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Flood Modeling of Musimusi River in Balingasag, Misamis Oriental

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ABSTRACT

Flood modelling is one of the recognized effective means of assessing the flood risk to people and property. In this study, the concept of flood modeling is applied in Musimusi river at Balingasag, Misamis Oriental. Using the Hydrologic Modeling System (HMS) and River Analysis System (RAS) of the Hydrologic Engineering Center (HEC), hydrologic and hydraulic models were developed to conduct simulations on the rainfall-run-off and flood inundation processes. Data from the Typhoon Seniang event was used as main input for the calibration of basin model and consequently validated using quantitative statistics. Further simulations on specific return periods using historical data from PAG-ASA were conducted using the calibrated model. River flow hydraulics was performed through unsteady flow analysis reconstructing the Typhoon Seniang event and constructing the 5-year, 25-year and 100-year return period scenarios, spatially illustrating flood inundations on the floodplain of Musimusi. Results of this research revealed successful simulation of flood scenarios indicating applicability of both developed HEC-HMS and HEC-RAS models. Moreover, with the integration of high resolution Digital Elevation Model (DEM), modelling is significant towards consequent development of highly precise and detailed flood hazard maps helpful especially to local governing units for the total improvement of disaster risk reduction strategies.

Keywords: *flood modeling, flood hazard map, HEC-HMS, HEC-RAS*

INTRODUCTION

Philippines is tagged as the third most hazard – prone country in the world (Quismundo, 2012) as evidently seen on the onslaught of storms repeatedly hitting the country. This has resulted to frequent flooding owing to the changing landscape brought about by the decreasing forest covers which are being converted to settlements and farmlands especially in the upstream areas of river basins. Flooding is now being regarded as the new norm especially in the once considered typhoon-free Mindanao. Extreme events of tropical storms and monsoon rains causing flooding are now repeatedly being experienced causing widespread damages to properties, infrastructures and even loss of lives.

One of the most recognized effective means of assessing the flood risk to people and property is flood modeling which determines the volume and discharge production of specific flooding events (Yuan and Qaiser, 2011). The U.S. Army Corps of Hydrologic Engineers Center's Hydrologic Modeling System (HEC-HMS) and River Analysis System (HEC-RAS) are among the widely used tools in analyzing watershed hydrologic behaviors. 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. Moreover, the integration of Light Detection and Ranging (LiDAR) digital elevation model (DEM) in the development of hazard maps ensures higher accuracy which is important especially on the application to flood disaster programs and planning.

By using the combined technologies of HEC-HMS, HEC-RAS and GIS utilities, this paper illustrates the methodology of flood modeling and the consequent development of flood hazard maps in Musimusi river, Balingasag, Misamis Oriental as integrated with LiDAR data. Specifically, the study aimed to create and calibrate HMS basin models, create and set-up RAS models, and perform flood simulations of actual events and different known return periods specifically for 5-year, 25-year and 100-year. Through this, flooding information such as flood depth and spatial extents are generated which are deemed helpful in LGU's disaster strategies' mobilization.

METHODOLOGY

Musimusi watershed is geographically located in the municipality of Balingasag, Misamis Oriental and approximately lies between 8°41′ to 8°48 north latitudes and 124°45′ to 124°54′ east longitudes (Figure 1). Fourteen (14) barangays lies within the watershed, 13 of which belong to the municipality of Balingasag and 1 barangay in the Municipality of Claveria. There are eight (8) barangays falling within the floodplain of the watershed namely barangay Waterfall, Baliwagan, Talusan, Blanco, Dumarait, and Binitinan which are all in the Municipality of Balingasag, Misamis Oriental.

Higher elevated portions of the watershed are mostly situated at the eastern part of the watershed with the highest elevation of 1,552 MASL. Areas with lower elevation constitute the floodplain located in the western region of the watershed. Musimusi's meteorological classification falls under the Type III described with no pronounced seasons, though it has a relatively dry climate from November to April and wet for the rest of the year. The area has a yearly average rainfall of 145.6 mm with heavier precipitation usually occurring on the second half of the year with drier days during the months of February to April (Balingasag 2008-2019 CLUP).

