MODELING FLOOD HAZARDS IN NORTHERN MINDANAO, PHILIPPINES USING HEC-RAS AND LIDAR-DERIVED DEM

George R. Puno[*1], Rose Angelica L. Amper[1], Bryan Allan M. Talisay[1], Rose Ann Barro[1], and Jenifer L. Ogania[1]

[1]College of Forestry and Environmental Science, Central Mindanao University, Musuan, Bukidnon, 8710, Philippines
Email: geopuno@yahoo.com

KEY WORDS: Disaster, GIS, hydrologic, map

ABSTRACT: The progress of high resolution flood hazard mapping become the mainstream in the academic exercise worldwide. In the Philippines, high resolutions maps have evolved to aid in flood-related disaster management and monitoring. High resolution maps become useful for localized emergency response such as evacuation and rescue operations during the disaster. However, high resolution flood maps in Northern Mindanao, Philippines are not readily available. This study aimed at modeling and mapping flood hazards within the six rivers in Misamis Oriental of Northern Mindanao, Philippines namely; Alubijid, Balatucan, Cabulig, Gingoog, Linugos, and Musimusi rivers. The study applied Geographic Information System (GIS) and the family of Hydrologic Engineering Center (HEC) model of US Army Corps such as Hydrologic Modeling System (HMS) and River Analysis System (RAS) with the integration of Light Detection and Ranging (LiDAR)-derived Digital Elevation Model (DEM). Hydrologic and hydraulic models were generated using HEC-HMS and HEC-RAS modeling tools. The developed hydrologic models were calibrated using the hydrologic data of the different typhoons hitting the respective river basins. Applicability of the calibrated models were evaluated using quantitative statistical measures such as R^2, RSR, NSE, and PBIAS. River flow hydraulics were performed through unsteady flow analysis using the hydraulic model reconstructing the events and simulating the several known return periods using Rainfall Intensity Duration Frequency (RIDF) data. Results revealed that the simulated flood depth were close to the actual event occurrences indicating applicability of both developed HEC-HMS and HEC-RAS models for all the river basins. Result of the study is significant for effective and efficient disaster risk reduction management especially during localized response operations. Moreover, the study is helpful for a more informed and a science-based decision especially in crafting policy recommendations on disaster awareness, mitigation and control measures through proper land use zoning and urban planning.

1. INTRODUCTION

Philippines is the third most hazard-prone country in the world (Quismundo, 2012) with arround 20 stroms repeatedly hitting the country annualy. This has resulted to frequent flooding owing to the decreasing forest covers especially in the upstream areas of river basins. Flooding is now being regarded as the new normal especially in the once considered a typhoon-free Mindanao region of the Philippines. Extreme events of tropical storms and monsoon rains causing flooding is now experienced.

Flood modeling is recognized as the effective techniques of assessing flood risk to people and property as well as determining volume and discharge of specific events (Yuan and Qaiser, 2011). The U.S. Army Corps of Hydrologic Engineers' Hydrologic Modeling System (HEC-HMS) and River Analysis System (HEC-RAS) are among of the widely used tools in analyzing watershed hydrologic behaviors. These computer programs enable the researchers to provide current or future runoff information such as volumes, peak flow rates and its timing through simulations and perform rainfall-runoff analysis and hydraulics. Such information is significant in flood forecasting and simulation of hydrological processes as well as to the generation of flood hazard maps.

Integration of Light Detection and Ranging (LiDAR) data in generating flood hazard maps ensures higher accuracy which is important in a more precise implementation of flood disaster programs and planning. The use of LiDAR-derived Digital Elevation Model (DEM) data in flood hazard mapping is gaining wide recognition due to its inherent high accuracy property. Its applicability extends to wide array of mapping systems enabling specialists to examine natural or built surface characteristics with greater accuracy, precision and flexibility (Zoleta-Nantes, 2000). Specifically, LiDAR data utilization in flood modeling has been very effective in analyzing the watershed hydrology and boundary delineation.

Using the combined technologies of HEC-HMS, HEC-RAS and GIS utilities, this paper illustrates the development of flood hazard maps in the six rivers of Misamis Oriental, Philippines namely Alubijid, Balatucan, Cabulig, Gingoog, Linugos and Musimusi Rivers integrated with LiDAR digital elevation model data. Specifically, the study aimed to create and calibrate HMS basin models, create and set-up RAS models, and perform flood simulations of actual event and different known return periods.

