FLOOD HAZARD MAPPING OF MAINIT-TUBAY RIVER BASIN, MINDANAO, PHILIPPINES USING LIDAR AND NUMERICAL MODELS

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ABSTRACT: In this paper, we present the methods and results for the flood hazard mapping of Mainit-Tubay River Basin through numerical modelling using LiDAR-derived Digital Terrain Model (DTM), with supplementation of other geospatial datasets that included Synthetic Aperture Radar Digital Elevation Model (DEM) and land-cover map derived from satellite image analysis, among many others. Mainit-Tubay River Basin is one of the river basins covered by the Caraga State University (CSU) Phil-LiDAR 1 Project under the 'Phil-LiDAR 1. Flood Hazard Mapping of the Philippines Using LiDAR' Program supported by the Department of Science and Technology (DOST). Flooding in the river basin has become frequent in recent years. Last 2014, severe flooding occurred in the basin when tropical storms "Lingling" (locally named Agaton) and "Jangmi" (locally named Seniang) brought heavy to torrential rains. We conducted detailed flood hazard mapping of the river basin to assess the impacts brought by these flooding events, and to provide the Local Government Units (LGUs) and the community in the river basin with vital information necessary for flood disaster preparedness and mitigation.

1. INTRODUCTION

Every year, the Philippines is frequently visited by several typhoons that come from the pacific region which brought heavy rains that causes flooding to the communities on the low-lying areas of the country. These flooding events had devastating effects to the properties and livelihood of the Filipinos, and sometimes even people's lives are taken.

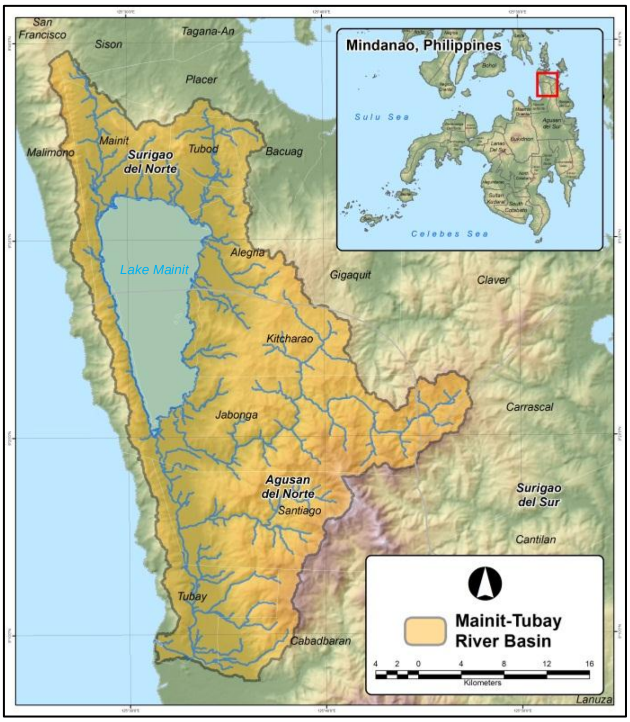


Figure 1. Map showing the location and coverage of Mainit-Tubay river basin.

Taking into account the increasing demand of information for flood disaster preparedness and mitigation, the Philippine Government through the Department of Science and Technology (DOST) initiated the Phil-LiDAR 1 Program which is also known as "Hazard Mapping of the Philippines Using LiDAR" program. This program aims to develop flood models and generate flood hazard maps by utilizing high-resolution LiDAR-derived elevation datasets such as Digital Terrain Model (DTM) as one of the major inputs. The program has fifteen component projects for the entire country and one of these is the CSU Phil-LiDAR 1 project which is the one tasked to create flood models and produce flood hazard maps of the twelve river basins within Caraga Region in Mindanao. For the project's first year of implementation, it covered the Mainit-Tubay river basin which has an approximate drainage area of 997.20 km^2 (Figure 1). It is located in the provinces of Agusan del Norte and Surigao del Norte and is composed of several major rivers and the Lake Mainit which is the Philippines' deepest and fourth largest lake. The lake has an approximate surface area of 149.86 km^2 (Tumanda et al., 2003) and has a maximum depth reaching about 223 m (Lewis, 1973). During heavy rainfall events, severe flooding occurs in Mainit-Tubay river basin. This was recently experienced during the hit of the tropical storms 'Lingling' (locally named 'Agaton') and 'Jangmi' (locally named 'Seniang') last January and December 2014, respectively (NDRMMC, 2014; 2015).

Generally, a hazard map for a specific flooding event or scenario would contain the expected inundation level and flooding extent categorized into low, medium and high hazards; locations of structures (such as households, schools, commercial buildings, roads, bridges, land cover types, and evacuation centers, among others); political boundaries (provincial, city/municipal, and barangay); and information about the flooding event where the map is applicable (e.g., according to volume and intensity of rainfall). Flood hazard maps are generated through a series of steps. First, information about the volume and intensity of rainfall is obtained. This information is then fed into a mathematical simulation model (or flood model) to compute how much volume of runoff or flood water is generated in the mountains when it rains, and to determine how this flood water flows downwards into the rivers and overflows into the floodplains. The accuracy and detail of information depicted in a flood hazard map is dependent on the topographic data used during flood modelling. With this dependency, the use of LiDAR-derived datasets such as DTMs as topographic data input to flood model is the best option. LiDAR data can provide the much-needed accuracy and topographic detail to model and delineate the potential extent of flooding due to the high accuracy of the data and the ability to resolve small features that influence flow paths.