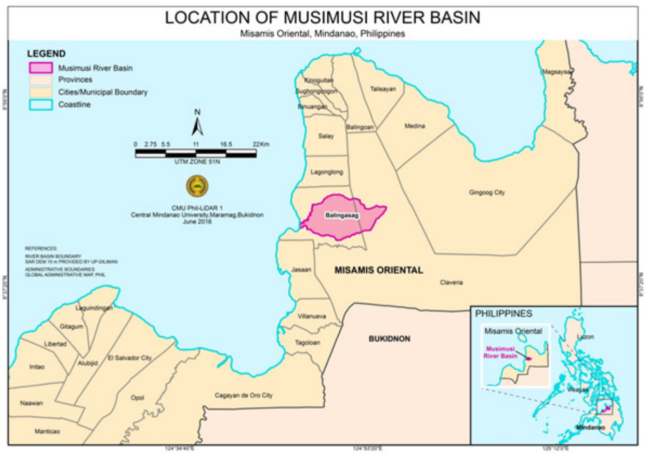

Figure 1. The Geomorphological Location of Musimusi Watershed

Flood modelling in this study covers the use of two distinct models namely the hydrologic and the hydraulic models. Hydrologic model specifically conducts surface runoff simulation as influenced by hydro-meteorological inputs covering a certain geographic area such as a river basin. Hydraulic model on the other hand is responsible for the simulation of flow of water along the terrain that mainly requires the LiDAR DEM from which elevations are extracted by the RAS layers composing the river geometry of the model. Both models are developed using the

Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) and River Analysis System (HEC-RAS) of the US Army Corps of Engineers.

The hydrologic model which serves as the model of the river basin for rainfall-runoff simulation was created using HEC -Geospatial Hydrologic Modeling System (GeoHMS), an extension of the HEC-HMS program under the ArcGIS interface. Datasets required for the generation of the model are the following: Synthetic Aperture Radar (SAR) Digital Elevation Model (DEM), land cover and soil type data, digitized river networks, hydrological data, and metrological data. The utilized SAR DEM with 10m resolution was obtained from the University of the Philippines – Dilliman. Meanwhile, the land cover and soil type were from the National Mapping and Resource Information Authority (NAMRIA) of year 2004 and the Bureau of Soils of Department of Agriculture (DA), respectively. Digitized river networks consist of a river centerline extracted from Google Earth through ArcGIS10.1 extension tool GeoHMS10.1.

Further modifications were made on the newly created basin model by setting up important components namely the meteorologic model, control specification and the time series data which contain the rainfall and discharge data—the two main input data of the model for runoff simulation. River discharge is the hydrological data required for the initial simulation and calibration of the basin model calculated using river velocity, Mean Sea Level (MSL) tied river stage, and cross section data which were determined through river flow measurement gathered during a rainfall event using manual flow meter, digital depth gauge, and DGPS surveying utilizing post process kinematic (PPK) technique, respectively. The metrological data on the other hand consist of a precipitation data taken from an automatic rain gauge (ARG) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) at Barangay Quezon, Balingasag. Specifically, rainfall datasets were retrieved from http://repo.pscigrid.gov.ph/predict. Values on unfilled parameters such as the initial discharge calculated using the initial discharge value evenly distributed to all sub-basins of the model according to the subbasin area were also inputted.

Initial simulation result was utilized for calibrating the model. Calibration was done by manually adjusting the values of parameters of the basin model. Performance and acceptability of the calibrated model for further simulations were evaluated using various quantitative statistics. These include Pearson’s correlation to determine the strength of the linear relationship between simulated and measured data and other efficiency criteria namely the Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of measured data (RSR).

Using the calibrated model which passed the employed statistical tests, different theoretical scenarios of 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 based on a 26-year historical rainfall data of rain gauge located at Barangay Lumbia, Cagayan de Oro City. Three (3) different return periods (5-year, 10-year and 100-year) 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 under HEC-HMS model.

