FLOOD MODELING AND HAZARD EXPOSURE ASSESSMENT OF LASANG RIVER USING LIDAR DATA SETS

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KEYWORDS: Flood Hazard Modeling and Mapping, Lasang River, Light Detection and Ranging (LiDAR), LiDAR Data Processing, LiDAR Data Validation

ABSTRACT: This study aimed to produce flood hazard maps of Lasang River in Davao Region, Southern Mindanao, Philippines with the use of Light Detection and Ranging (LiDAR) to produce flood model with at least a 6-hour early warning system and hazard exposure assessment. Particularly, this study processed, validated, and modelled flood event of the river. The results revealed that there were 10 LiDAR blocks for Lasang floodplain covering 1,415.57 km^2. The Digital Elevation Models were calibrated and integrated with bathymetric data gathered from the field. Salient features to flood were extracted from the LiDAR Digital Surface Model such as buildings, road networks, bridges, and waterbodies. The extracted features were given attributes based during field validation. Hydrological measurements such as rainfall, river velocity, and water level were also conducted. Subsequently, the relationship between the observed water levels and outflow known as rating curve were calculated to ensure goodness of fit between the data. The calculated discharge of acceptable rating curve value, was used in calibrating the hydrologic model. Undergoing through these processes, the hydrologic model have achieved the acceptable result. Simulation of hypothetical scenarios were also prepared for this river. The edited and calibrated LiDAR DTM of the floodplain along with the base flow, event flow, and simulated hypothetical scenarios in 5-year, 25-year, and 100-year rain return periods were processed resulting to the production of flood inundation maps of Lasang River floodplain. Two-dimensional (2D) flood maps were also produced in 5-year, 25-year, and 100-year rain return periods and were validated to verify the reliability of the flood depth and hazard maps. At least 200 field validation points were selected based on the 2D flood depth maps of the Lasang River. Lastly, flood exposure assessment that shows the number of structures affected by flood per barangay within the floodplain were produced in 100-year rain return period.

1. INTRODUCTION

The Philippines, being geographically situated along the typhoon belt, is estimated to have 80 typhoons developed above its tropical water annually; 19 enters in its region, and six to nine make landfall (Wingard & Brändlin, 2013). As a result, the project Nationwide Operational Assessment of Hazard (NOAH) was launched on July 6, 2012. The Disaster Risk and Exposure Assessment for Mitigation (DREAM) was created as one of the eight components of the Department of Science and Technology (DOST) groundbreaking Project NOAH, the country's flagship program in disaster mitigation. The DREAM Hazard Mapping Program started to use the LiDAR technology to scan 1/3 of the Philippines river basins which included 18 major river basins in the Philippines, leaving the other 2/3 of the areas in the Philippines to the new project named as Phil-LiDAR 1 Program. This continuing program tapped the state universities and private universities to work hand in hand with them. The University of the Philippines Mindanao is one of these universities who was tasked for the 13 river systems in Davao Region/Southern Mindanao Region 11 to produce flood models and flood inundation maps.

In this study, the focus is on flood modeling and hazard exposure assessment of Lasang River found in the southeastern portion of Mindanao Philippines under the Phil-LiDAR 1 of UP Mindanao. The purpose of this study are to process, model, and validate flood maps. The objectives of this study are the following: (i) to process LiDAR data of Lasang river; (ii) to gather field data for the purpose of calibration and validation of hydrologic models; (iii) to generate and calibrate hydrologic and flood model of the river basin; and (iv) to produce and validate flood hazard maps. The output of this study can be used as basis for any disaster and environment-related challenge, with the capacity for continuous development. The national and local government units can utilize the data in providing Filipinos with science-based information in an era of a rapidly changing environment, through skilled, committed, and driven workforce using state-of-the-art technologies.