In this paper, we present the methods and results for the flood hazard mapping of Mainit-Tubay River Basin through numerical modelling using LiDAR, with supplementation of other geospatial datasets that included Synthetic Aperture Radar Digital Elevation Model (DEM) and land-cover map derived from satellite image analysis, among many others. We highlight in this work the flood hazard mapping for the ‘Agaton” and ‘Seniang’ flood events. The reconstruction of these flood events can assist in understanding how flooding occurs, and in mapping areas that were flooded. If an area has been flooded before, it more likely that it will be flooded again in the near future. If this is known through flood reconstruction, then it is easy to pinpoint which areas are to be avoided should heavy/torrential rains will pour over the area. This information can be utilized by the Local Government Units and the concerned community in formulating flood disaster preparedness plans and mitigating procedures.

2. METHODOLOGY

2.1 Overview

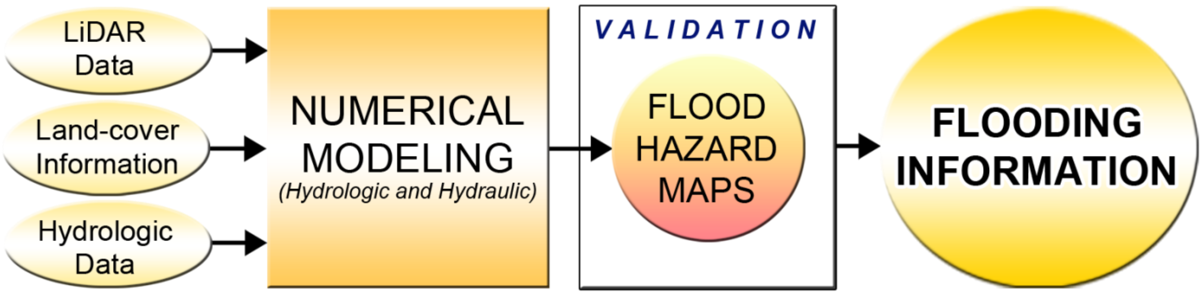


Figure 2. The flood hazard map generation process.

Figure 2 shows the flowchart summarizing the steps involved in flood hazard map generation. We utilized the 1-m spatial resolution LiDAR-derived DTM integrated with river bathymetric data as the major input data in numerical modeling, together with land-cover information and hydrologic data. The numerical modelling consisted of developing a hydrologic model of the river basin, and a one-dimensional hydraulic model of the rivers, lake and the flood plains. The purpose of the hydrologic model was to determine the volume of water coming from the various sub-basins (also called watersheds) due to rainfall brought about by the tropical storms. Rainfall depths recorded by rain gauges within and in the vicinity of the river basin gauges installed by the Advanced Science and Technology Institute of the Department of Science and Technology (ASTI-DOST) were used as input into the hydrologic model to compute discharge hydrographs for specific locations in the river basin, specifically at those locations where the upstream watersheds ends and the floodplain portions begin. The discharge hydrographs depict the volume of water per unit time (in m^3/s) that drains into the main river at these locations. These hydrographs were then used as inputs into the hydraulic model to simulate various processes such as the movement of water from the upstream watersheds into the main river and the lake, as well as how its overflows from the rivers and the lake and travels into the flood plains. The output of the hydraulic model simulations are flood depth and hazard maps. These maps were validated for its accuracy of depicting flooded areas through comparison with the actual flooding data that were gathered in the field.

2.2 Numerical Modeling and Flood Hazard Map Generation

2.2.1 Hydrologic Model Development and Calibration: The hydrologic model of Mainit-Tubay river basin was based on the Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS), a simulation software specifically designed to simulate the precipitation-runoff processes of watershed systems. HEC HMS modeling is dependent on the three components: the basin model, meteorological model, and the set of control specification. For Mainit-Tubay, the basin model, which is the physical representation of the watershed, was developed by utilizing a 10-m Synthetic Aperture Radar Digital Elevation Model (SAR DEM) and the rivers networks in the delineation of watersheds; and is parameterized using the information from the land-cover maps that was generated through the analysis of Landsat 7 ETM+ and Landsat 8 OLI satellite images. Land-cover information was extracted through Maximum Likelihood classification, with an overall classification accuracy of 93.25%.

The HEC HMS model setup of Mainit-Tubay consisted of 383 sub-basins, 158 reaches, 178 junctions, 2 diversions and 1 reservoir (Figure 7). The model simulates flow hydrographs based on rainfall data recorded by ASTI DOST rain gauges located at Cabadbaran, Jagupit, Poblacion, Kitcharao Municipality, Kitcharao, Mainit Municipality, Mainit, Tubod, Malimono, San Francisco Municipality, San Francisco, Sison, Gigaquit, Claver and Cantilan (Figure 8). The parameters of the model were calibrated by relating the simulated flow hydrographs to the actual measured flow in the river. The station utilized during HEC HMS model calibration was on Puyo Bridge, which is one of the outlets after the diversion in Bangonay River (Figure 5). Hydrological data necessary for calibration was gathered from this station last 11/26/2014 to 12/05/2014 with the use of water level and velocity data logging sensors together with the river cross-sectional data.