The hydraulic model which is responsible for the simulation of flow of water along the terrain mainly requires the LiDAR DEM from which elevations were extracted by the RAS layers composing the river geometry of the model. HEC-RAS 1D flow model geometry consisting of the river network and cross-sections were created using HEC-Geographic River Analysis System (geoRAS), an extension in ArcGIS, and were exported to HEC-RAS in a RAS file format. Discharge values form the resulting RIDF HMS simulations are inputted in the RAS model for the simulations of flow inundation hydraulics which were later converted to flood hazard maps using RAS Mapper in HEC-RAS program. The utilized LiDAR elevation model was obtained through flight surveys executed by a laser-emitting equipment mounted on an aircraft. Data are processed and edited using the ArcTeam toolbar extension in ArcMap 10.x software producing Digital Terrain Model (DTM) and Digital Surface Model (DSM) output raster layers. Since this technology is limited by water bodies, complementing hydrographic survey was conducted to fill the gaps of LiDAR along the river areas not penetrated by the laser. Bathymetry and cross section surveys conducted by gathering river bed elevations along the length of the river were incorporated to LiDAR DTM through the process of bathymetry burning. Moreover, ground features which were evident in LiDAR DSM were extracted and attributed according to general built up classifications through Geo-tagging activity using hand-held Global Positioning System (GPS) device. Shape files containing the extracted and classified built-up areas along the floodplains of each river basin were developed and were utilized to quantify the number of built-ups affected by the simulated flood.

RESULTS AND DISCUSSION

HEC-GeoHMS Basin Model

The generated basin model of Musimusi watershed using HEC-HMS (Figure 2) has a total area of 7,772.11 hectares with 27 subbasins including subdivided watersheds of the potential areas for flow measurement, 14 reaches and 12 junctions. Reaches represent the tributary rivers within the entire watershed boundary while junctions represent for the points where every river meet. The basins were identified based on soil and land cover characteristics of the area. The system covers several separate models to represent each component of the runoff process, including models that compute runoff volume, models of direct runoff, and models of base flow which is run in a combined basin model, meteorological model and control specifications (Choudhari et al., 2014).

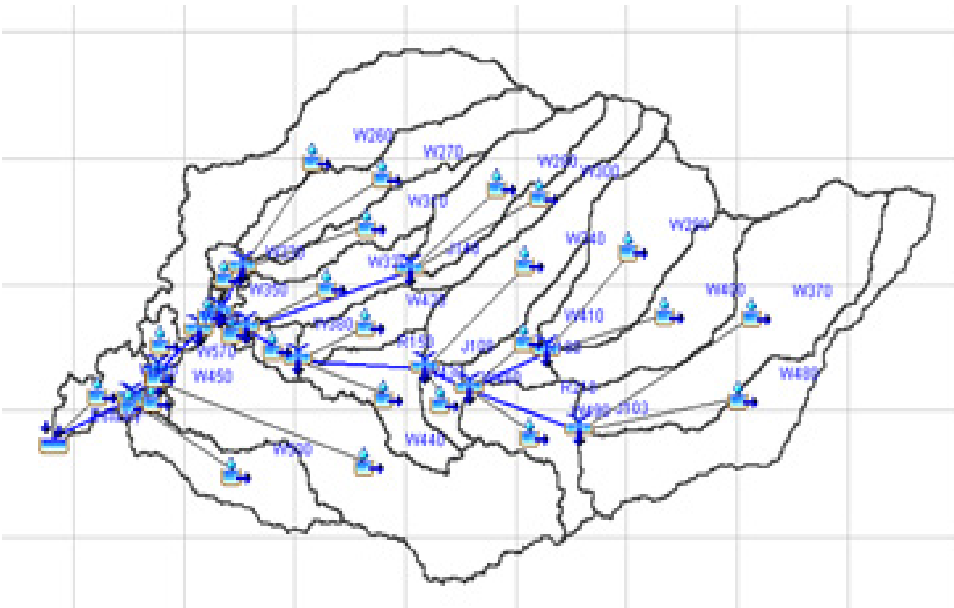

Figure 2. The HEC-HMS Model of Musimusi River Basin

Figure 3 shows the actual data inputted in the model for simulation. It comprises rainfall and discharge data taken during the Typhoon Seniang event on December 29-30, 2014. There were two rainfalls and discharge peaks observed. First and second rainfall peaks were 9mm and 5.8mm at 1130 hours, and 1945 to 2000 hours of December 29, 2014. Meanwhile, the first and second discharge peaks were 27.87 m3/s and 25.74 m3/s at 1310 hours and 2030 hours of the same date, respectively.