2. MATERIALS AND METHODS

The acquisition of LiDAR data of this study was conducted; hence, the Digital Surface Model (DSM) and Digital Terrain Model (DTM) from classified LiDAR point cloud data was processed. Afterwards, the blocks were mosaicked to produce the edited LiDAR DTM and DSM output for one flight mission. Quality checking using data from the validation team was conducted to correct any systematic errors in the products such as calibrating the DTM, removing the water areas of a river from the LiDAR DTM and integrating field bathymetric data to the LiDAR DTM. Moreover, the acquisition of river flow data to produce Stage-Discharge (HQ) was conducted. This was done to determine the behavior of the river given specific precipitation levels. Precipitation is the biggest factor influencing stage and river velocity. These two sets of data must be synchronized relative to time in order to compute its cross-section area, and subsequently, used as discharge. The correlation of Stage-Discharge computations was plugged into a flood simulation program to predict the behavior of the river. The element of time is crucial in determining the delay between the onset of precipitation and the time of significant water level change along key points of the river for early flood warning system of communities. Stage-Discharge computation requires on-site gathering of cross-section, water level change data (deployment of depth gauge) and river velocity (deployment of digital current flow meter) data for identified area in the river.

Furthermore, generation of RAS models using multiple cross-section data that were derived from the edited Digital Terrain Model (DTM) was conducted. The cross-section data were then converted to another GIS format that HEC-RAS understands. This model was used as basis to create the 1D flood map. If the calibrated HMS model is available, the hypothetical scenarios can then be simulated. The 5, 10, 25, 50, and 100-year rain intensity duration and frequency (RIDF) data of the watershed will serve as input to the calibrated basin model and produces an output of a simulated discharge. Processing the RAS model and simulated discharge together produces a 1D flood map.

2.1 LiDAR DEM Processing

2.1.1 Digital Elevation Model Editing and Hydro-Correction: Ten mission blocks were processed for Lasang floodplain. These blocks are composed of Davao del Sur and Compostela Valley blocks with a total area of 1,415.57 km^2. Portions of DTM before and after manual editing are shown in Figure 1. The embankment (Figure 1a) has been misclassified and removed during classification process and was retrieved to complete the surface (Figure 1b) to allow the correct flow of water. The bridge (Figure 1c) is also considered to be an impedance to the flow of water along the river and has to be removed (Figure 1d) in order to hydrologically correct the river. Another example is a building that is still present in the DTM after classification (Figure 1e) and has to be removed through manual editing (Figure 1f).

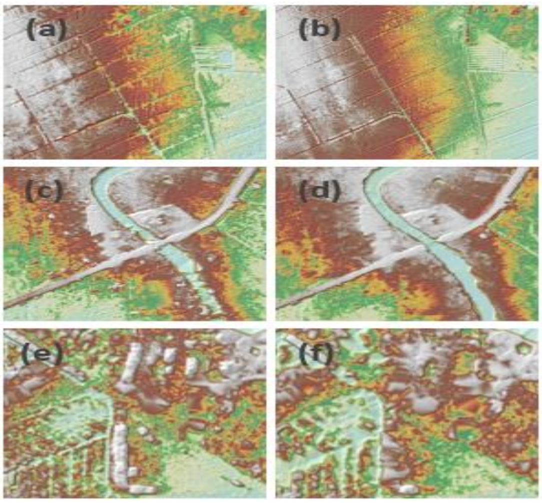

Figure 1. Portions in the DTM of Lasang floodplain – a paddy field before (a) and after (b) data retrieval; a bridge before (c) and after (d) manual editing; and a building before (e) and after (f) manual editing.

2.1.2 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model: A total of 13,127 survey points were used for calibration and validation of Lasang LiDAR data. Random selection of 80% of the survey points, resulting to 10,501 points, were used for calibration. A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 2. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 1.67 m with a standard deviation of 0.10 m. Calibration of Lasang LiDAR data was done by adding the height difference value, 1.67 m, to Lasang mosaicked LiDAR data. Table 1 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

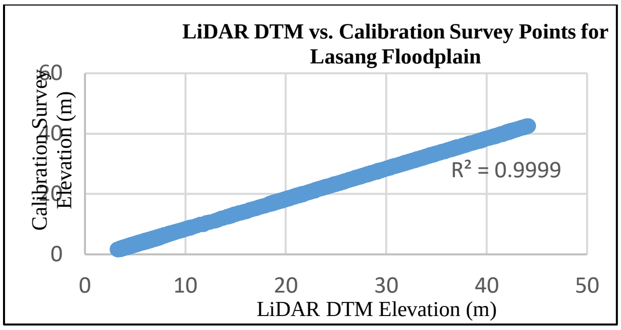

Figure 2. Correlation plot between calibration survey points and LiDAR data in Lasang floodplain.