2. METHODOLOGY

2.1. Study Sites

The rivers covered in this study are Alubijid, Balatucan, Cabulig, Gingoog, Linugos and Musimusi located in the province of Misamis Oriental, Philippines. Figure 1 illustrates the geographical location of the rivers while Table 1 shows the list of rivers, the locations and the corresponding approximate basin area.

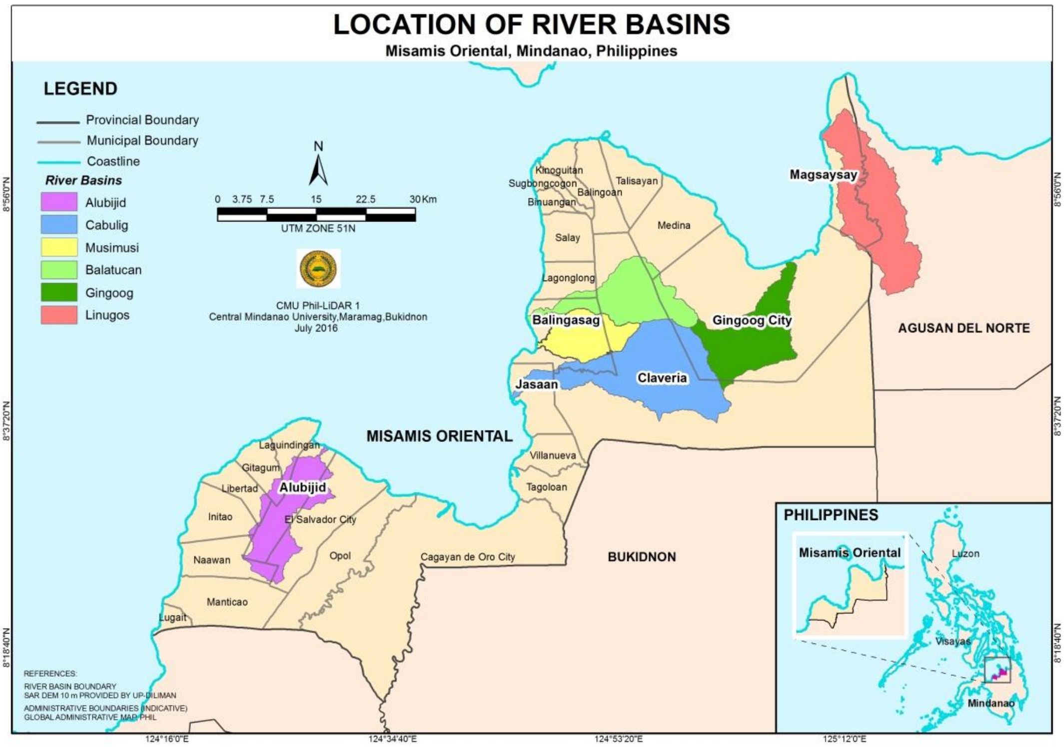

Figure 1. Location map

Table 1. Locations and approximate area of river basins.

Rivers	Locations (Province of Misamis Oriental, Philippines)	Approximate total area of basin (ha)*
Alubijid	Municipality of Alubijid	12,206
Balatucan	Municipality of Balingasag and Claveria	12,184
Cabulig	Municipality of Jasaan and Claveria	23,370
Gingoog	City of Gingoog	13,290
Linugos	Municipality of Magsaysay	16,501
Musimusi	Municipality of Balingasag	7,772

*Basin area was derived in ArcGIS using a 10m resolution SAR DEM provided by the University of the Philippines-Diliman.

2.2. Flood Modeling

Flood modeling comprises two components, the hydrologic and hydraulic modeling which make use of the modeling programs HEC-HMS and HEC-RAS of the US Army Corps. Hydrologic modeling which refers to rainfall-runoff simulation give rise to a discharge hydrograph as a result of a particular rainfall event while hydraulic modeling refers to the simulation of flood water movement through waterways and floodplain along with the computed flood heights and flow patterns using the HMS-simulated flow hydrograph data (US Army Corps of Engineering, 2010). Figure 2 illustrates the flow chart of the development of flood hazard maps.