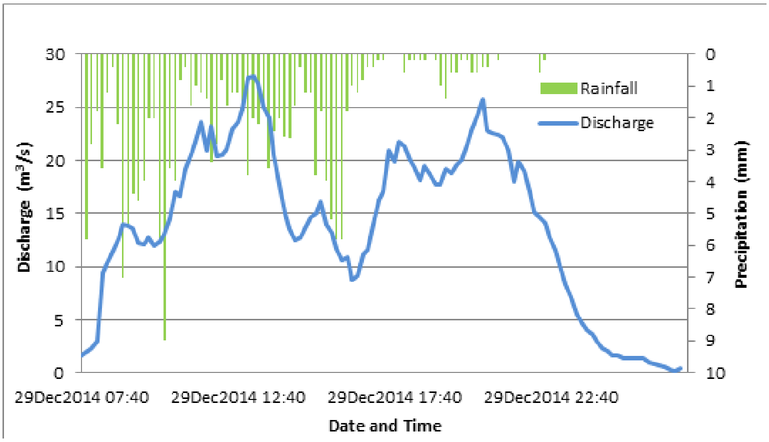

Figure 3. Rainfall and Outflow Data Input for Modeling

Model Calibration and Validation

The initial simulation of the hydrologic model inputted with observed rainfall and flow data during Tropical Storm Seniang was subjected to calibration. Parameters within the model involved in manual adjustments were the Curve Number grid, Initial Abstraction, Time Concentration, Storage Coefficient, and Recession Constant. The generated hydrograph of the initial simulation illustrates an exaggerated runoff simulation resulting to a discharge of 140 m3/s, too high compared to the actual peak flow of only 27 m3/s. Calibration was conducted through manual adjustments of parameter values until difference between the actual and simulated runoff is decreased fitting both of the hydrographs. Progress of calibration was inspected through the visual comparisons of the observed and simulated hydrographs, a method 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 a nearly fitted hydrographs. Figure 4 shows the comparison between the observed and simulated outflow before and after the calibration.

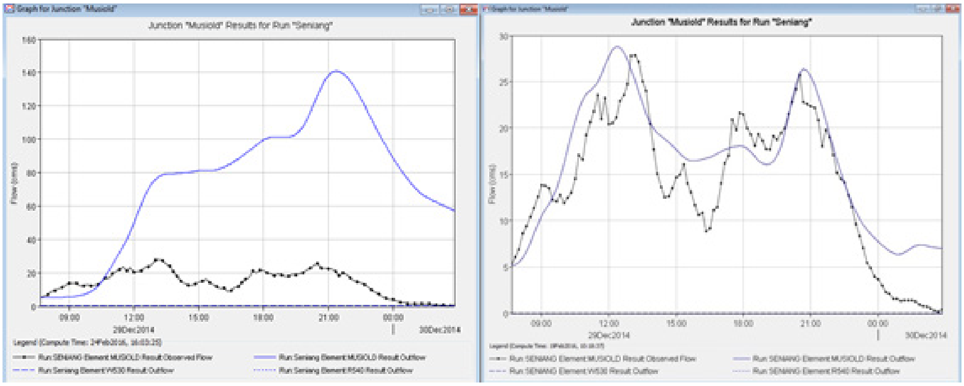

Figure 4. The Comparison of Simulated and Observed Hydrographs for Seniang event before (A) and after (B) the Calibration of the Model in HEC-HMS

To evaluate the performance and efficiency of the calibration for further use, it was subjected to accuracy tests using statistics. Table 1 shows the results of the employed evaluation techniques which represent the estimation of the difference between the measured and simulated values referring to the residual variance.