Table 1. Calibration statistical measures for Lasang floodplain.

Calibration Statistical Measures	Value (m)
Height Difference	1.67
Standard Deviation	0.10
Average	1.67
Minimum	1.47
Maximum	1.86

The remaining 20% of the total survey points, resulting to 2,625 points, were used for the validation of calibrated Lasang DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 3. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.19 m with a standard deviation of 0.18 m, as shown in Table 2.

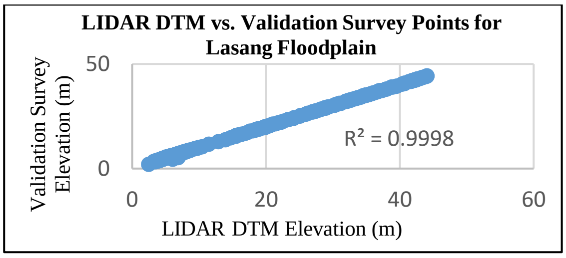

Figure 3. Correlation plot between validation survey points and LiDAR data in Lasang floodplain.

Table 2. Validation Statistical Measures for Lasang floodplain.

Validation Statistical Measures	Value (m)
RMSE	0.19
Standard Deviation	0.18
Average	0.08
Minimum	-0.27
Maximum	0.43

2.1.3 Integration of Bathymetric Data into the LiDAR Digital Terrain Model: For bathymetric integration, only centerline and cross-section data were available for Lasang with 1,253 bathymetric survey points. The resulting raster surface produced was done by Inverse Distance Weighted (IDW) interpolation method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.53 m. The extent of the bathymetric survey in Lasang integrated with the processed LiDAR DEM is shown in Figure 4.

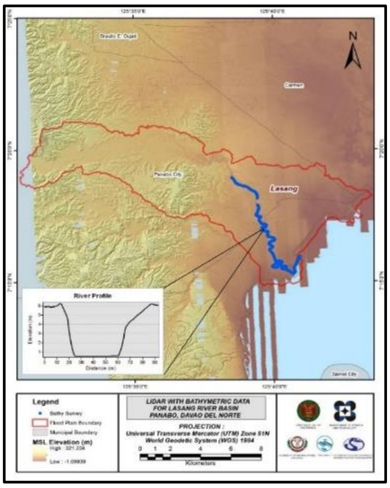

Figure 4. Map of Lasang floodplain with bathymetric survey points shown in blue.

2.2 Feature Extraction

2.2.1 Height Extraction and Feature Attribution: Height extraction was done for 35,256 building features in Lasang floodplain. Of these building features, 3,675 were filtered out after height extraction, resulting to 31,581 buildings with height attributes. The lowest building height is at 2.00 m, while the highest building is at 15.28 m. Table 3 summarizes the number of building features per type. On the other hand, Table 4 shows the total length of each road type, while Table 5 shows the number of water features extracted per type. A total of five bridges and culverts over small channels that are part of the river network were also extracted for the floodplain.

Table 3. Number of building features extracted for Lasang floodplain.

Facility Type	**No. of Features**
Residential	32,702
School	587
Market	42
Agricultural/Agro-Industrial Facilities	450
Medical Institutions	67
Barangay Hall	31
Military Institution	40
Sports Center/Gymnasium/Covered Court	28
Telecommunication Facilities	1
Transport Terminal	4
Warehouse	29
Power Plant/Substation	2
NGO/CSO Offices	14
Police Station	11
Water Supply/Sewerage	12
Religious Institutions	232
Bank	14
Factory	128
Gas Station	37
Fire Station	3
Other Government Offices	57
Other Commercial Establishments	765
Total	**35,256**

Table 4. Total length of extracted roads for Lasang floodplain.

Floodplain	**Road Network Length (km)**				**Total**
	BR	**CM**	**PR**	**NA**	
Lasang	274.63	63.38	0.00	41.23	**379.24**

Table 5. Number of extracted water bodies for Lasang floodplain.

Floodplain	**Water Body Type**					**Total**
	RS	**LP**	**SE**	**DM**	**FP**	
Lasang	1	0	0	0	0	**1**

2.2.2 Final Quality Checking of Extracted Features: All extracted ground features were attributed according to the needed data. The final shapefiles passed the quality checking assessment by the QC team in UP Diliman and rendered the following rating: completeness 97.09%, correctness 100 %, and quality 93.76%. This completes the feature extraction phase of the project. All these output features comprise the flood hazard exposure database for the floodplain. Figure 5 shows the Digital Surface Model (DSM) of Lasang floodplain overlaid with its ground features.