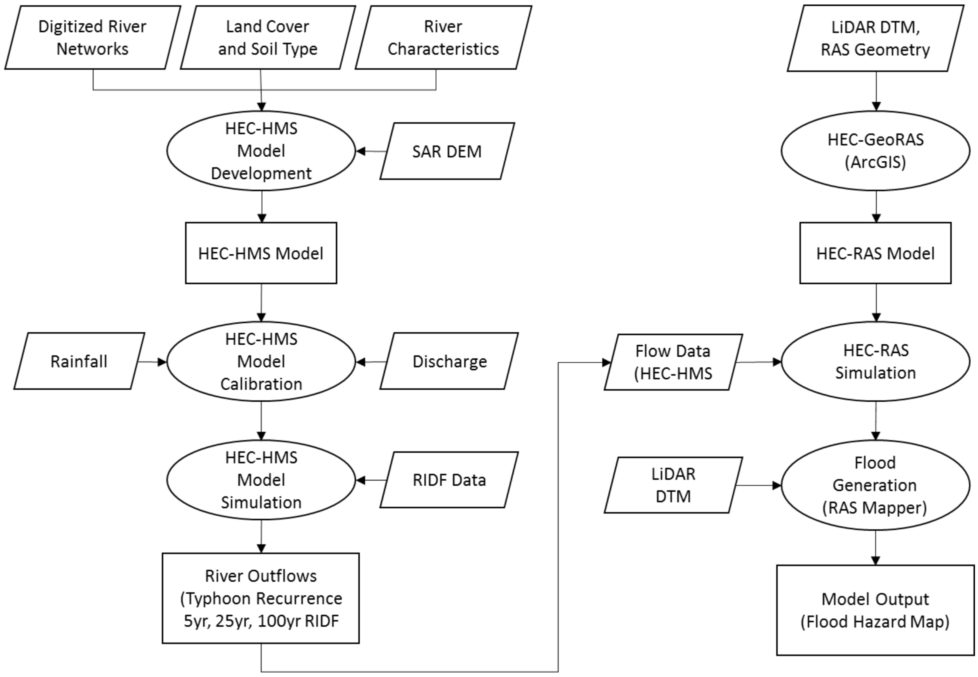

Figure 2. Flow chart of the flood hazard map generation.

2.2.1. Hydrologic Simulations. A basin model of the watershed was created using HEC- Geospatial Hydrologic Modeling System (GeoHMS), which operates as an extension of ArcGIS. Digitized river networks, land cover, soil type, river characteristics such as manning's n value, and the Synthetic Aperture Radar (SAR) Digital Elevation Model (DEM) are the required input datasets. Land cover and soil type data were acquired from the National Mapping and Resource Information Authority (NAMRIA, 2004) and Bureau of Soils and Water Management (BSWM)-Department of Agriculture (DA, 2004), respectively. Using actual collected rainfall and river discharge data during an event, basin models were calibrated by increasing the fitness between the actual observed hydrograph to the simulated hydrograph of the model. This was done through manual adjustments of the different parameters of the basin model by means of trial and error. To evaluate acceptability of calibrated model, four statistical measures were applied namely the Coefficient of Determination (R^2) Nash-Sutcliffe Efficiency (NSE), Root mean square errors-observations Standard deviation Ratio (RSR) and percent bias (PBIAS). Passing the statistical tests implies applicability of the model to perform further simulations which can either be executed to reconstruct flood events using the corresponding rainfall data and even simulate probable future occurrence of flooding on distinct return periods. For this study, Rainfall Intensity Duration Frequency (RIDF) data prepared by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAG-ASA) was utilized for the yearly known return period simulations.

2.2.2. Hydraulic Simulations. The hydraulic model which is responsible for the simulation of flow of water along the terrain mainly requires the LiDAR digital elevation model from which elevations are extracted by the RAS layers composing the river geometry of the model. HEC-RAS 1D flow model geometry consisting the river network and cross-sections were created in 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 are later converted to flood hazard maps using RAS Mapper in HEC-RAS program.

LiDAR elevation model was acquired using a laser-emitting equipment mounted on an aircraft which gathers ground information during flight survey. Data were processed and edited using the ArcTeam toolbar extension in ArcMap 10.x software producing raster layers such as Digital Terrain Model (DTM) and Digital Surface Model (DSM). Since this technology is limited by water bodies, complementing hydrographic survey was conducted to fill the gaps of LiDAR along water bodies 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 are evident in LiDAR DSM were extracted and attributed according to general built up classifications through geotagging activity using handheld 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.

3. RESULTS AND DISCUSSION

3.1. Hydrologic Simulation

Figure 3 illustrates the different basin models representing each basin boundary generated using HEC-geoHMS. The HMS models for each watersheds which functions for rainfall-runoff simulations consists of varying numbers of subbasins, reaches and junctions. A point in the basin was determined to serve as the site of discharge collection and the border point between the two models - where HMS model ends for the discharge simulation and where the RAS model startrs for the flood inundation simulation.

