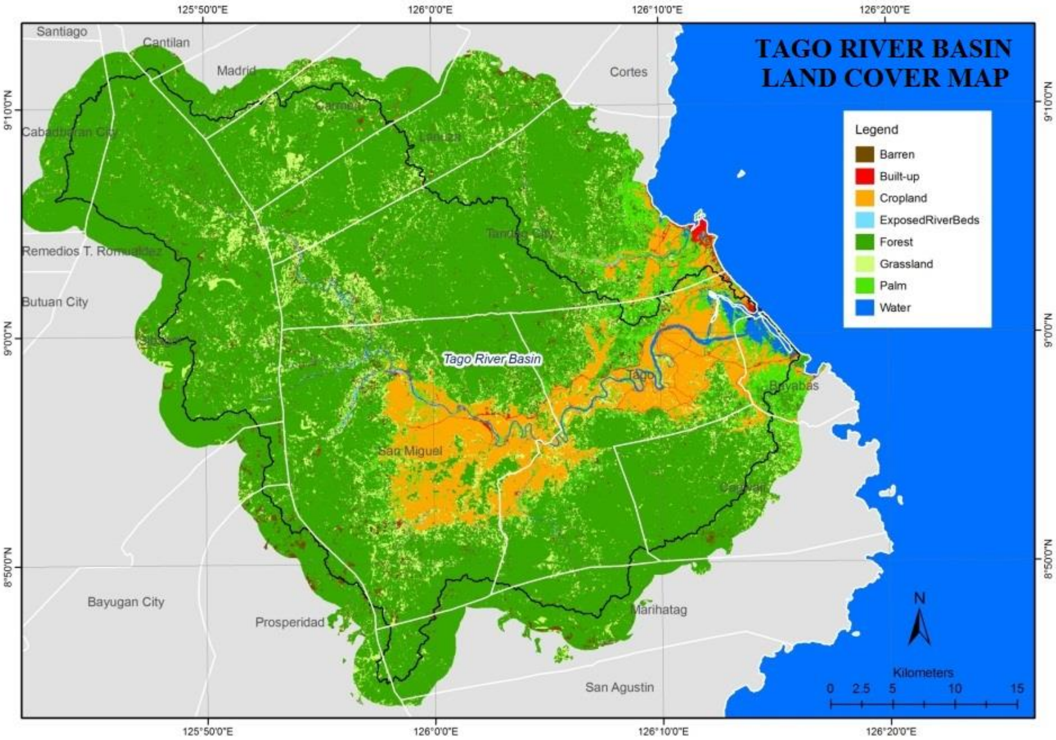

Figure 2. Year 2014 Tago river basin land cover map derived from satellite images.

Table 1. Area of land cover classes on Tago river basin.

Class Name	Area (km²)
Barren	51.14
Built up areas	4.39
Cropland	168.35
Forest	999.12
Grassland	146.43
Palm	55.3
Water	19.75
Total Area	1,444.49

2.3 Flood Depth and Velocity Generation using 2D Hydraulic Model

The 1-m LiDAR derived Digital Terrain Model (DTM) was utilized as an input in 2D hydraulic model using the HECRAS version 5.0. The details on the process of hydrologic model development and calibration, and the 2D hydraulic modeling are again reported in an earlier work (Santillan et al., 2016). As an overview, the 2D HECRAS model domain was developed by creating 2D flow area (i.e. 2D model domain) of the entire floodplain (Figure 3). The domain has an approximate area of 565.31 km^2, and was represented in the 2D model as composed of162,565 cells. The flow hydrographs of calibrated hydrologic model together with rainfall data and tidal data at sea portion were utilized as inputs into the 2D hydraulic model to estimate the flood extent and flood depth. Another advantage of the 2D hydraulic model is the capability to compute and export the maximum velocity of the flood water. The maximum flood depth and maximum flood velocity generated by the 2D hydraulic model were utilized in flood depth and velocity assessment.

