FLOOD MODELING AND HAZARD MAPPING USING LIDAR IN MUSIMUSI RIVER, MISAMIS ORIENTAL, PHILIPPINES

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ABSTRACT: Recognizing the substantial use of Light and Detection and Ranging (LIDAR) technology in mapping systems has resulted to the formulation of this research which aims to integrate the highly accurate and dense digital geo-referenced data sets in flood modeling and flood hazard development in the river of Musimusi in Misamis Oriental, Philippines. Generation of flood hazard maps were carried through by using the Hydrologic Engineering Center's (HEC) Hydrologic Modeling System (HMS) and River Analysis System (RAS) programs of the US Army Corps for the development of hydrologic and hydraulic models. Discharge simulations were performed in HMS model which was calibrated using the hydrologic data during Typhoon Jangmi (locally known as Seniang). Outflows were then simulated using the Rainfall Intensity Duration Frequency (RIDF) data from Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) for the several year return period projections of flooding. Using these discharge figures, flood depth and extent simulation were conducted in RAS model where elevation model of LiDAR is integrated. Results of this research revealed higher precision of flood extents and depths of the developed flood hazard maps. The generated information of LiDAR integrated hazard maps is useful to the local governing units for improved disaster awareness and enhanced strategies for disaster mitigation, preparation, response and rehabilitation measures.

1. INTRODUCTION

With around 20 devastating storms visiting annually, Philippines is known to be a naturally disaster-stricken country which is also tagged as 3rd most hazard-prone country in the world (Quismundo, 2012). The Mindanao Island, once considered as typhoon-free has now regarded occurrences of these natural phenomena as the new normal associated to extreme events of tropical storms and monsoon rains causing flooding. Along with the onset of climate change is the decrease of forest covers in the watersheds due to the flourishing socio-economic developments which has magnified the impacts of flooding causing considerable loss of lives, homes, livelihood and services in different parts of the country in the past several years (Senate of the Philippines, 2013).

There are several means employed in dealing with flood assessments, however among all of these, flood modeling is one of the most recognized effective way of assessing the flood risk to people and property by determining volume and discharge production of specific events (Yuan and K. Qaiser, 2011). The U.S. Army Corps of Hydrologic Engineers' Hydrologic Modeling System (HEC-HMS) and River Analysis System (HEC-RAS) is among the widely used tools in analyzing watershed hydrologic behaviors in flood modeling. These computer programs provide current or future runoff information such as volumes, peak flow rates and its timing through simulations in a hydrologic system and perform rainfall-runoff analysis and hydraulics. Such information will provide significant contribution to the applications of flood forecasting and simulation of hydrological processes as well as to the generation of flood hazard maps developed from the simulated flood inundations.

The use of Light Detection and Ranging (LiDAR) data in mapping is gaining wide recognition due to its highly accurate and densed digital geo-referenced data sets. Its applicability extends to wide array of mapping systems enabling specialists to examine natural or built surface characteristics with greater accuracy, precision and flexibility (NOAA, 2013). Specifically, LiDAR utilization in flood modeling has been very efficient in analyzing the watershed hydrology and boundary delineation. Integration of LiDAR data in the development of hazard maps ensures higher accuracy which is important especially on the application to flood disaster programs and planning.

Utilizing the combined technologies of HEC-HMS, HEC-RAS and GIS utilities, this paper illustrate the modeling of flood and development of flood hazard maps in Musimusi river, Balingasag, Philippines as integrated with LiDAR digital elevation model data. Through this technology, reconstruction of actual flood event occurrence is being achieved along with the simulation of flood return periods in various years.

2. METHODOLOGY

2.1. Locale of the Study

Musimusi watershed is situated in the municipality of Balingasag, Misamis Oriental. It is geographically located approximately between 8°41’ to 8°48 north latitudes and 124°45’ to 124°54’ east longitudes (Figure 1). The river basin has an approximate area of 7,772 ha and covers 16 barangay local government units, 15 of which belong to the Municipality of Balingasag and 1 barangay to the Municipality of Claveria. Majority (77%) of the watershed falls within Balingasag, and the rest (23%) under the Municipality of Claveria.