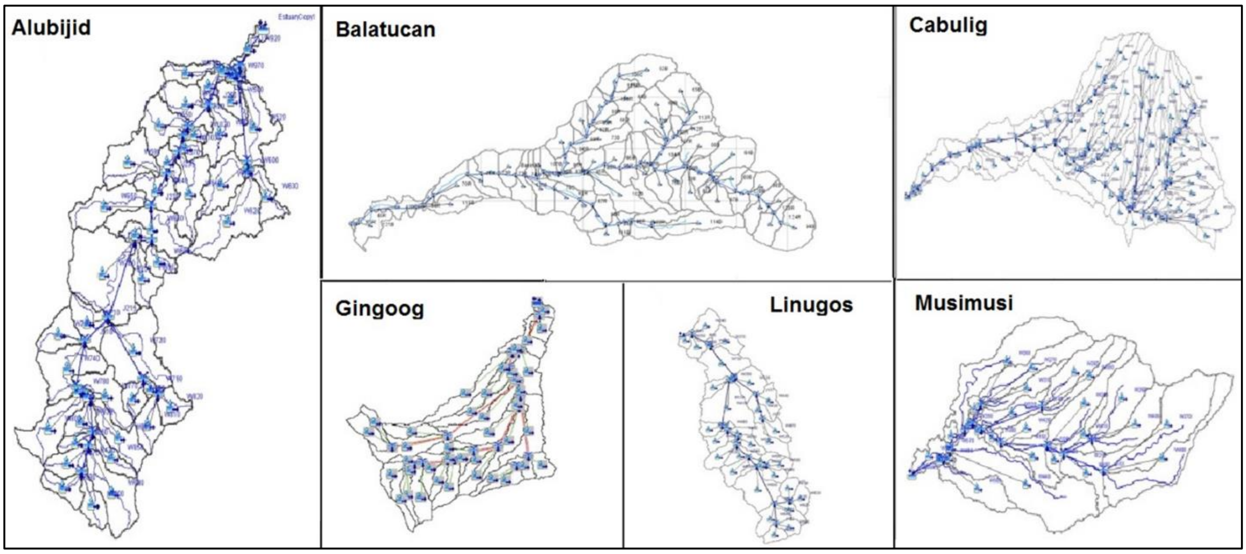

Figure 3. HMS basin models of the six rivers.

Generated basin models had underwent series of calibration to correct the simulation capabilities of the hydrological model. Statistical testing of the calibrated models was a means to measure the efficiency and validity of the model to conduct future simulations. Test results must at least be satifactotry to be considered acceptable and valid for future simulations. Result of the calibration of the HMS models is summarized in Table 2.

Table 2. Model evaluation using the quantitative statistics.

River Basins	Statistical Tests' Results and Interpretation			
	R^2	**NSE**	**RSR**	**PBIAS**
Alubijid	0.76	0.75 - Very good	0.50 - Very good	24.74 - Satisfactory
Balatucan	0.93	0.82 - Very good	0.43 - Very good	22.40 - Good
Cabulig	0.80	0.52 - Satisfactory	0.70 - Satisfactory	19.32 - Satisfactory
Gingoog	0.94	0.94 - Very good	0.23 - Very good	16.55 - Satisfactory
Linugos	0.93	0.93 - Very good	1.30 - Unsatisfactory*	-2.07 - Very good
Musimusi	0.80	0.71 - Good	0.54 - Good	20.96 - Satisfactory

*Considered passed due to its nearness to acceptable value

The six basin models are statistically acceptable indicating applicability for rainfall-runoff simulations. Application of model includes reconstruction of past flood events using available rainfall data as well as simulation of flood recurrences for the identified return periods using RIDF data. RIDF is computated from a historical data obtained using a raingauge 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). With the use of RIDF data based on a several year of rainfall data from PAG-ASA, outflows were simulated for each basin model for three known periods such as 5-year, 25-year and 100-year. The correponding simulated discharges for the three return periods are shown in Figure 4 while the total outflows are summarized in Table 3.