2.2.2 Hydraulic Model Development: The hydraulic model of Mainit-Tubay river basin was based on the Hydrologic Engineering Center River Analysis System (HEC RAS), which is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels (USACE, 2010). The Mainit-Tubay HEC RAS model was developed by first creating geometric representations of the rivers, lake and the floodplains. These geometries are the river centerlines, banks and cross-sections, storage area and the floodplain boundary (Figure **6**). The LiDAR DTM was used as the primary source of elevation data for the cross-section lines. Parameterization of the HEC RAS model utilized the land cover information by extracting the Manning's roughness coefficients and was assigned to the cross-section segments. Steady flow simulation module of HEC RAS was used for the model to generate flood depth estimations during the two storms. This module can do one-dimensional water profile calculations for steady gradually varied flow. Under the steady flow, the flow or discharge values at the inflow were specified using the result of the HEC HMS simulation. The HEC RAS model of Mainit-Tubay consisted of 58 junctions and 140 reaches. Among these reaches, 60 are internal flows and 80 are inflows boundary conditions. The interface of Mainit-Tubay HEC RAS model is shown in Figure 7.

2.2.3 Flood Hazard Map Generation for 'Agaton' and 'Seniang' Events: Using the HEC HMS hydrologic model, discharge hydrographs were generated for the 'Agaton' (January 10-24, 2014) and 'Seniang' (December 20, 2014-January 5, 2015) events. For generating flood depth and hazard maps for each event, the maximum flow rate at inflow and internal flow boundary condition locations were obtained from discharge hydrographs. These values were used as inputs for HEC RAS to compute the maximum water surface profiles in all the cross-sections within the model domain for the two events. The water surface profiles computed by the HEC RAS model was converted into flood depth maps through GIS post-processing using HEC GeoRAS, an extension of ArcGIS. The procedures include generating a Triangulated Irregular Network (TIN) of water surface elevation based on the computed water surface profiles at the cross-sections, converting the TIN into a water surface elevation (WSE) grid, and then overlaying the WSE grid into the 1-m LIDAR DTM to estimate the flood depths (i.e., subtracting the WSE grid by the DEM grid). The generated depth grid was then categorized based on its corresponding hazard level. The categorizations are: low hazard for depths of less than 0.50 m, medium hazard for depths from 0.50 m to 1.50 m, and high hazard for depths of greater than 1.50 m.

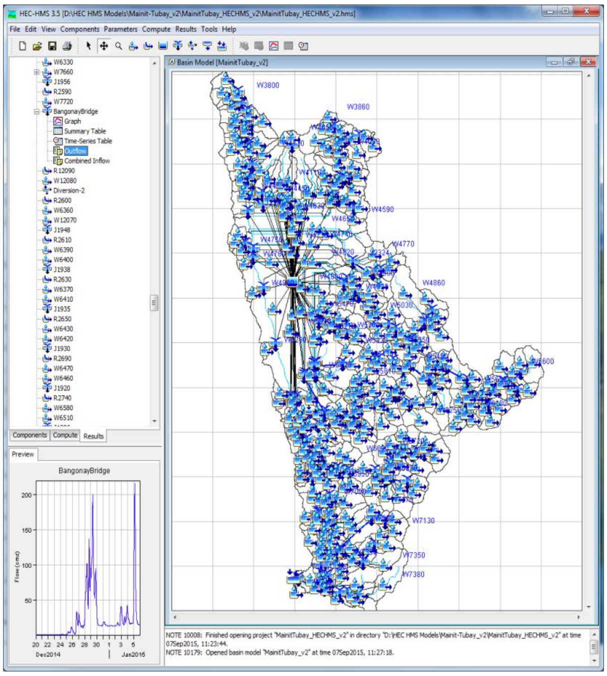


Figure 3. The interface of the HEC HMS-based hydrologic model of Mainit-Tubay river basin.

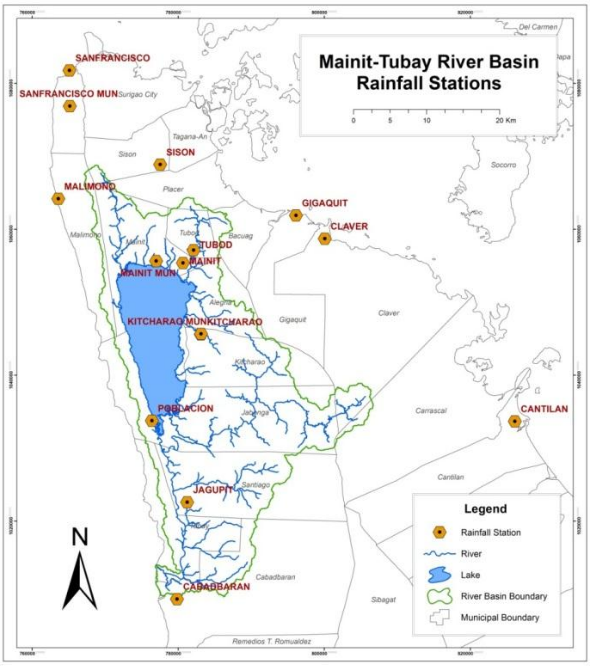


Figure 4. Map showing the location of rainfall stations for Mainit-Tubay river basin.