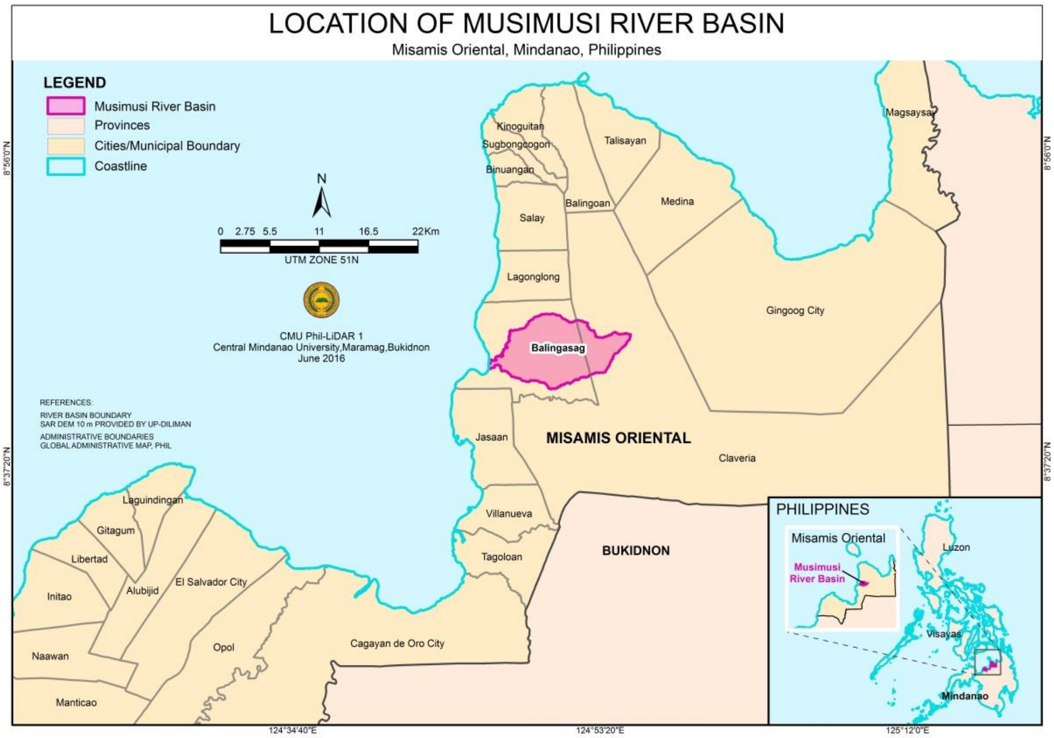

Figure 1. The location of Musimusi watershed relative to Philippines.

2.2. Basin Model Generation

Basin model of Musimusi was generated using HEC-GeoHMS, an extension of the HEC-HMS program under the GIS interface. The basin and subbasins were generated using Synthetic Aperture Radar (SAR) 10m DEM and a digitized river centerline extracted from Google Earth. Different models were selected for the subcomponents of the HMS model. Default values were used for some parameters while land cover and soil type datasets were utilized to aid in the calculation of other parameters such as the Curve number grid.

2.3. HEC-HMS Model Calibration and Simulation

The necessary components in the newly generated model namely the meteorologic model, control specification and the time series data which contains the data for discharge and rainfall were created and set up. Basin model was run for initial simulation and parameters were manually adjusted to calibrate the model by reducing the difference of the hydrographs between the simulated and observed values. The model was tested for calibration acceptance using various quantitative statistics. Through this the general performance of the model is also determined. The used efficiency criteria were the Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of measured data (RSR).

Scenarios of the flooding were simulated using Rainfall Intensity Duration Frequency (RIDF) data prepared and obtained from Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA). Data were computed based on a 26-year historical rainfall data of rain gauge located at Barangay Lumbia, Cagayan de Oro City, the closest rain gauge to the river basin with available data. Three (3) different return periods (5year, 10year and 100year) all having 24-hour long data were utilized for the hypothetical simulation. Rainfall depths of each return period in specific durations were inputted in separate meteorologic models created for each return period through the Frequency storm method.

2.4. HEC-RAS Model Development and Simulation

The geometric data was developed in the environment of ArcGIS using the extension Hec-geoRAS toolbars. With the aid of Light and Detection Ranging (LiDAR) DEM data, different RAS layers namely the stream centerlines, bank lines, flow path and XS Cutlines were created. Both features of centerlines and bank lines were digitized based on the LiDAR data, while flowpaths were copied features of both centerlines and bank lines with differentiated line types. RAS data is then ready for export after 3D profiles for centerlines and XS Cutlines are generated.