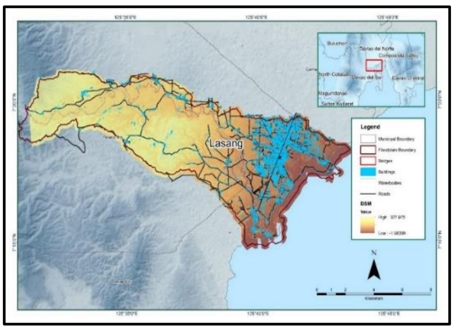

Figure 5. Extracted features for Lasang floodplain.

2.3 Hydrological Measurements

2.3.1 Reconnaissance, Courtesy Call, and Establishment of Reference Points: The preliminary identification of flood prone barangays along Lasang River was based on the gathered PhilGIS barangay boundary shapefiles overlaid to the available flood hazard map of Mines Geoscience Bureau (MGB) of Region XI. There were 15 identified flood prone barangays, namely: Lasang, Pandaitan, Mabuhay and Pañalum in Davao City; J.P. Laurel, Datu Abdhul Dadia, Little Panay, Nanyo, New Malitbug, Katipunan, Kasilak, Manay, Consolacion, Sto. Niño, and Palma Gil in Panabo City. The team interviewed barangay officials to collect information that will lead to the identification of flood prone areas along Lasang River. When these areas were identified, the team conducted another set of interview among community members. During river reconnaissance survey, assessment of structures along the river such as bridges and dikes, estimation of Manning's Roughness Coefficient, actual vegetation cover, and manual measurement of the river depth were conducted. The data was utilized by the Flood Modeling Component (FMC) for the initial inputs in the simulation of flood occurrences.

2.3.2 Rainfall Data Collection: Rain gauge (RG-3M) installation along Lasang River was conducted at Barangay Tapak, Paquibato District, Davao City. The site of installation was strategically located within the central part of Lasang Watershed (Figure 6). The collection of rainfall data was conducted alongside with the observation period of the deployment of the Digital Current Flow Meter (DCFM) and depth gauge instrument. An alternative source of rainfall data (Figure 7) was also considered which was established by the Department of Science and Technology-Advance Science and Technology Institute (DOST-ASTI) situated at Talaingod Municipal Hall which was the nearest station with available data. The collected rainfall data was utilized for flood simulation of Lasang Watershed.

Figure 6. Installation of rain gauge station at Brgy. Tapak, Paquibato District, Davao City.

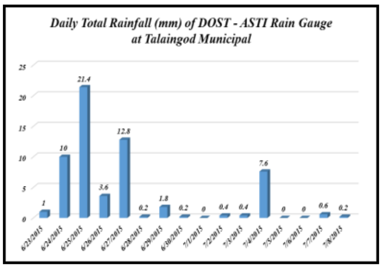

Figure 7. Daily rainfall graph of the collected data from rain gauge installed by DOST-ASTI at Talaingod Municipal Hall.

2.3.3 River Velocity Measurement: To measure the river velocity, a Digital Current Flow Meter was deployed in Lasang River at Little Panay Bridge, Barangay Little Panay, Panabo City (Figure 8). The collected data from the DCFM deployed in Lasang River was analyzed and was used to generate the daily average, maximum, and minimum velocity. The processed data gathered from the 10-minute recording interval is presented in Figure 9. The highest recorded average water velocity of the river was observed at 3.484 m/s last June 30, 2015 and lowest average water velocity was at 0.562 m/s observed last July 2, 2015.

Figure 8. DCFM deployment in Lasang River at Little Panay Bridge, Panabo City, Davao del Norte.