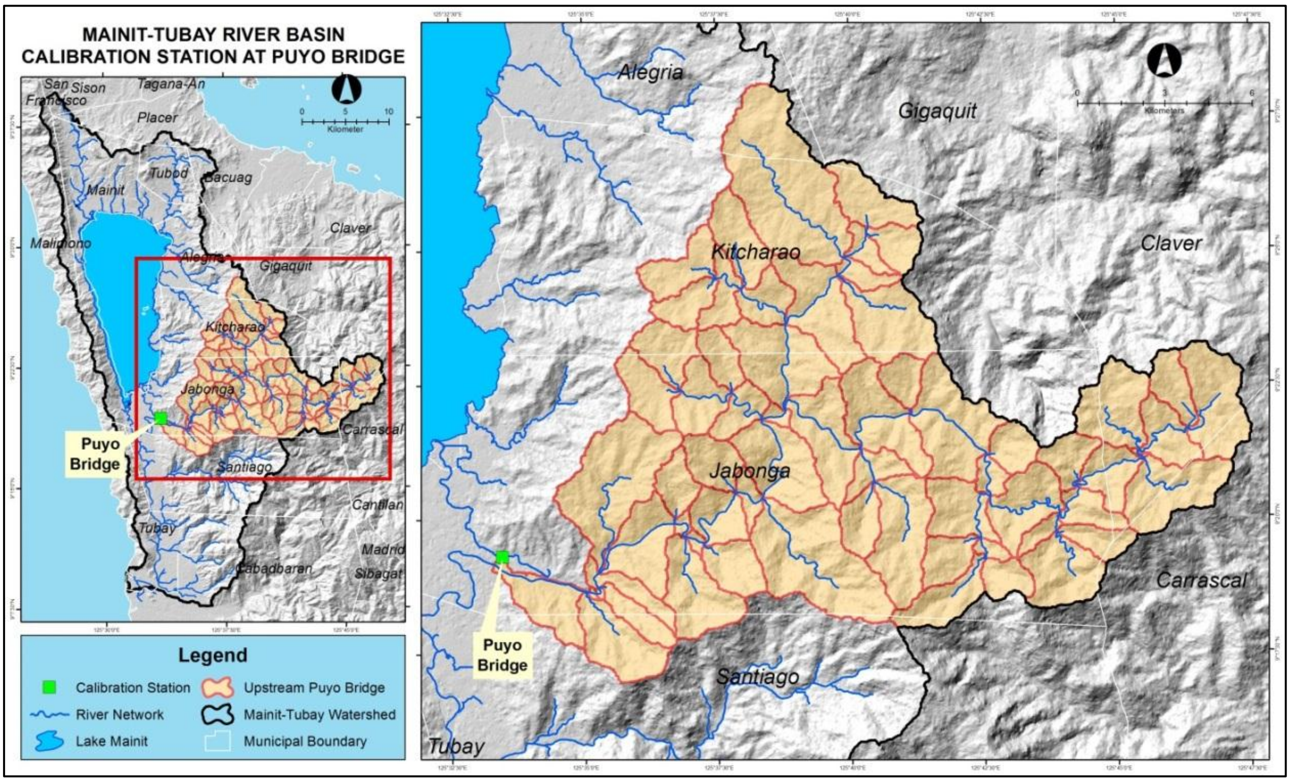


Figure 5. Mainit-Tubay River basin and the upstream sub-basins of the Puyo Bridge calibration station.

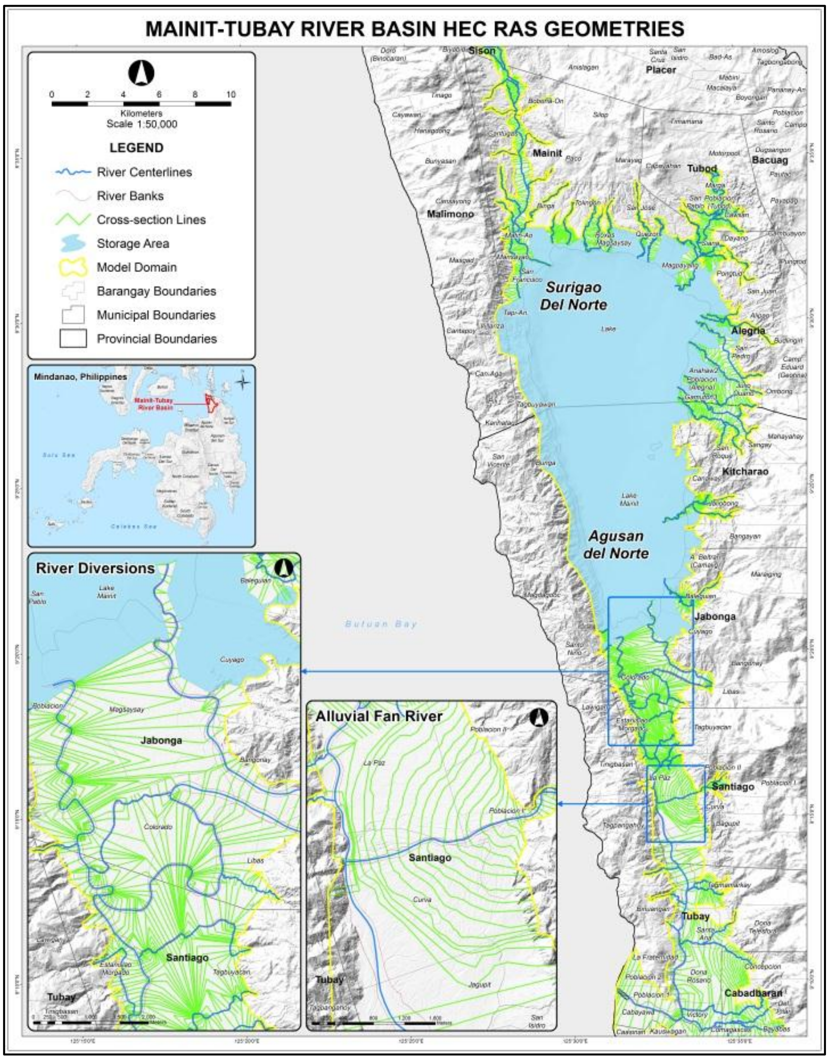


Figure 6. Geometric representations created for Mainit-Tubay river basin.