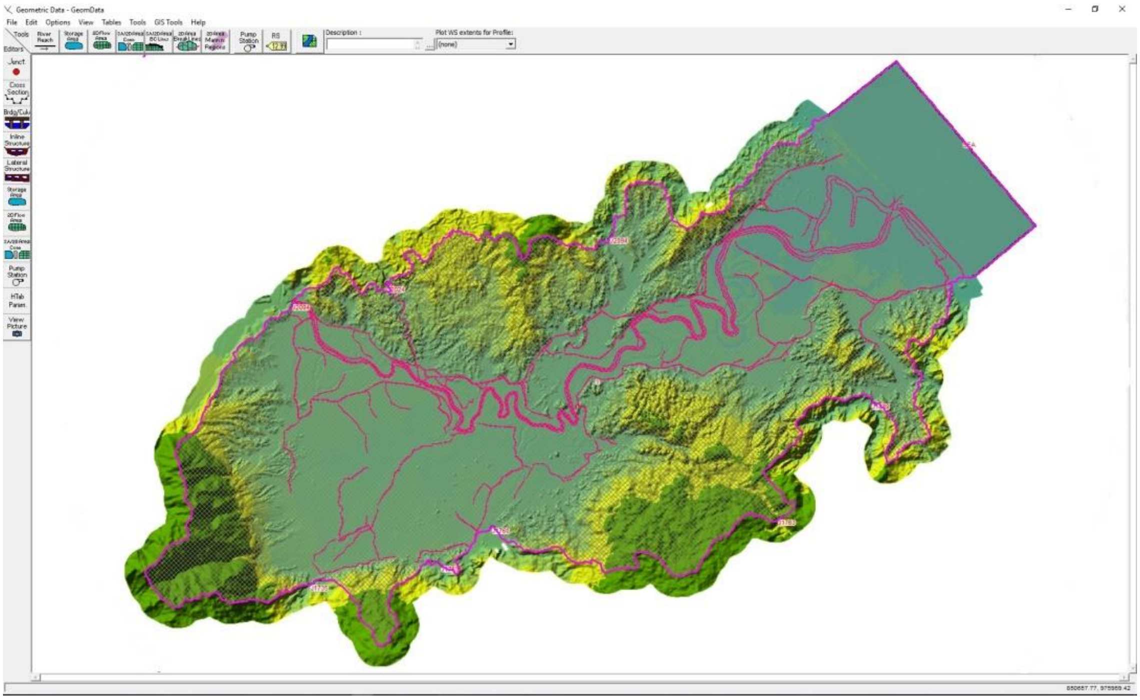

Figure 3. The HEC RAS 2D computational domain of Tago River Basin, with the LIDAR DTM in the background.

2.4 Accuracy Assessment of the Model

The model was assessed by comparing the resulting flood map of the *Agaton* event to the actual flooding information gathered from the field. Flood map validation survey was conducted in predetermined location points within the floodplain of the river basin. Those points were verified on the ground whether they were flooded during *Agaton.* The confusion matrix approach and the *F measure* were used in accuracy computation. The accuracy of the model based on the result of the confusion matrix analysis is 83.33 % (Table 2). It was also evaluated and assessed to be "Good Fit" with computed *F* value of 0.81 (Santillan et al., 2016).

Table 2. Result of the flood map accuracy analysis in Tago River

		Actual Flooding Scenario			User's Accuracy
		Flooded	Not Flooded	Total	
Flood Model Simulated Flooding Scenario	Flooded	**74**	11	85	87.06%
	Not Flooded	6	**11**	17	64.71%
	Total	80	22	**102**	
Producer's Accuracy		92.50%	50.00%		
Sum of Diagonal Values		85			
Overall Accuracy (%)		**83.33%**			

2.5 Flood Depth and Velocity Impact Assessment

The flooding impacts to buildings were determined by categorizing every building according to hazard level depending on what hazard level they intersected. The hazard levels was based on the flood depths and were categorized to low hazard for flood depths less than 0.50 m, medium hazard for flood depth from 0.50 m to 1.50 m, and high hazard for depths greater than 1.50 m (Makinano-Santillan, et al, 2015).

Before assessing the impacts of flood velocity to buildings, there was a need to categorize first the velocities. Velocities less than 1 m/s are those velocities that are safe to wade or drive through waters, velocities from 1 to 1.5 m (vehicles unstable from this velocity), velocities more than 1.5 to 2 m (velocities that are not safe for wading), and velocities more than 2 m/s (velocities that can damage light structures) (NSW, 2005). From these categories, the impacts of velocity to buildings were assessed by categorizing the buildings according to hydraulic hazard categories they intersected.