HEC-RAS simulations were conducted by setting up the hydraulic model through a project consisting a set of data files associated with the river system. Files were categorized as the following: geometric data previously developed in ArcGIS and imported in HEC-RAS; steady flow data which contains peak outflows of upstream junctions determined through the global summary results of the calibrated basin model; and the plan data comprised of specific set of geometric and flow data ready for simulation run. Geometric data in particular undergoes further adjustments such as naming of junctions, filtering of cross section points and inputting of Manning's n values on the main channel, left and right overbank areas of cross section data. Result of simulation is viewed and analyzed under RAS Mapper. Flood hazard maps were generated using the flood depths simulation results of each event.

3. RESULTS AND DISCUSSIONS

3.1. HMS Basin Model

The generated basin model of Musimusi watershed (Figure 2) has a total area of 7,772.11 hectares with 27 subbasins, 14 reaches and 12 junctions. Reaches represent for tributary rivers within the entire watershed boundary while junctions represents for the points where every rivers meet.

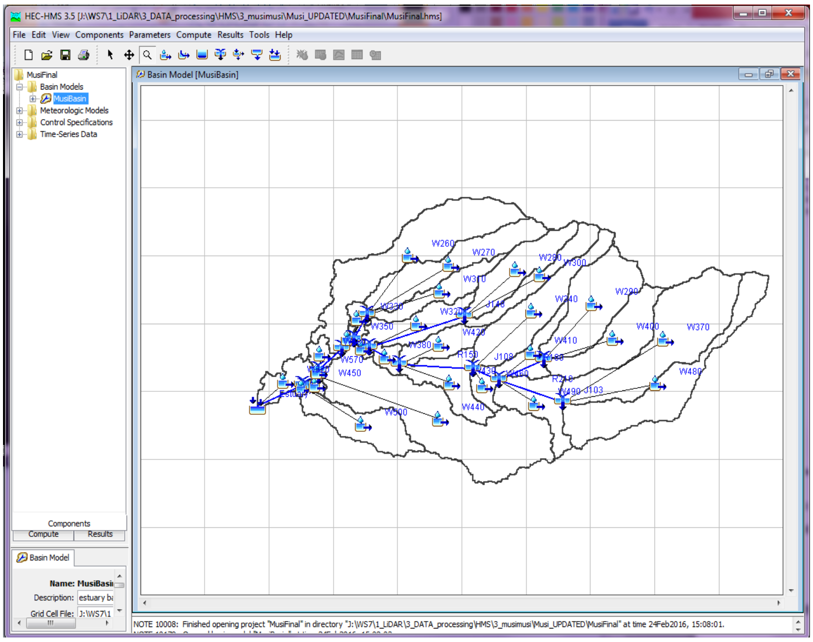

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Figure 1. The generated Musimusi river HMS basin model.

The developed hydrologic model is composed of four components necessary for the simulation of the basic hydrologic processes such as the runoff generation from rainfall, transformation and combination with baseflow, and routing towards the outlet. Methods used for each component were the following: US Soil Conservation Service – Curve Number (US SCSCN) method for infiltration loss model, Clark Unit Hydrograph for direct runoff model, Exponential Recession for baseflow, and Muskingum-Cunge Standard for Channel routing.

Computation of Curve Number (CN) parameter of SCS-CN infiltration loss component was accomplished using soil and land cover maps. Specifically, the CN parameter is based on land-cover, hydrologic soil group and antecedent moisture. Shape files of the maps were acquired from Bureau of Soils and Water Management-

Department of Agriculture (DA) and National Mapping and Resource Information Authority (NAMRIA), respectively.

Discharge and rainfall data of the actual event of Typhoon Jangmi (locally known as Seniang) on December 29, 2014 was utilized for the initial rainfall-runoff simulation of HEC-HMS model. Figure 3 illustrates the hydrometry of Musimusi river, with captured rainfall data from ARG at Barangay Quezon, Balingasag and the river discharge taken at Musimusi Bridge, Barnagay Baliwagan, Balingasag, Misamis Oriental. Total rain volume acquired by the ARG is 157.2 mm. It peaked to 9mm on 29 December 2014 at1130 hours. Gathered discharge data began at 0740 hours to 0250 hours of December 29-30, 2014 with peak discharge of 27.87m^3/s on December 29, 2014 at 1310 hours. The lag time between the peak rainfall and discharge is one (1) hour and 40 minutes.