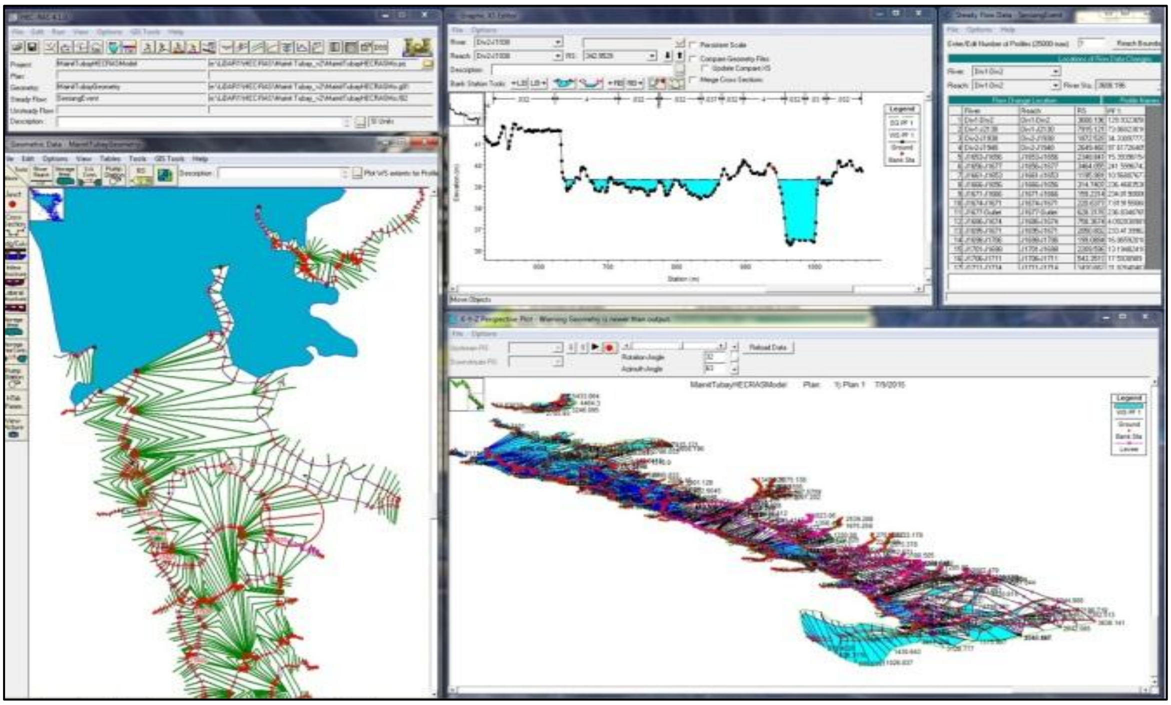


Figure 7. Interface of Mainit-Tubay River Basin HEC RAS model.

2.3 Flood Hazard Map Validation

Flood map validation surveys were conducted last January 2015 to determine the reliability and accuracy of the generated flood hazard maps. Pre-determined random locations within the floodplain of Mainit-Tubay river basin were visited to determine whether they were flooded or not during ‘Agaton’ (January 2014) and ‘Seniang ‘(December 2014). The validation procedure consisted of comparing the actual flooding data from the field to the flooding that was generated by the flood model. The total number of correctly predicted points over the total number of points collected determines the overall accuracy of the flood hazard map.

Figure 8. Some of the photos showing the flood map validation surveys in Mainit-Tubay River Basin.

3. RESULTS AND DISCUSSION

3.1 Accuracy of the Hydrologic Model

As shown in Figure 9, the preliminary model simulated stage values at the lake coincides with the stage readings at Kalinawan Bridge water level station which is located at the outlet of the lake. This implies that the preliminary Mainit-Tubay HEC HMS model, although not yet calibrated, can be able to simulate actual water level of the lake.

The result of the calibration is shown in Figure 10, which shows the simulated flow hydrographs before and after the calibration of the Mainit-Tubay HEC HMs model. In evaluating the model performance before and after calibration, three measures of accuracy were used. These are the Nash-Sutcliffe Coefficient of Model Efficiency (NSE), percentage bias (PBIAS), and the RMSE-observations standard deviation ratio (RSR). These measurements are computed by comparing the observed and the simulated hydrographs based on the evaluation guidelines (Moraisi et al., 2007). Based on the model performance evaluation, the overall performance of the hydrologic model before calibration is “unsatisfactory” (NSE=-0.47, PBIAS=-56.53, and RSR=1.21) which is very noticeable in the comparison between the observed and simulated hydrographs. After the calibration, the statistics improved (NSE=0.56, PBIAS=-22.54, and RSR=0.56), indicating a satisfactory-to-good model performance.