3. RESULTS AND DISCUSSION

3.1 Flood Depth and Velocity Maps Generated

Figure 4 shows the maximum flood depth maps generated by the 2D model. The *Agaton* event shows that the floodplain areas were almost covered by the flood water. For *Seniang* event, majority of the flooded areas are those flood depth ranging from 0.51 to 1 m. In Figure 5, the maximum flood depth velocity map depicts the maximum velocity of flood waters of a specific location. The maximum flood velocities in the floodplain areas are velocities range from 0.10 m to 0.50 m.

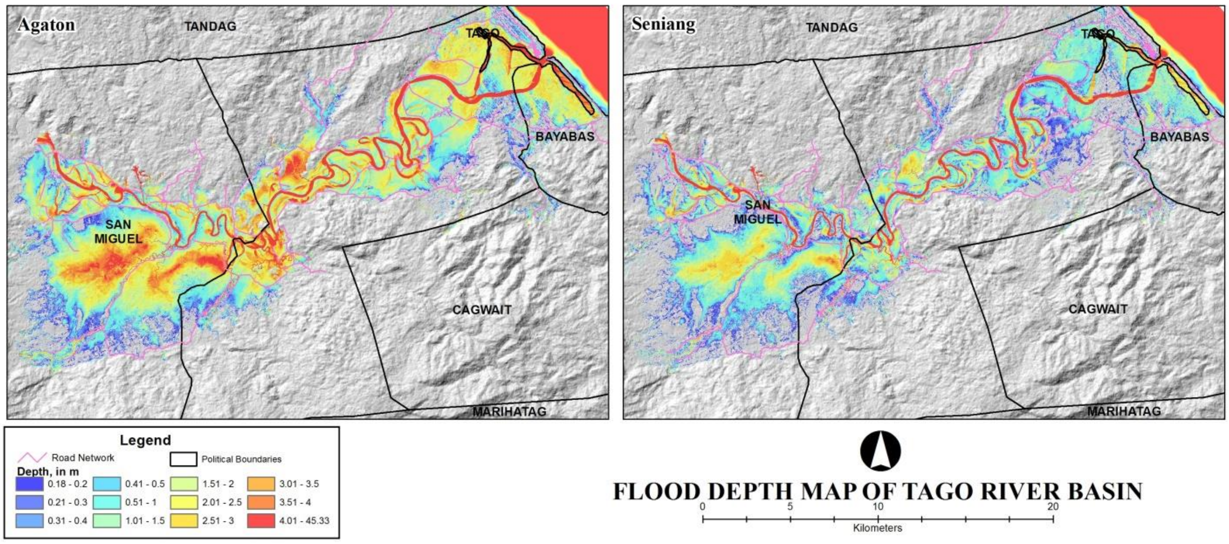

Figure 4. The generated flood depth map of Tago River Basin during typhoon 'Agaton' and 'Seniang'.