Table 1
Model Evaluation using the Quantitative Statistics

Statistics	Values	Interpretation
Pearson Correlation Coefficient (r)	0.90	Very Strong
NSE	0.71	Good
RSR	0.54	Good
PBIAS	20.96	Satisfactory

Pearson correlation coefficient was utilized for the evaluation of the calibrated model in terms of the strength of linear relationship. Figure 5 illustrates the relationship of the observed and the simulated discharge values before and after the calibration. Discharge values prior to calibration reveal a weak relationship with only an r of 0.26. However after the calibration, a very strong relationship was established with an r of 0.90 and an r2 of 0.80 indicating an 80% relatedness of the two discharge values.

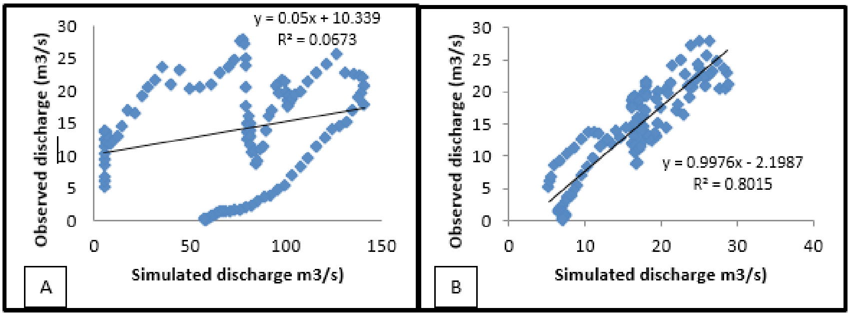

Figure 5. Correlation between the Observed and Simulated Sischarge data before (A) and after (B) the Calibration

For the Nash-Sutcliffe (E) and Observation Standard Deviation Ratio or RSR 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 the study of Gupta et al. (as cited in Moriasi, Arnold, Van Liew, Bingner, Harmel, & Veith, 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 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 using a gauge with the closest proximity in the area which generates a graphical representation of the probability that an average rainfall intensity will occur. 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. Five (5) year return period illustrated in the simulated hazard maps represents the event that it would occur in a 5 year interval. The same is true with the simulated 25 year and 100 year return periods. 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. Figure 6 and Table 2 show and summarize the resulting simulated discharge for the three return periods and the event.

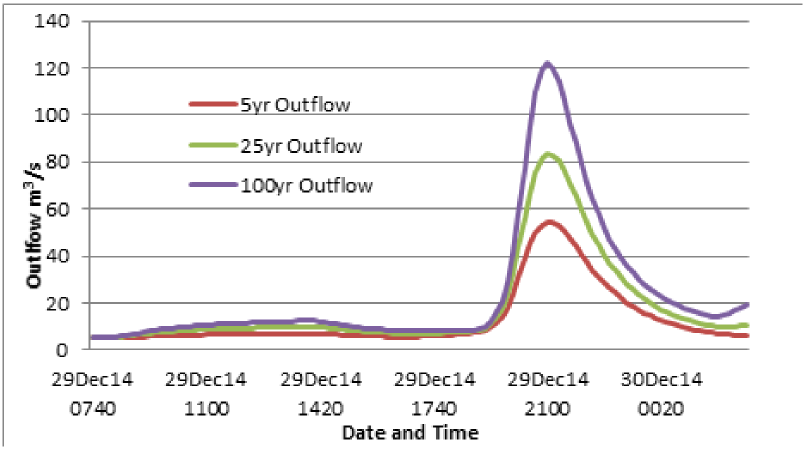

Figure 6. Simulated Outflow using RIDF Data

Table 2.
Summary of HMS Basin Model Return Period Simulations Musimusi River

Return Periods	Peak Outflow (m^3/s)	Total Outflow (m^3/s)
5 year	52.2	1 644.5
25 year	77.4	2 536.2
100 year	108.3	3 708.5

Evident increase of outflows is observed as return period progresses. Peak outflow for 5 year return period is projected to be 52.2 m3/s, for 25 year is 77.4 m3/s and for the 100 year return period is 108.3 m3/s. The simulated discharge values are inputted to RAS model for the simulation of flood inundation in the floodplain. Figure 8 shows the RAS model setup which comprises the river geometry embedded in the LiDAR DEM. The river geometry consists of streamlines, bank lines, flow paths and cross section cut lines which function for the approximation of the rivers, banks, definition of distance between cross sections and the extent covered for the flood inundation simulation. With the resulting simulated discharge from the hydrologic model, hydraulic simulation was performed using HEC-RAS. Simulation and flood mapping were subsequently done under the RAS Mapper where water profile calculation was completed. Figures 8-11 shows that resulting flood depth simulations are subsequently converted to flood hazard maps of the Typhoon Seniang event and the return periods for 5 years, 25 years, and 100 years.