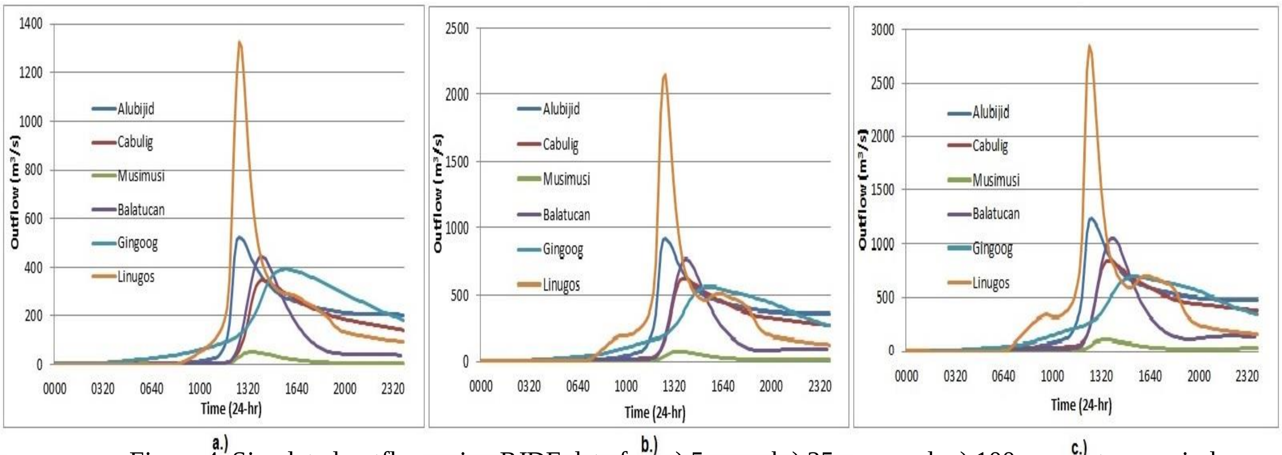

Figure 4. Simulated outflow using RIDF data for a.) 5-year, b.) 25-year and c.) 100-year return periods

Table 3. Summary of HMS basin model return period simulations for the six river basins

River Basins	Return periods	Peak Outflow (m^3/s)	Total Outflow (m^3/s)
Alubijid	5-year	525.5	20,769.3
	25-year	922.6	36,527.9
	100-year	1,229.8	48,979.4
Balatucan	5-year	443.4	10,403.0
	25-year	769.5	18,290.9
	100-year	1,048.3	25,302.0
Cabulig	5-year	347.2	15,311.8
	25-year	621.9	28,126.4
	100-year	839.9	38,635.9
Gingoog	5-year	392.4	22,254.4
	25-year	560.4	33,202.7
	100-year	700.1	42,412.7
Linugos	5-year	1,326.5	24,768.3
	25-year	2,147.1	42,165.4
	100-year	2,849.0	57,347.1
Musimusi	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 for all the river basins. Among the six river basins, Linugos produced largest amount of outflow peaking up and totalling to 2,849.0 m^3/s and 57,347.1 m^3/s for the 100 year return period. On the other hand, Musimusi has the lowest simulated discharge values, 26 times lower than Linugos' 100 year peak outflow simulations.

3.2. Hydraulic Simulation

Simulated discharge values are inputted to RAS model for the simulation of flood inundation in the floodplain. The RAS model setups of all the river basins comprising the river geometry embedded in the LiDAR DEM. The river geometry consists of streamlines, bank lines, flowpaths and cross section cutlines 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. Resulting flood depth simulations were subsequently converted to flood hazard maps (Figure 5). The corresponding maximum flood depth for the three return periods of the six rivers are presented in Table 4.