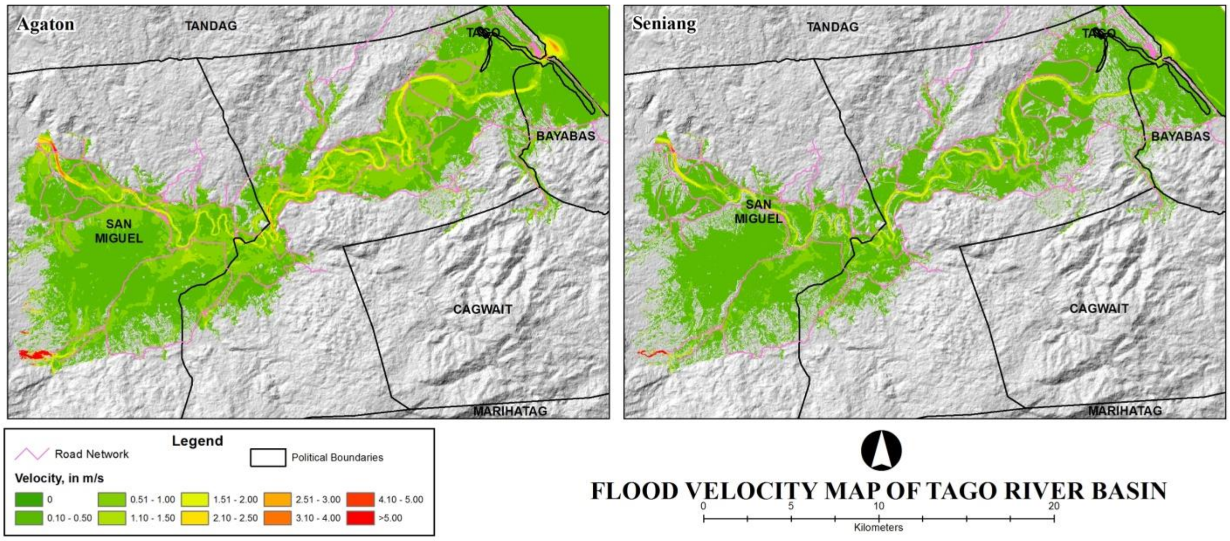

Figure 5. The generated flood velocity map of Tago River Basin during typhoon 'Agaton' and 'Seniang'.

3.2 Flood Depth and Velocity Impact Assessment

The computed flood depth and flood velocity impact assessment are summarized in Table 3 . The statistics shows that there were more buildings inundated during *Agaton.* For this event, 9,289 out of 12,830 or 72.4% buildings were affected. For the *Seniang* event, 5,786 or 45.1% buildings were affected. A total of 4,700 buildings were at medium risk during *Agaton* which have a flood depth 0.50 m to 1.50 m. It can also be noted that during *Seniang* event, majority of the flooded buildings were at low risk which have a flood depth less than 0.50 m.

The result of flood velocity assessment recorded 1,653 and 290 buildings affected with velocities ranging from 1 m to 1.5 m during *Agaton* and *Seniang*, respectively. For the assessment of the land cover area (Table 4), it can be observed that among the land cover classes, the cropland areas are the most affected where 78.71% and 57.74% were flooded during *Agaton* and *Seniang* event. The least affected areas were the forest land, with 1.54% and 1.21% being flooded during the *Agaton* and *Seniang* event. These results are to be expected since this land cover class is situated on higher elevation.

The graphical representations of the flood depth and flood velocity impact assessment are shown in Figure 6, Figure 7 and Figure 8. Figure 6 shows the graph of the affected buildings which has noticeable difference in graphical values between *Agaton* and *Seniang* event. Tropical storm *Agaton* caused more damage compared to *Seniang*. In Figure 7, the impact of flood velocity can indicate a contributing factor to the increased extent of damage. As flood velocity increases, the numerical difference of numbers of affected buildings also increases between the two events.

Table 3. Summary of affected buildings during typhoon 'Agaton' and 'Seniang'.

Flood Parameters		Number of Affected Buildings	
		Agaton	Seniang
Depth	Not Flooded	3,541	7,044
	Low (< 0.5 m)	2,209	3,351
	Medium (0.50 m - 1.50 m)	4,700	2,119
	High (> 1.50 m)	2,380	316
Velocity	Not Flooded	5,255	6,370
	< 1 m/s	6,789	6,042
	1 - 1.5 m/s	1653	290
	1.5 - 2 m/s	553	68
	> 2 m/s	570	60