Date	Ave V (m/s)	Max V (m/s)	Min V (m/s)
6/23/2015	0.858	1.010	0.774
6/24/2015	0.798	0.930	0.609
6/25/2015	0.740	1.610	0.280
6/26/2015	1.668	8.847	0.414
6/27/2015	0.721	1.316	0.171
6/28/2015	0.710	1.929	0.132
6/29/2015	1.204	7.985	0.016
6/30/2015	3.484	8.856	0.243
7/1/2015	0.591	0.975	0.046
7/2/2015	0.562	0.922	0.063
7/3/2015	0.788	1.024	0.504
7/4/2015	0.795	0.976	0.466
7/5/2015	0.700	0.882	0.128
7/6/2015	0.589	0.947	0.100
7/7/2015	0.639	0.851	0.281
7/8/2015	0.620	0.749	0.037

Figure 9. Tabulated 15-day daily average water velocity of Lasang River at Little Panay Bridge.

2.3.4 River Water Level Measurement: To measure the water level, a depth gauge was deployed alongside with the deployment of DCFM. Data was collected through the HOBOware data logger. The data was used to generate average, maximum, and minimum daily stage height based on the mean sea level reference value. The highest daily average stage recorded was 6.091 m MSL. The lowest observed stage value was 5.037 m MSL. The observed daily raw data of stage is presented in Figure 10 for Lasang River.

Date	Ave S(m)	Max S(m)	Min S(m)
6/23/2015	5.558	5.565	5.549
6/24/2015	5.562	5.668	5.522
6/25/2015	5.725	6.147	5.599
6/26/2015	6.091	6.944	5.615
6/27/2015	5.555	5.805	5.397
6/28/2015	5.721	6.046	5.505
6/29/2015	5.523	6.012	5.356
6/30/2015	5.540	5.965	5.390
7/1/2015	5.322	5.386	5.284
7/2/2015	5.247	5.280	5.219
7/3/2015	5.209	5.253	5.161
7/4/2015	5.143	5.171	5.113
7/5/2015	5.129	5.171	5.093
7/6/2015	5.083	5.107	5.055
7/7/2015	5.048	5.072	5.019
7/8/2015	5.037	5.054	5.017

Figure 10. Tabulated daily average, maximum, and minimum stage (MSL-based) in meter.

2.4 HEC-HMS Modeling

2.4.1 Discharge Computation: Precipitation data was taken from the automatic rain gauge (ARG) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) at Barangay Sto. Niño, Talaingod, Davao del Norte and another one installed by UP Mindanao Phil-LiDAR 1 at Barangay Tapak, Paquibato District, Davao City. Digital Current Flow Meter (DCFM) and depth gauge were deployed at Little Panay Bridge, Barangay Little Panay, Panabo City. Total rain recorded from the Talaingod rain gauge was 38.0 mm. It peaked to 8.40 mm on 25 June 2015 19:45. The interval between the peak rainfall and discharge is 6 hours and 15 minutes, as seen in Figure 11.

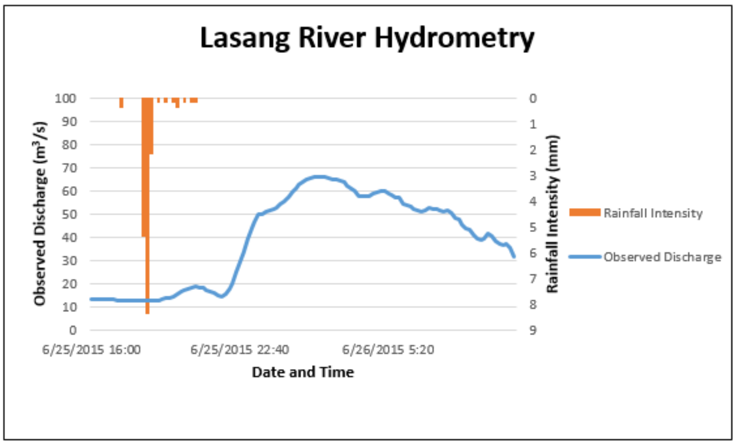

Figure 11. Rainfall and outflow data used for modeling of Lasang River.

2.4.2 River Outflow and Rating Curve Generation: River outflow from the Data Validation Component was used to calibrate the HEC-HMS model. This was taken from Little Panay Bridge, Panabo City, Davao del Norte (07°17’54.38”N 125°39’25.88”E). This was recorded on June 25-29, 2015.