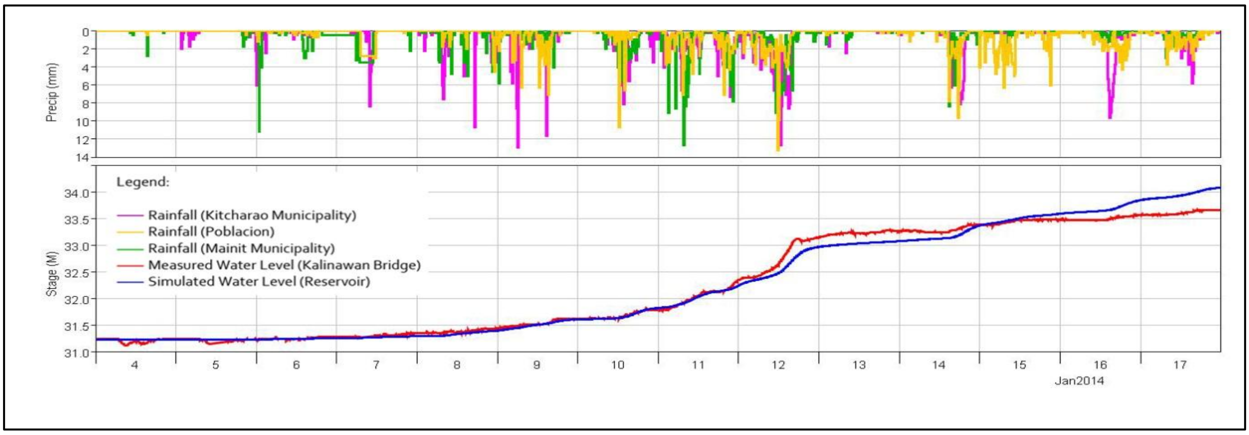


Figure 9. Graph showing the comparison between the edited stage readings at Kalinawan Bridge water level station and the simulated stage readings at the lake of the preliminary Mainit-Tubay HEC HMS model.

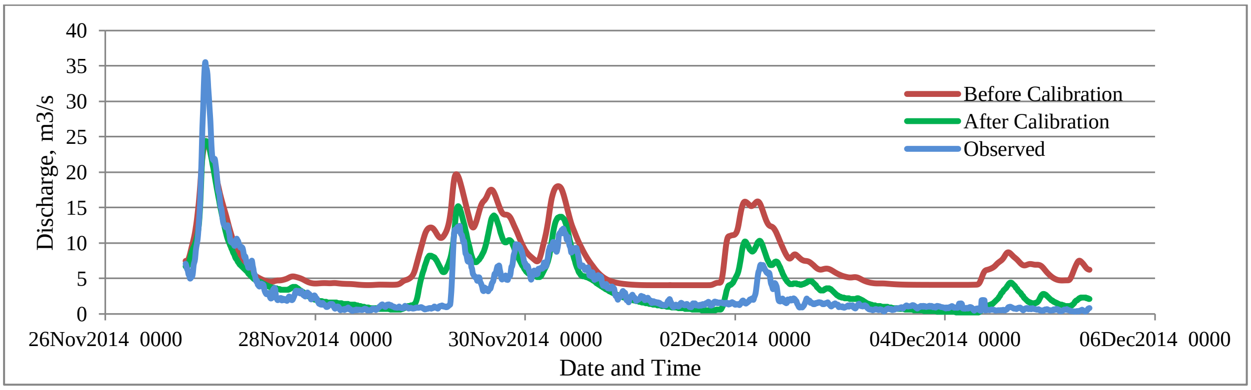


Figure 10. Comparison between the simulated discharge before and after calibration of the HEC HMS model.

3.2 Flood Hazard Maps of 'Agaton' and 'Seniang'

The generated flood hazard maps of Mainit-Tubay River Basin for "Agaton" and "Seniang" events are shown in Figure 11 and Figure 12, respectively.

These flood hazard maps were validated and the results are shown in Table 1 and Table 2. Based on the results of flood hazard map validation, the 'Agaton' flood hazard map has an overall accuracy of 68.26% while the 'Seniang' flood hazard map has an overall accuracy of 71.86%. For both events, the computed producer's accuracy for actual "flooded" points gained low percentages values of 41.46% and 23.21%. This implied that there were numerous actual "flooded" points which were not correctly predicted by the model as "flooded". On the other hand, the producer's accuracy for "not flooded" points gained high percentages of 76.98% and 96.40%, which means that majority of the actual "not flooded" points were correctly predicted by the model as "not flooded". Looking on the user's accuracy for "Agaton" flood hazard map, there were only 36.96% of the "flooded" points on map which are really flooded and 80.17% of the "not flooded " points on map which are really not flooded on the ground. For "Seniang" flood hazard map, the user's accuracy implied that 76.47% of the "flooded" points on the map are truly flooded and 71.33% of the "not flooded" points on the map were also not flooded on the ground.

Table 1. Result of the flood validation analysis in Mainit-Tubay river basin for typhoon 'Agaton' event.