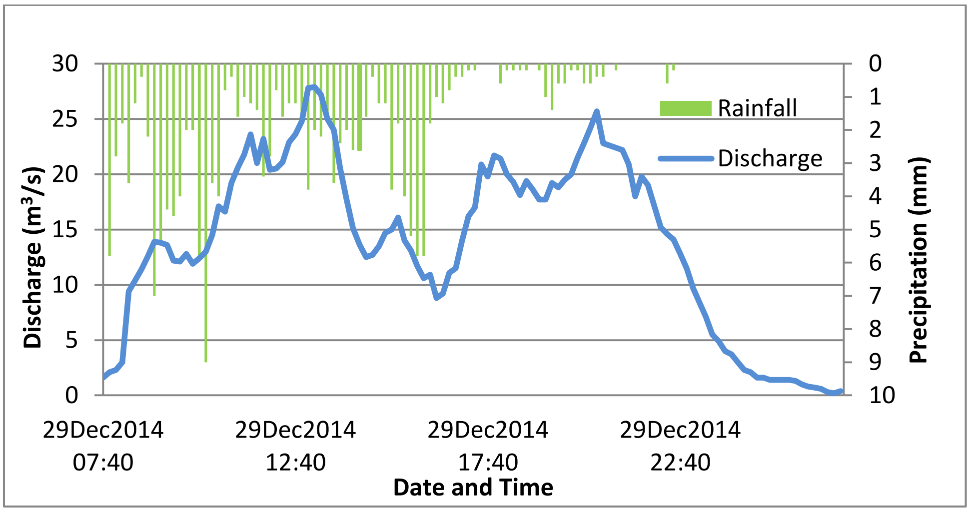

Figure 3. Rainfall and outflow data input for modeling.

3.2. HMS Model Calibration and Simulation

The hydrologic model with observed flow data during Tropical Storm Jangmi (Seniang) and the corresponding rainfall data gathered by the ARG stationed at Quezon, Balingasag was subjected to simulation using HMS model. The initial generated hydrograph illustrates an exaggerated simulation resulting to a peak discharge of 140.8 m^3/s and total outflow of 67.90mm, very far to the actual peak flow of only 27.87m^3/s and a total observed outflow of 12.81mm. Calibration was commenced through manual adjustments of parameter values with the target to fit the hydrographs of the simulated and discharge outflows. Progress of calibration was inspected through the visual comparisons of the observed and simulated hydrographs, considered as one of the most fundamental approach in assessing model performance (Krause et al., 2005). After a series of manual adjustments by means of trial and error, difference of the simulated and observed data was reduced leading to the nearly fitted hydrographs. Figure 4 shows the comparison between the observed and simulated outflow before and after the calibration. Table 1 shows the resulting statistics for the assessment of the acceptance of the calibrated model.

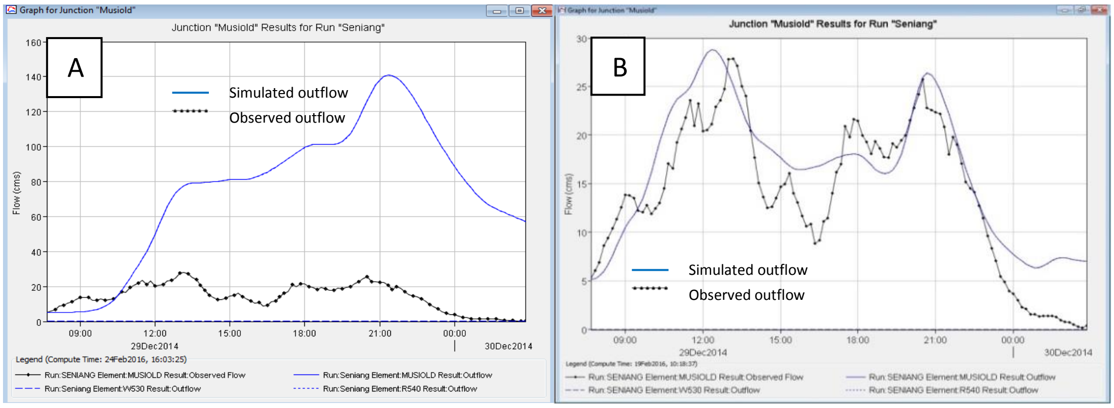

Figure 4. Hydrographs of observed and simulated event (A) before and (B) after the calibration.