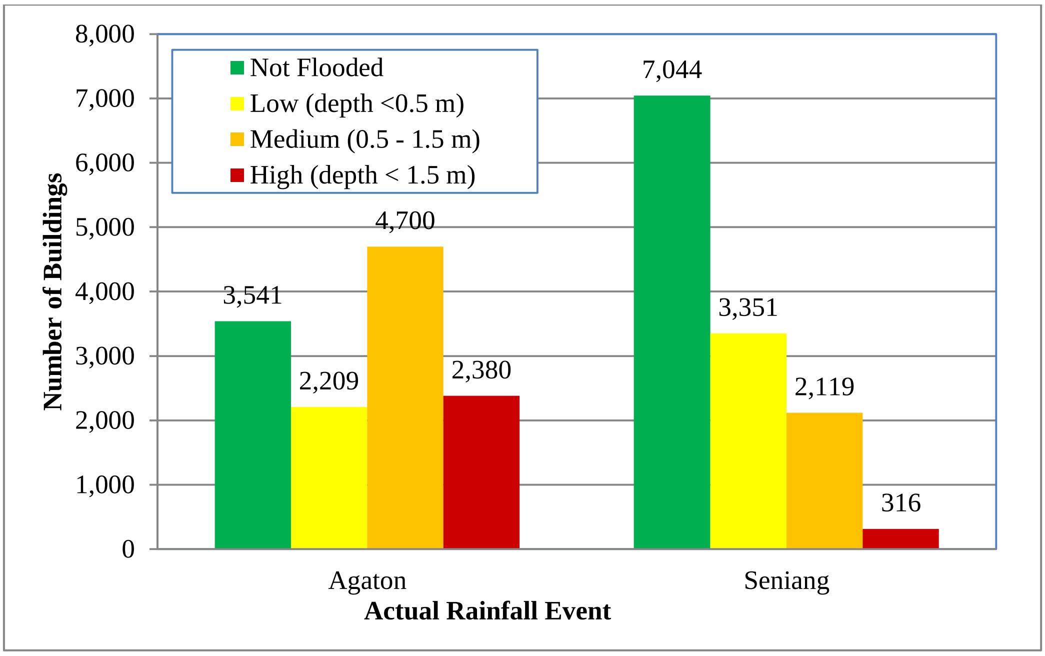

Figure 6. Flood depth affected buildings of Tago River Basin during typhoon ‘Agaton’ and ‘Seniang’.

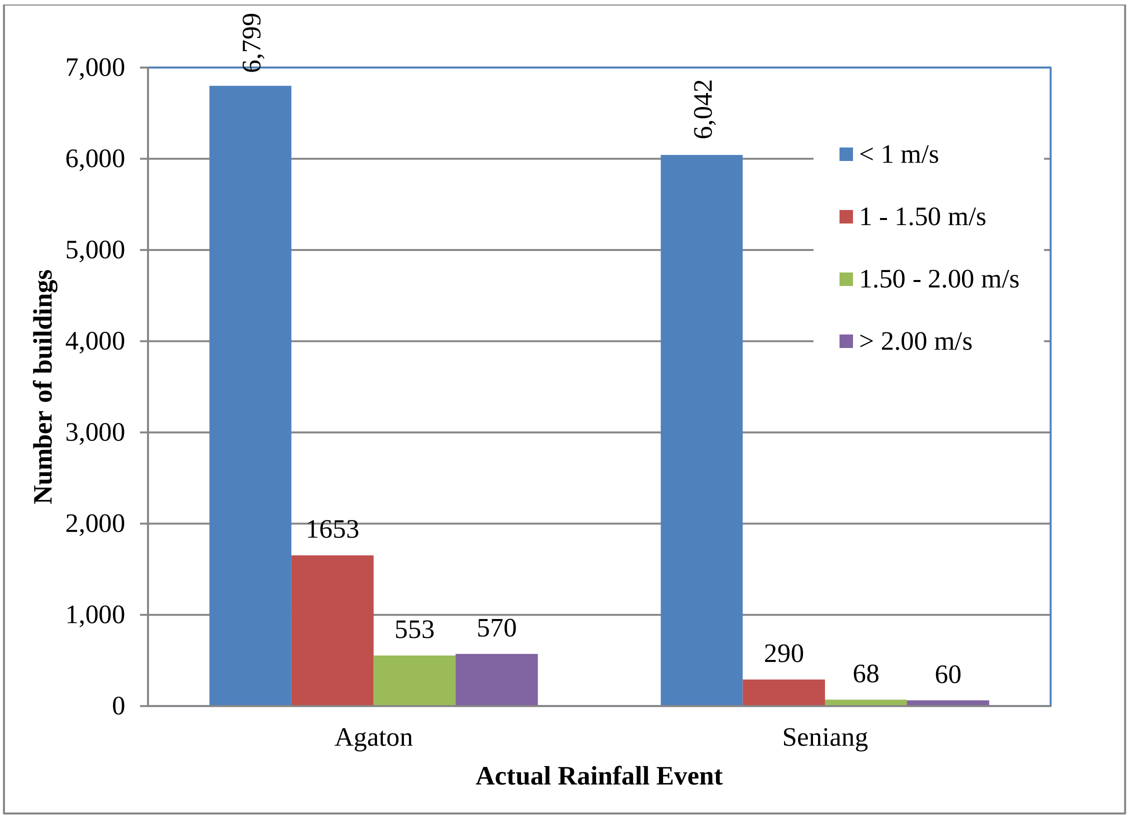

Figure 7. Graph shows the buildings affected by flood velocities.