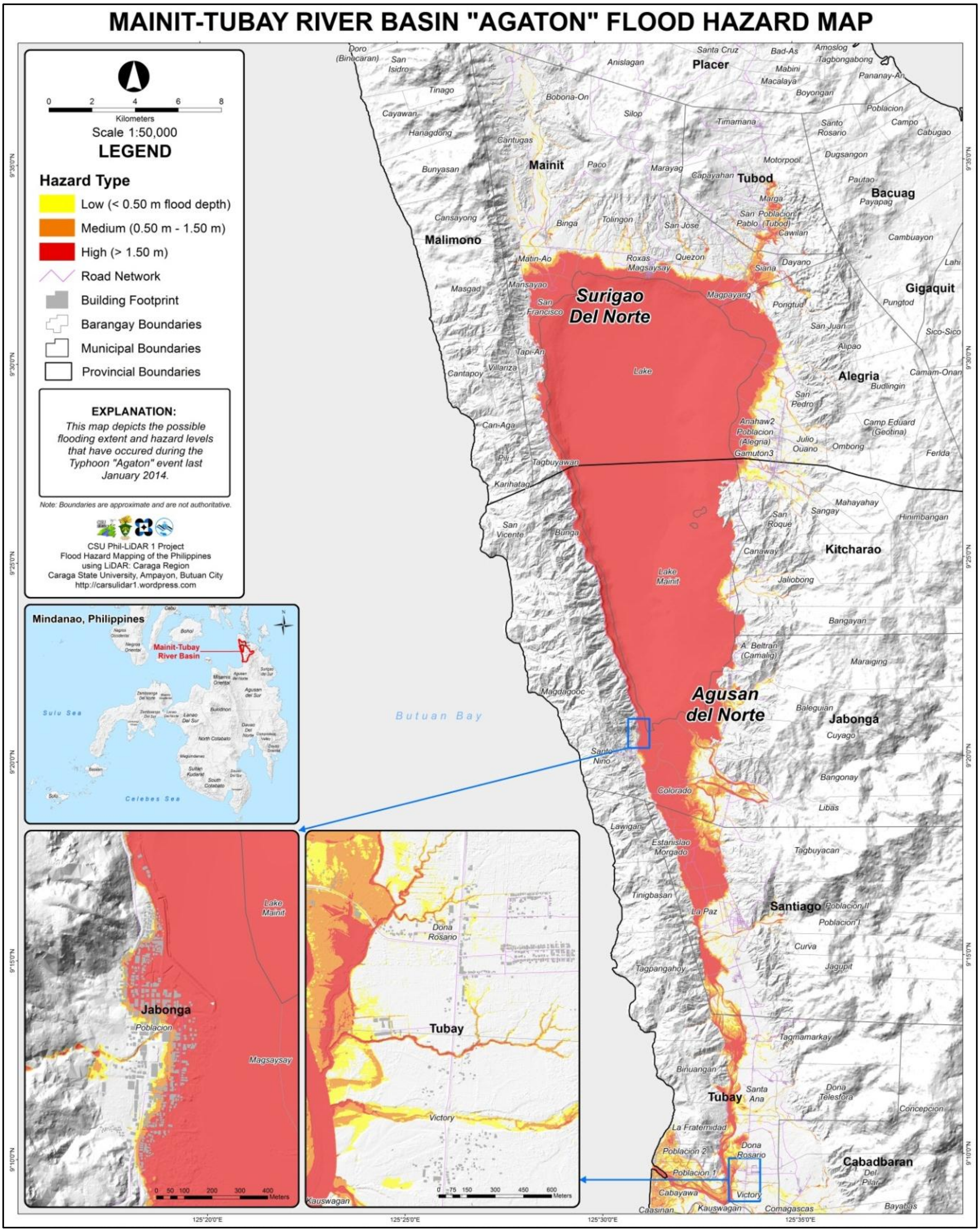
		Actual Flooding Scenario			User's Accuracy (%)
		Flooded	Not Flooded	Total	
Flood Model Simulated Flooding Scenario	Flooded	**17**	29	46	**36.96**
	Not Flooded	24	**97**	121	**80.17**
	Total	41	126	**167**	
Producer's Accuracy (%)		**41.46**	**76.98**		
Sum of Diagonal Values		114			
Overall Accuracy (%)		**68.26**			

Table 2. Result of the flood validation analysis in Mainit-Tubay river basin for typhoon "Seniang" event.

		Actual Flooding Scenario			User's Accuracy (%)
		Flooded	Not Flooded	Total	
Flood Model Simulated Flooding Scenario	Flooded	**13**	4	17	**76.47**
	Not Flooded	43	**107**	150	**71.33**
	Total	56	111	**167**	
Producer's Accuracy (%)		**23.21**	**96.40**		
Sum of Diagonal Values		120			
Overall Accuracy (%)		**71.86**			

3.3 Flood Hazard Statistics

The computed values of flooded areas during 'Agaton' and 'Seniang' categorized according to hazard levels are shown in Table 3. It can be observed that the flooding during 'Agaton' has a wider extent (222.96 km²) was wider than that during 'Seniang' (192.43) km². In both events, the areas under high hazard levels are significantly large compared to the areas under medium and low hazard levels. This might be due to the existence of Lake Mainit which composed majority of the high hazard level areas.


MAINIT-TUBAY RIVER BASIN "AGATON" FLOOD HAZARD MAP
Kilometers
Scale 1:50,000
LEGEND
Hazard Type
Low (< 0.50 m flood depth)
Medium (0.50 m - 1.50 m)
High (> 1.50 m)
Road Network
Building Footprint
Barangay Boundaries
Municipal Boundaries
Provincial Boundaries
EXPLANATION:
This map depicts the possible flooding extent and hazard levels that have occured during the Typhoon "Agaton" event last January 2014.
Note: Boundaries are approximate and are not authoritative.
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Flood Hazard Mapping of the Philippines using LiDAR: Caraga Region
Caraga State University, Ampayon, Butuan City
http://carsulidar1.wordpress.com
Mindanao, Philippines
Mainit-Tubay River Basin
Surigao Del Norte
Agusan del Norte
Lake Mainit
Butuan Bay
Placer
Mainit
Tubod
Bacuag
Malimono
Gigaquit
Alegria
Kitcharao
Jabonga
Santiago
Tubay
Cabadbaran
Poblacion
Magsaysay
Dona Rosario
Victory
Kauswagan