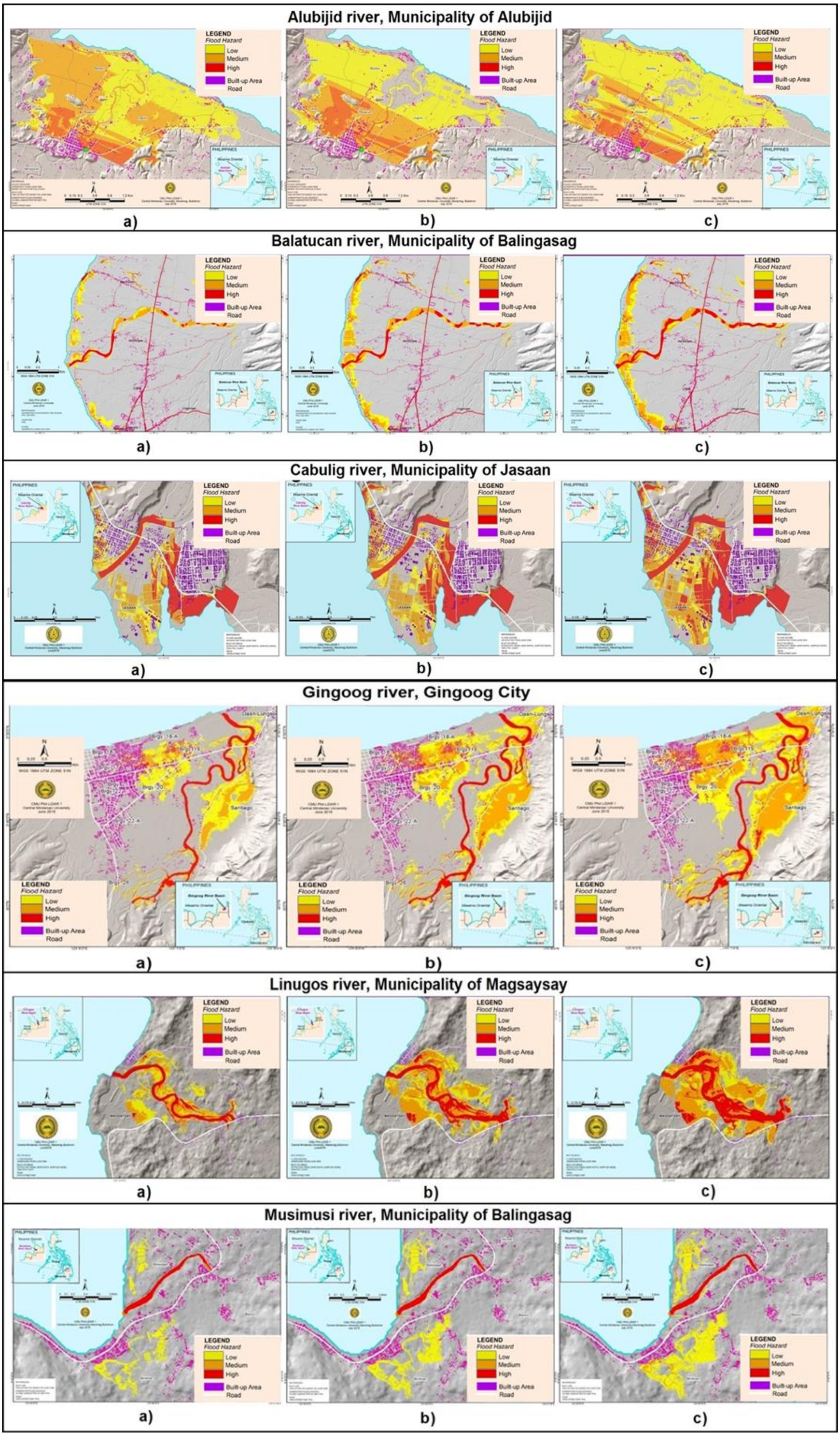

Figure 5. Flood hazard maps of the six rivers showing a.) 5-year, b.) 25-year, and c.) 100-year return periods.

Table 4. Maximum flood depths in three different return periods.

River Basins	Maximum Flood Depths (meters)		
	5-year	25-year	100-year
Alubijid	12.98	15.59	17.54
Cabulig	5.40	5.93	6.50
Musimusi	2.44	2.55	2.67
Balatucan	3.56	7.57	7.87
Gingoog	7.77	8.22	8.93
Linugos	7.53	8.62	9.24

Five (5)-year return period illustrated in the simulated hazard maps represents the event that would occur in 5 year interval. So on with the simulated 25-year and 100-year return periods. Higher year interval depicts higher rainfall intensities as well as higher flood depths and wider extents as visualized in the hazard maps using both the hydrologic and hydraulic models.

Through geotagging activity, features in the ground which are mostly built-ups were extracted from the LiDAR DEM. The 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. Moreover, flood coverage extends to other establishments present in areas adjacent to the modeled rivers.

Figure 6 shows the projected number of built-ups for the six river basins. Projections of flooding in Alubijid for 5-year, 25-year and 100-year return periods revealed that there were around 1,300, 1,500 and 1,300 affected built ups in its flood plain. Residential houses were the most affected reaching up to around 1,300. Other establishments such as barangay hall, covered court, gas station, market, religious institutions, school, warehouse and other commercial structure were likewise affected. Cabulig flood simulations show that there were around 600, 700 and 900 affected built-ups for the 5-year, 25-year and 100-year return periods. Still residential holds the largest number, together with other fewer built ups like barangay hall, gas station, other commercial establishment, prominent commercial establishment, religious institution, residential and school buildings. Flood simulations in Musimusi River revealed a smaller number of affected built-ups with 6, 10 and 20 households affected for 5-year, 25-year and 100-year return periods, respectively. Gingoog River revealed a great deal of numbers prone to flooding. There were around 2,500, 2,600 and 3,300 affected built-ups for the 5-year, 25-year and 100-year return period, respectively, with residential as the most vulnerable structures. Flood simulation in Linugos River revealed around 60, 200 and 300 affected built-up for the 5-year, 25-year and 100-year return periods, respectively. The same pattern of incidents were observed with the rest of the basins where residential has the highest number being affected. In every river basin, residential built-ups were found to be the most vulnerable to flooding. Among the six river basins, Gingoog was the most susceptible to flooding while Musimusi river of Balingasag was the least.