Table 4. Table showing the area and the corresponding percentage of flooded land-cover classes during tropical storms 'Agaton' and 'Seniang' event.

Class Name	Total Area (km²)	TS Agaton		TS Seniang	
		Flooded Area (km²)	Percentage (%)	Flooded Area (km²)	Percentage (%)
Barren	51.14	3.07	6.00	2.31	4.51
Built up areas	4.39	2.50	56.98	1.25	28.45
Cropland	168.35	132.51	78.71	97.21	57.74
Forest	999.12	15.38	1.54	12.13	1.21
Grassland	146.43	15.92	10.87	12.29	8.39
Palm	55.3	18.38	33.24	13.26	23.97

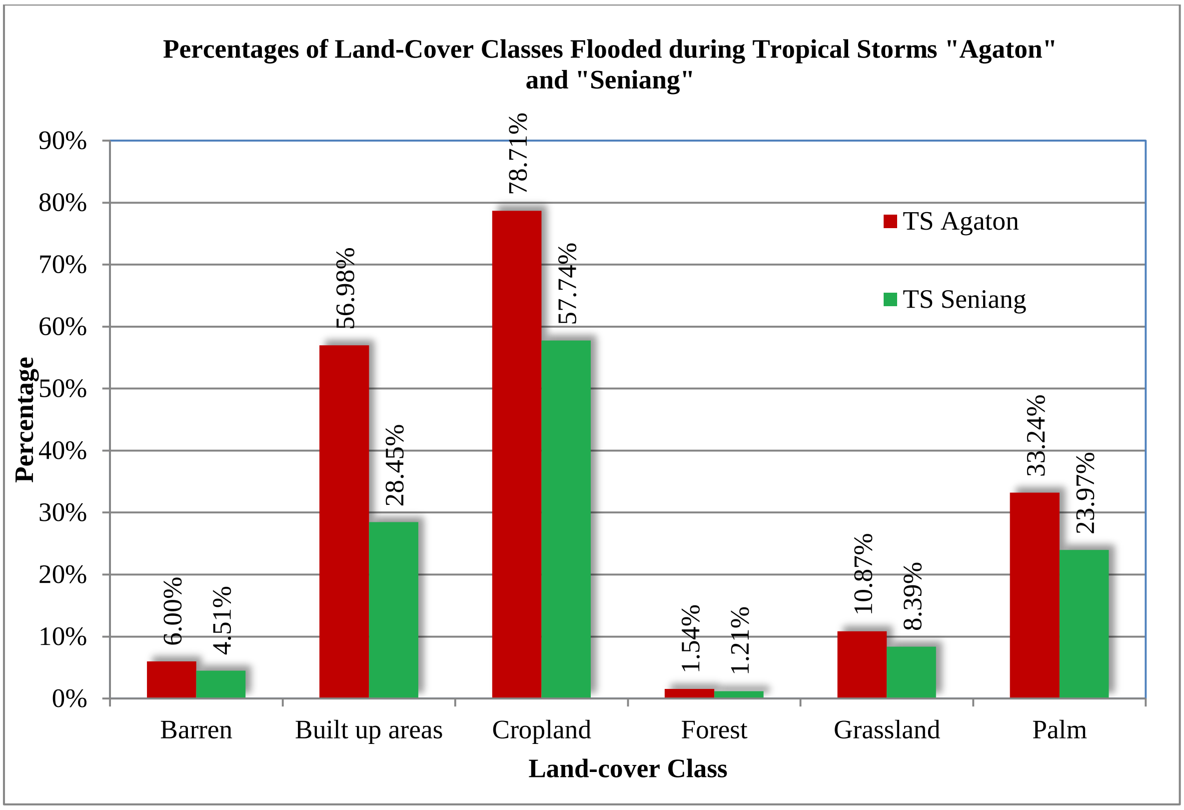

Figure 8. . Graph showing the percentages of land-cover classes flooded during tropical storms 'Agaton' and 'Seniang'.

4. CONCLUSION

The use of highly detailed LiDAR datasets combined with hydrologic and 2D hydraulic modeling aided in the reconstruction of the recent flood events that affected Tago River Basin. The approach we applied in this work was able to generate the flood depth and velocity maps that were used in the detailed assessment of flooding impacts. The maps and other information generated in this work can be very useful to the LGUs within the study area, especially for planning and implementation of flood mitigation strategies.

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