Table 1. Model evaluation using the quantitative statistics

Statistical Tools	Values	Rating
NSE	0.71	good
RSR	0.54	good
PBIAS	20.96	satisfactory

For the Nash-Sutcliffe (E) and Observation Standard Deviation Ratio method, the model attained an efficiency coefficient of 0.71 and an RSR value of 0.54 both evaluated as ‘good’. Moreover, PBIAS value of 20.96 evaluates the model as ‘satisfactory’. According to Gupta et al. (1999) as cited by Moriasi et al. (2007), PBIAS has the ability to clearly indicate poor model performance. With this, the general evaluation of the calibrated model is ‘satisfactory’. Moreover, the least evaluation of the model from the all the statistics used determines the overall evaluation of the model. Generally, the improved performance of the model was attained through the effective reduction of the overestimated values of the default simulation.

Using the calibrated model, consequent simulations were conducted for the flood recurrences of 5 year, 25 year and 100 year return periods using RIDF data. RIDF is computated from a historical data obtained from a gauge located at Barangay Lumbia, Cagayan de Oro City, the closest rain gauge with availbale historical data to the basin. The use of RIDF for simulation has been a common method in conducting flood hydraulic analysis useful for flood hazard and risk mitigation programs (Botero and Frances, 2010). RIDF refers to recurrence interval or the likelihood that the event will occur, generating graphical representation of the probability that average rainfall intensity will occur. Five (5) year return period represents the event that would occur in 5 year interval or an event with this particular magnitude would occur once every five years. Same is true with the 25 year and 100 year return period when a certain event with such magnitude occurring once every 25 and 100 years, respectively. Higher year interval depicts higher rainfall intensities as well as higher resulting flood depths and extents as spatially presented by the produced hazard maps using both the hydrologic and hydraulic models. Table 2 shows the river junctions of the RAS model with corresponding peak discharge values simulated by the calibrated HMS model to be inputted for unsteady state simulation of HEC-RAS model.

Table 2. Summary of outflows in each river junctions for the particular event and flood return periods.

Junctions	Peak Discharge (m^3/s)			
	Typhoon Seniang	5yr	25yr	100yr
J145	3.1	7.4	10.3	12.5
J128	13.4	24.8	34.6	52.5
J97	28.8	54.3	83.5	122.5
J133	16.8	32.3	45	64.5
W440	7.8	15.6	21.8	26.4

3.3. HEC-RAS Model Simulation

There are a total of 120 cross section lines, 5 river reaches, 10 bank lines, and 2 junctions for the HEC-RAS model set-up. Geometric data was prepared by establishing RAS layers based on LiDAR DEM data integrated with river bed data from the bathymetry survey. Profiles of cross-section lines were incorporated with the elevation data of the LiDAR DEM and were extended covering the flood plain so as to capture the extent of flood inundations during the simulation, implementing the flood-plain considering the area as part of the river (Haghizadeh et al., 2011). River networks were assigned with codes synchronized with HMS basin model applicable for the assignment of Peak Flows in HEC-RAS. Figure 5 shows the schematic representation in HEC-GeoRAS and the interface of the loaded geometric data of Musimusi river basin HEC-RAS model.