A rating curve was developed at the same location. It gives the relationship between the observed water levels and outflow of the watershed at this location using depth gauge and Digital Current Flow Meter (DCFM). It is expressed in the form of the following equation:

$$Q=a^{nh} \quad (1)$$

where Q is the discharge (m^3/s), h is the gauge height (reading from Little Panay Bridge), and a and n are constants. For Little Panay Bridge, the rating curve is expressed as $Q = 0.0182e^{1.2105h}$ as shown in Figure 12.

2.4.3 Calibration of Hydrologic Model: The calibration of the Lasang HEC-HMS river basin model was measured against the observed values for its accuracy. Figure 13 shows the comparison between the two discharge data. The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements.

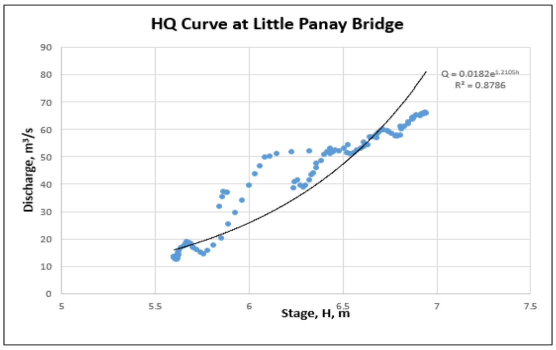

Figure 12. HQ curve of HEC-HMS Model for Lasang River.

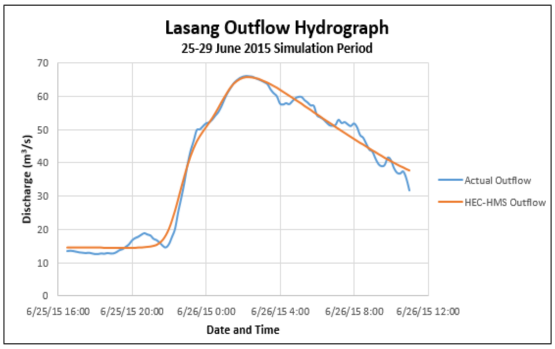

Figure 13. Comparison of HEC-HMS Model outflow and actual outflow hydrographs of Lasang River.

It was identified at 2.18110. The Coefficient of Determination (R^2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC-HMS Model. Here, it measured 0.98769. The Nash-Sutcliffe Efficiency (E) method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of 0.98748. A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction – the optimal value is 0. In the model, the PBIAS is 0.40127. The RMSE-Observations Standard Deviation Ratio (RSR) is an error index. A perfect model attains a value of 0 when the error in the units of the variable is quantified. The model has an RSR value of 0.11190.

2.4.4 Simulation of Hypothetical Scenario: The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Davao rain gauge. This station was chosen based on its proximity to the Lasang Watershed. The extreme values for this watershed were computed based on a 26-year record.

The summary graphs show the Lasang outflow using the Davao Rainfall Intensity Duration Frequency curves (RIDF) in five different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

In the 5-year return period, the peak outflow is 447.1 m^3/s. This occurs after 4 hours, and a precipitation of 25.1 mm. In the 10-year return period, the peak outflow is 527.9 m^3/s. In the 25-year return period graph, the peak outflow is 630.6 m^3/s. This occurs after 3 hours and 50 minutes after the peak precipitation of 33.5 mm. This occurs after 3 hours and 50 minutes, and a precipitation of 28.8 mm. In the 50-year return period, the peak outflow is 707.4 m^3/s. This occurs after 3 hours and 40 minutes, and a precipitation of 37 mm. In the 100-year return period graph, the peak outflow is 782.3 m^3/s. This occurs after 3 hours and 40 minutes after the peak precipitation of 40.5 mm. A summary of the data is seen in Figure 14.

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of Lasang discharge using the Davao Rainfall Intensity Duration Frequency curves (RIDF) in five different return periods is shown in Table 6.