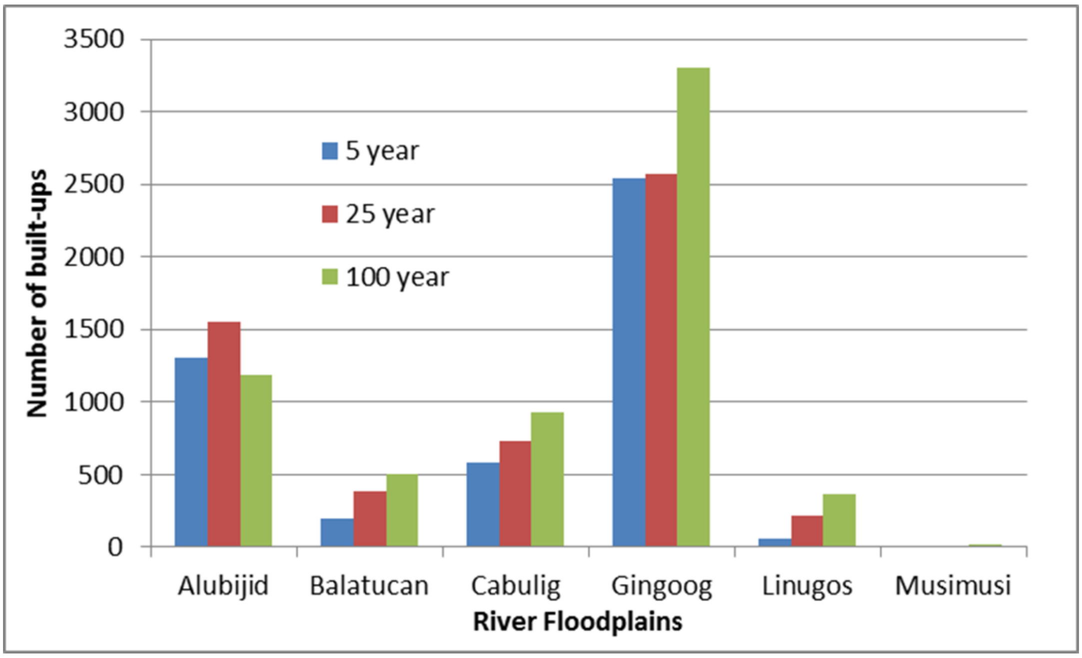

Figure 6. Number of built-ups affected by the simulated floods in three return periods.

4. CONCLUSIONS

Generation of flood hazard maps for the rivers in Misamis Oriental, Philippines involved the use of HEC-HMS and HEC-RAS applications for the creation of basin models, both hydrologic and hydraulic. Created HMS basin models for each river basins were calibrated and its efficiencies were evaluated using the three statistical tests namely the NSE, RSR and PBIAS. All 6 basin models passed the minimal required performance of “satisfactory” indicating applicability of the model for hydrologic simulations. Simulation of recurring flooding events in the three return periods were successfully conducted using RIDF rainfall as input data. With these simulated outflows, hydraulic simulation in the river floodplain as integrated with the highly dense georeferenced datasets LiDAR data were performed using the developed HEC-RAS model. Results of the flood depth and extent simulations were subsequently developed to flood hazard maps.

In six river basins, varying magnitudes of discharge values were simulated using the HMS model. Specifically, Linugos basin model simulated the greatest amount of discharge values while Musimusi basin model created the lowest amount of simulated discharge. The resulting flood hazard maps revealed large extents of floods especially on the 100 year return period. Most vulnerable to flooding are residential built-ups rolling around 1,500 for Alubijid, 20 at Musimusi, and 3,300 at Gingoog as the maximum number estimate for 100 year return period.

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.

5. ACKNOWLEDGEMENTS

This paper is part of the project “Phil-LiDAR 1: LiDAR Data Processing and Validation in Mindanao: Region 10, 12 and ARMM” funded by the Philippine Council for Industry, Energy and Emerging Technology Research and Development of the Department of Science and Technology (PCIEERD-DOST). The author is grateful to the Central Mindanao University administration for its support.