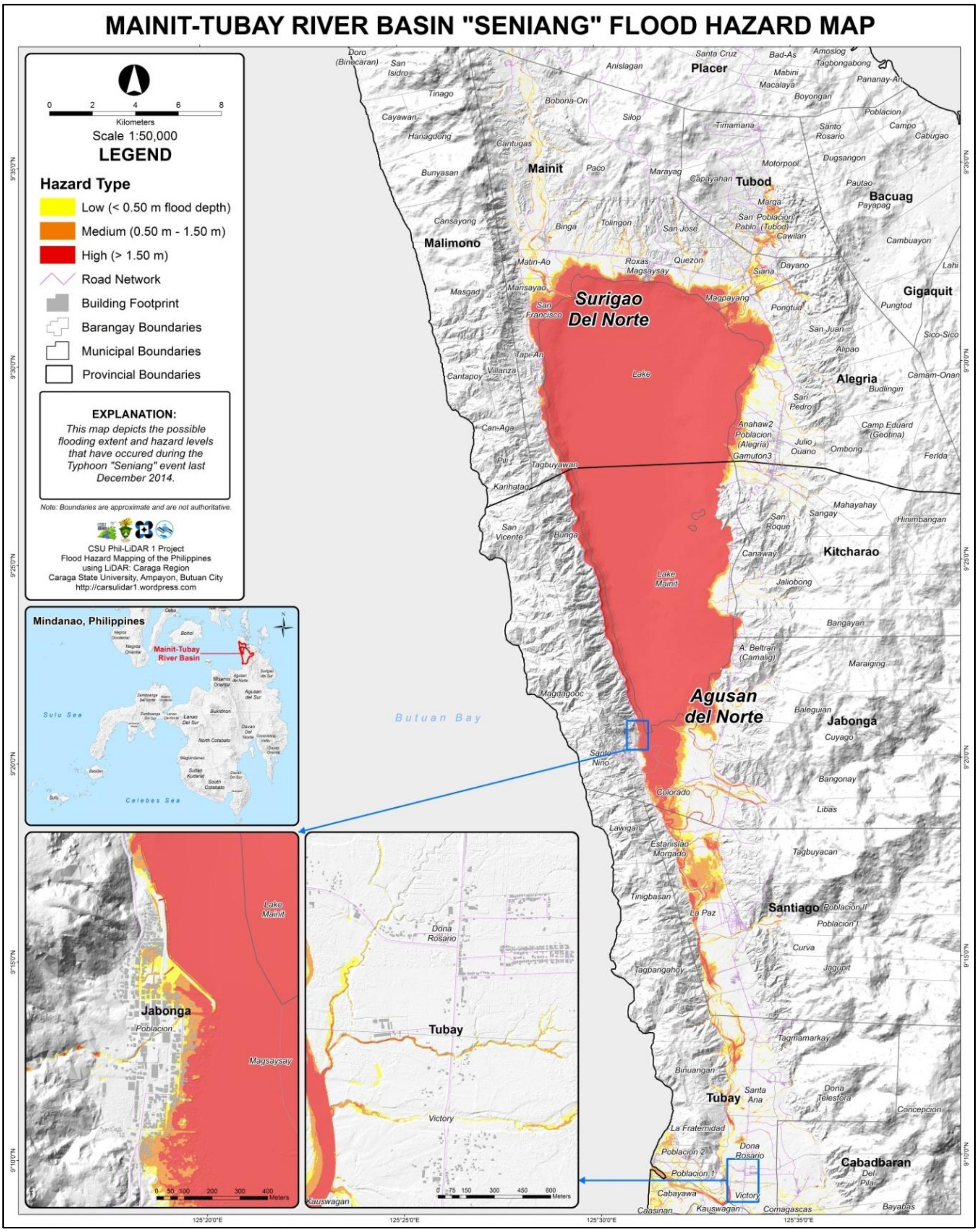

Figure 12. The generated flood hazard map of Mainit-Tubay River Basin during tropical storm ‘Seniang’ that has occurred last December 2014.

Table 3. Calculated areas of flooding in Mainit-Tubay river basin according to hazard level.

Hazard Level	**Flooded Area (km²)**	
	Agaton	**Seniang**
Low (< 0.50 m flood depth)	13.69	15.09
Medium (0.50 m - 1.50 m)	20.26	18.33
High (> 1.50 m)	189.01	159.01
Total Area	222.96	192.43

4. CONCLUSION

In this paper we showed that detailed flood hazard maps and hazard information can be generated through the utilization of high spatial resolution LiDAR-derived Digital Terrain Model (DTM) and other geospatial datasets as inputs into numerical models. These maps and information can be used not only for assessing the flood hazards caused by 'Agaton' and 'Seniang', but also as visual aids to help people understand the differences of the impacts of different tropical storms in the occurrence of flooding. The latter is very important especially now that tropical storms (and the rains that it brings along) has become fiercer in recent years, and will continue to be so due to the effects of climate change. With the knowledge learned from the numerical model simulations and flood hazard mapping, the Local Government Units (LGUs) and the communities in the Mainit-Tubay River Basin can be informed and empowered in finding ways to mitigate the negative impacts of flooding, as well as in evaluating adaptation strategies if such flooding (caused by 'Agaton' and 'Seniang') or more intense events will occur again in the near future. Such flood adaptation strategies may include (i.) localized land-use planning integrating flood hazard information, (ii.) relocating communities to safe grounds, (iii.) identification and improvement of evacuation routes, and (iv.) building flood defenses (specifically in areas where river overflowing occurs), among many others.

5. RECOMMENDATIONS

Although the model can already generate and estimate realistic flood depths, it still needs to be improved by (i) updating the bathymetric data of Lake Mainit since the initially utilized bathymetric data were gathered last 2003; and (ii) conducting hydrological measurements at the lake and at the downstream portion of the river basin to further calibrate the parameters of the numerical models.

ACKNOWLEDGEMENTS

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