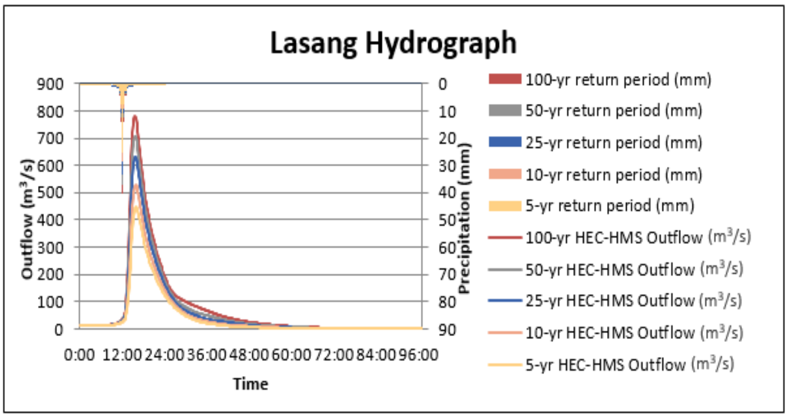

Figure 14. Outflow hydrograph generated using the Davao 5-year, 10-year, 25-year, 50-year, and 100-year RIDF as input in Lasang HEC-HMS Model.

Table 6. Peak values of the Lasang HEC-HMS Model outflow using the Davao RIDF.

RIDF Period	Total Precipitation	Peak rainfall	Peak outflow	Time to Peak
5-Year	121.1 mm	25.1 mm	447.1 m^3/s	4 hours
10-Year	140.7 mm	28.8 mm	527.9 m^3/s	3 hours, 50 minutes
25-Year	165.5 mm	33.5 mm	630.6 m^3/s	3 hours, 50 minutes
50-Year	183.9 mm	37.0 mm	707.4 m^3/s	3 hours, 40 minutes
100-Year	202.1 mm	40.5 mm	782.3 m^3/s	3 hours, 40 minutes

2.5 HEC-RAS Modeling

The Lasang River Flood Model was developed using the Hydrologic Engineering Center River Analysis System (HEC-RAS). The purpose of this model is to determine the maximum flood extent and inundation levels due to rainfall events of varying intensity. The model setup was based from the calibration using the base and event flow data gathered by the Data Validation Component of UP Mindanao Phil-LiDAR 1.

2.5.1 Generation of HEC-RAS Model: The LiDAR DEM was taken from the Data Processing Component of the UP Disaster Risk and Exposure Assessment for Mitigation. The elevation dataset used in the HEC-RAS model has a 1 m resolution. The coverage of LiDAR DEM of the floodplain is shown in Figure 15. For the development of the model, the discharge data from the Data Validation Component's fieldwork was utilized. The discharge data were taken from the water level sensors installed at Little Panay Bridge. The base flow discharge of 12 m^3/s was specifically inputted to assume a normal flow in the river. Riverbed cross-sections of the watershed are crucial in the HEC-RAS Model setup. The cross-section data for the HEC-RAS model was derived using the LiDAR DEM data. It was defined using the HEC-GeoRAS tool and was post-processed in ArcGIS (Figure 16).

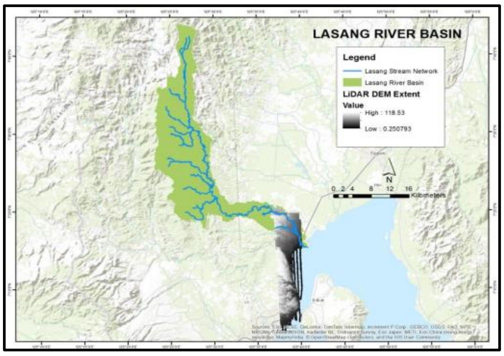

Figure 15. Areas with LiDAR DEM for Lasang River Basin.

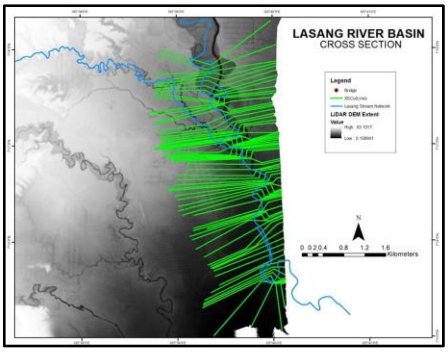

Figure 16. River cross-section of Lasang River generated through HEC-GeoRAS tool.

2.5.2 Generation of 1D Flood Map: The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model will be used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample generated map of Lasang River using the calibrated HMS event flow (Fig 17a), and the simulated hypothetical scenarios in 5-year (Fig 17b), 25-year (Fig 17c), and 100-year (Fig 17d) rain return period.