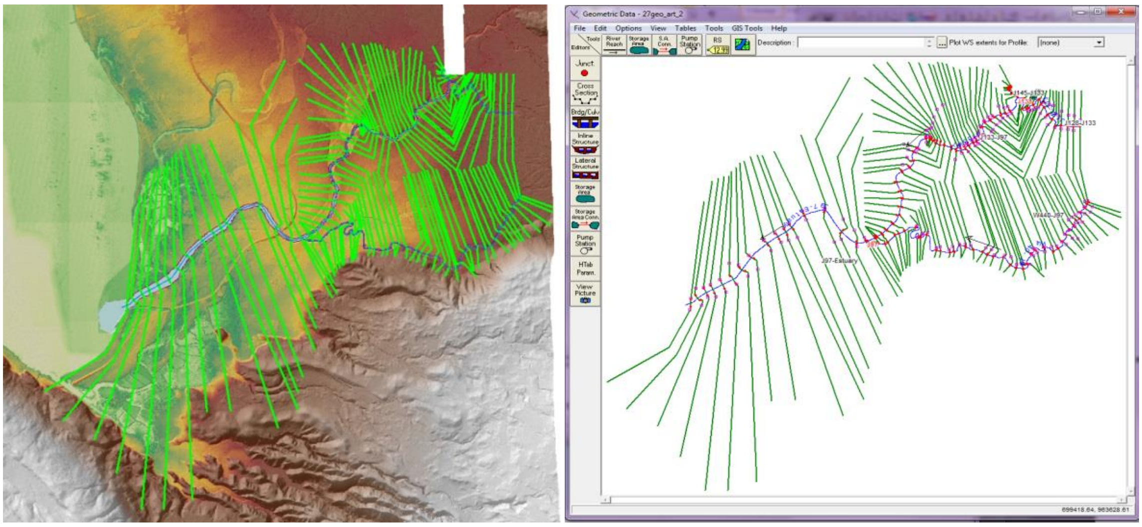

Figure 5. The Musimusi river system schematic of HEC-RAS model.

Peak discharge inflows from the HMS simulation results were used for the steady simulations of the Typhoon Seniang event and various flood return periods using RIDF data. The simulation for Typhoon Seniang event resulted to a flood depth of as high as 2.21m. Overbank flows are not prevalent in the floodplain except in some rice field areas of Barangay Dumarait. Area covered by the flood is 14.25ha for Typhoon Seniang simulation. Initial personal interviews conducted revealed that flood is frequently experienced in the barangay with flood waters leveling with the rice fields. Accordingly, at a certain sitio called Minggapis, around 40 households are affected by flooding with knee-depth water lasting up to 5-6 hours. Affected rice fields and other crop lands such as corn and banana plantations were severely damaged.

For the simulation using the RIDF data revealed maximum flood depths of 2.51m for 5-year return period, 2.77m for 25-year return period, and 2.95m for 100-year return period. The same with the result of the Typhoon Seniang simulation, inundation was mostly observed in Barangay Dumarait with varying size of area coverage. Total flooded area for 5year, 25 year and 100-year return periods are 41.87 ha, 56.54 ha and 66.05 ha, respectively. Table 3 summarizes the results of the hydraulic simulations while Figure 6 illustrates the flood maps of the Typhoon Jangmi and the three year return periods developed from the hydraulic simulations using HEC-RAS model.

Table 3. Summary of RAS hydraulic model simulation of flood depths and extent

Return periods	Maximum flood depths (m)	Flood area (ha)
Typhoon Seniang	2.21 m	14.25
5 year	2.51 m	41.87
25 year	2.77 m	56.54
100 year	2.95 m	66.05

Flood plain simulations are represented by the computed water surface elevation at each cross-section. Flood depth simulations are consequently converted to flood hazard maps using ArcGIS. Flood hazards are categorized as ‘low’ with flood depth of 0-0.5m, ‘medium’ with flood depth of 0.5-1.5m and ‘high’ with flood depth of more than 1.5m. Development of hazard map using the Typhoon Jangmi event revealed a highest hazard category of medium with flood depths as high as 1.5 m. This covers portions of rice field located in low lying areas of Barangay Dumarait including few residential houses. Flood hazard for 5 year return period illustrates larger coverage of inundation. Low flood hazard are extended covering several other residential houses in the same area. Flood hazard for the 25-year and 100-year return period have an increasing coverage of flood inundation with highest hazard category of medium affecting several other residential houses.