6. REFERENCES

Arekhi, S. 2012. Runoff modeling by HEC-HMS Model (Case Study: Kan watershed, Iran). International Journal of Agriculture and Crop Sciences. Available online at www.ijagcs.com.

Balingasag - Local Government Unit. n.d. Municipal Disaster Risk Reduction and Management Council (MDRRMC). Municipality of Balingasag.

Botero. B.A. and Frances, F. 2010. Estimation of high return period flood quantiles using additional non-systematic information with upper bounded statistical models. Hydrol. Earth Syst. Sci., 14, 2617–2628, 2010. www.hydrol-earth-syst-sci.net/14/2617/2010/.

Chatterjee, M., De, R., Roy, D., Das, S. and Mazumdar, A. 2014. Hydrological Modeling Studies with HEC-HMS for Damodar Basin, India. IDOSI Publications. World Applied Sciences Journal 31 (12).

Choudhari, K., Panigrahi, B. and Paul, J.C. 2014. Simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India. International Journal of Geomatics and Geosciences. Volume 5, No 2, 2014.

Devia, G.L., Ganasri, B.P. and Dwarakish, G.S. 2015. A Review on Hydrological Models. International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015). Aquatic Procedia 4 (2015) 1001 – 1007. Available online at www.sciencedirect.com Science Direct.

Felman, A.D. 2000. Hydrologic Modelling System HEC-HMS Technical Reference Manual. US Army Corps of Engineers. NW, Washington.

Ghoraba, S.M. 2015. Hydrological modeling of the Simly Dam watershed (Pakistan) using GIS and SWAT model. Alexandria Engineering Journal (2015) 54, 583–594.

Haghizadeh, A., Shui, L.T., Mirzaei, M. and Memarian, H. 2012. Incorporation of GIS Based Program into Hydraulic Model for Water Level Modeling on River Basin. Journal of Water Resource and Protection, 2012, 4, 25-31 http://dx.doi.org/10.4236/jwarp.2012.41004. Published online January 2012 (http://www.SciRP.org/journal/jwarp) 25.

Halwatura, D. and Najim, M.M.M. 2013. Application of the HEC-HMS model for runoff simulation in a tropical catchment. Environmental Modelling & Software 46. Elsevier Ltd.

Krause, P., Boyle, D.P. and Base, F. 2005. Comparison of different efficiency criteria for hydrological model assessment. European Geosciences Union. Advances in Geosciences, 5, 89–97.

Majidi, A. and Shahedi, K. 2012. Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran). International Journal of Hydraulic Engineering 2012, 1(1).

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D. and Veith, T. L. 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulation. American Society of Agricultural and Biological Engineers ISSN 0001−235. Vol. 50(3): 885−900 2007.

National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. 2012. "Lidar 101: An Introduction to Lidar Technology, Data, and Applications." Revised. Charleston, SC: NOAA Coastal Services Center.

Quismundo, T. 2012. Philippines is 3rd most disaster-prone country, new study shows. Retrieved August 15, 2016 from http://globalnation.inquirer.net.

Roy, D., Begam, S., Ghosh, S. and Jana, S. 2013. Calibration and Validation of HEC-HMS Model for a River Basin in Eastern India. ARPN Journal of Engineering and Applied Sciences. Asian Research Publishing Network (ARPN). VOL. 8, NO. 1.

US Army Corps of Engineers. 2010. Hydrologic Modeling System HEC-HMS User's Manual. Available online at http://www.hec.usace.army.mil/software/hec hms/documentation/HEC-HMS_Users_Manual_3.5.pdf.

Yuan, Y. and Qaiser, K. 2011. Floodplain Modeling in the Kansas River Basin Using Hydrologic Engineering Center (HEC) Models Impacts of Urbanization and Wetlands for Mitigation. EPA/600/R-11/116. www.epa.gov.

Zhang, H. L., Wang, Y. J., Y, Li, D. X. and Wang, X. K. 2013. The effect of watershed scale on HEC-HMS calibrated parameters: a case study in the Clear Creek watershed in Iowa, US. Hydrol. Earth Syst. Sci... www.hydrol-earth-syst-sci.net.

Zoleta-Nantes, D.B. 2000. Flood Hazards in Metro Manila: Recognizing Commonalities, Differences, and Courses of Action. Social Science Diliman (January-June 2000) 1:1, pp. 60-105.