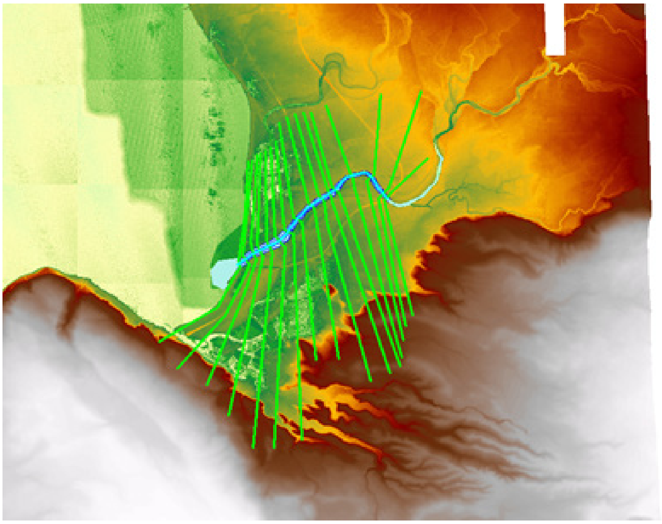

Figure 7. River Geometry of Musimusi River Basin

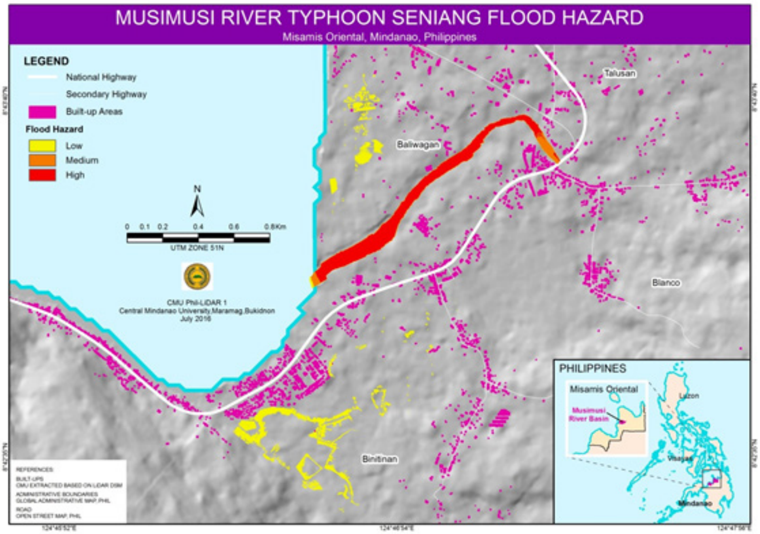

Figure 8. Musimusi River Flood Hazard for Typhoon Seniang

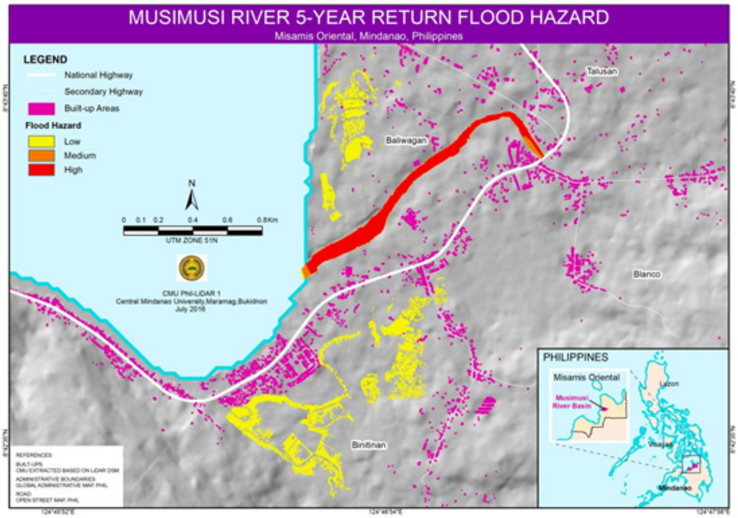

Figure 9. Musimusi River Flood Hazard for 5-year Return Period

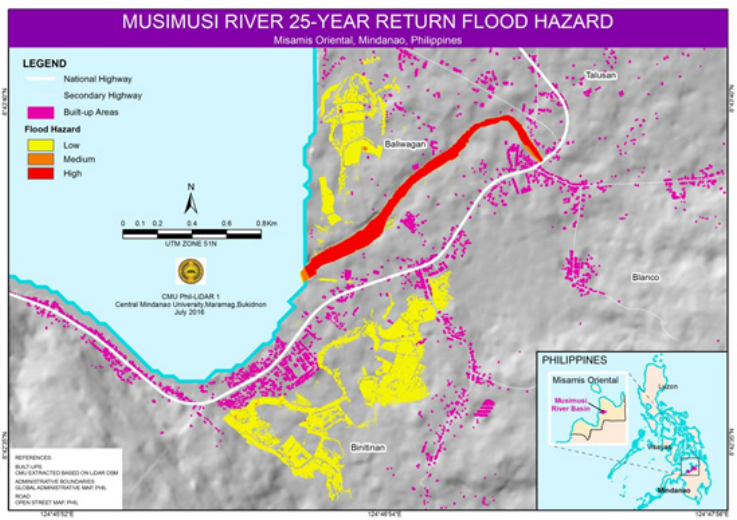

Figure 10. Musimusi River Flood Hazard for 25-year Return Period

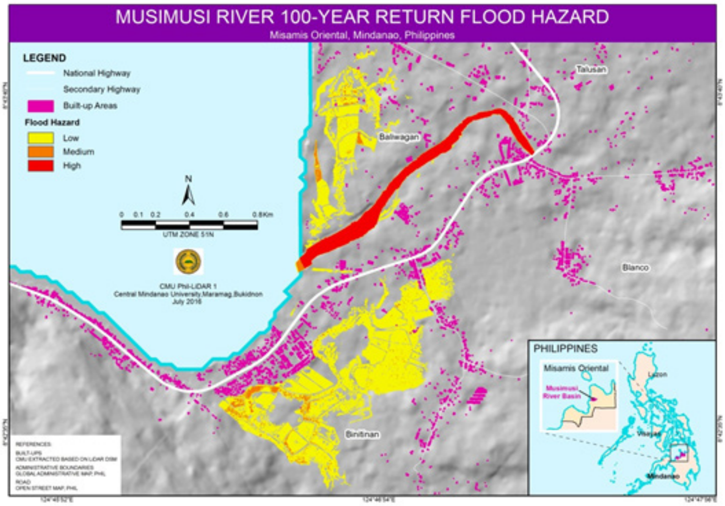

Figure 11. Musimusi River Flood Hazard for 100-year Return Period

Table 3 summarizes the maximum flood depths of the simulated return periods. For the 5 year, 25 year and 100 year return periods, flood is projected to reach as high as 2.44m, 2.55m and 2.67m.

Table 3.
Maximum Flood Depths in Three (3) Different Return Periods

Return Periods	Peak Outflow (m^3/s)	Total Outflow (m^3/s)
5 year	52.2	1 644.5
25 year	77.4	2 536.2
100 year	108.3	3 708.5

Through geo-tagging activity, features in the ground which are mostly built-ups were extracted from the LiDAR DEM. Through this, numbers of the classified built–ups covered by the simulated flood extent were determined. The generated hazard maps revealed that residential built-ups are the most vulnerable to flooding as seen in the simulated flood extents. Moreover, flood coverage extends to other establishments present in areas adjacent to the modeled rivers. In Musimusi, there are 6 affected households for a 5 year return period, 10 for the 25 year return period, and 20 flood-prone residential houses for a 100 year period.

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 HEC-HMS 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 entails precise hydraulics in modeling the inundation of resulting flood waters of a particular event.

RECOMMENDATIONS

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' drive towards the development and enhancement of flood disasters and risks strategies.

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