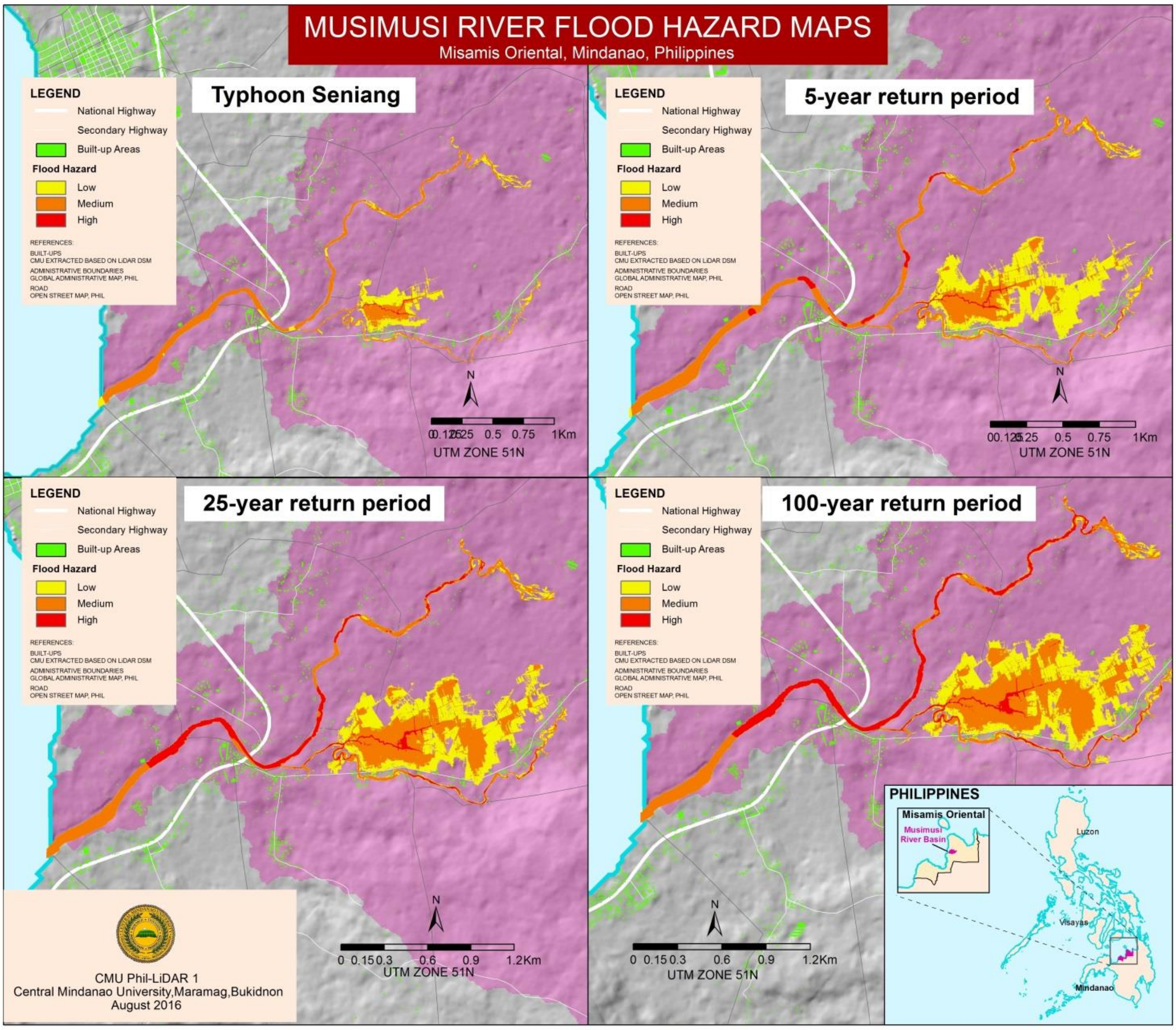

Figure 6. Flood hazard map of Typhoon Seniang

4. CONCLUSIONS

Flood modeling involves the use of two (2) components representing the hydrologic model for the simulation of discharge from a specific rainfall event, and the hydraulic model for the simulation of flood water movement in the floodplain. Respective models of the components were developed using the program applications HEC-HMS and HEC-RAS. HMS model calibrated using the hydro-meteorological data of Typhoon Seniang event was used for further simulation of flooding recurrence event using RIDF data.

Simulations reconstructing the Typhoon Seniang event and the construction of return period scenarios were successfully conducted using the developed models. Results of this research indicate applicability of both developed HMS models and HEC-RAS models in performing flood simulations and subsequent development of flood hazard maps. The integration of LiDAR DEM with as high as 1m resolution resulted to a very detailed flood hazard output providing precise estimates of vulnerable built up numbers. Moreover, the high resolution elevation model entails precise hydraulics in modeling the inundation of resulting flood waters of a particular event. Generally, application of this research would be helpful in the enhancement of the disaster strategies in the context of mitigation, preparation, response and rehabilitation measures especially in the local level. The information obtained from the applied method is very significant for the local governments' thrive towards the development and enhancement of flood disasters and risks strategies.

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