Figure 17. Lasang River using the calibrated and simulated hypothetical scenarios

2.6 2D Flood Map Validation

The Lasang 2D Flood Hazard Map was generated by the UP Diliman Phil-LiDAR in 5-year (Fig 18a), 25-year (Fig 18b), and 100-year (Fig 18c) rain return periods. On the other hand, the UP Mindanao team collected field points and validated it on the grounds along Lasang River. Flood map validation was conducted on the following barangays, namely: Alejandra Navarra (Lasang) in Davao City, J.P. Laurel, Cagangohan, Maduao, New Visayas, Datu Abdul

Dadia, Little Panay, and Katipunan in Panabo City. The team used handheld GPS, steel tape and trip maps for the entire fieldwork activities.

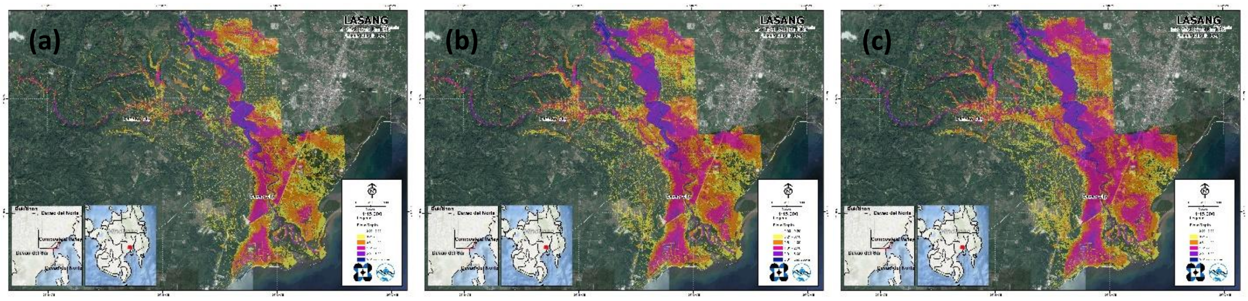

Figure 18. The Lasang 2D Flood Hazard Maps in 5-year, 25-year, and 100-year rain return periods

2.6.1 Collection of Field Validation Points: There were a total of 217 points that were collected for 5-year (Fig 19a), 25-year (Fig 19b), and 100-year (Fig 19c) rain return periods. which were divided into six ranges: (1) 74 points for range 0-0.20; (2) 40 points for range 0.21-0.50; (3) 26 points for range 0.51-1.00; (4) 35 for range 1.01-2.00; (5) 38 points for range 2.01-5.00; and (6) 4 points for range 5.01 and above. These points were based from the 5-year return period flood depth map of Lasang (Figure 18).

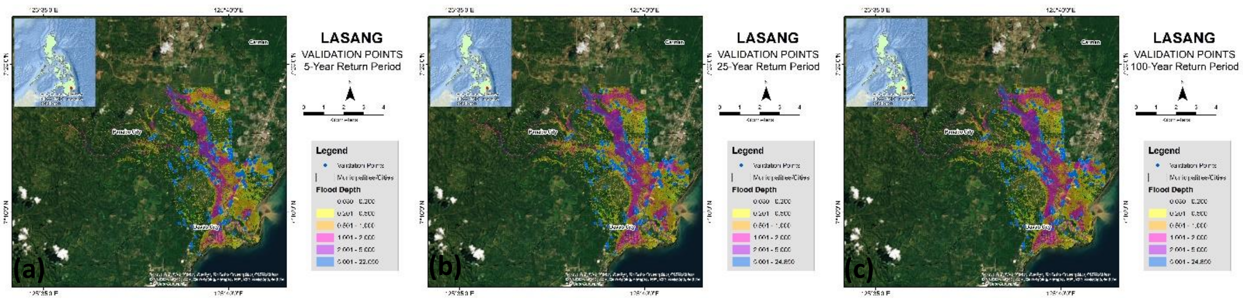

Figure 19. Flood map validation points of Lasang floodplain based from 5-year, 25-year, and 100-year return periods

2.6.2 Error Computation and Analysis: The Nash-Sutcliffe Efficiency (E), RMSE-Observations Standard Deviation Ratio (RSR), and Root Mean Square Error (RMSE) methods were used for the error computation. The E and RSR have computed values of were 0.80345 and 0.44334, respectively which falls in the satisfactory category. In addition, the RMSE value is 0.810185 for the 5-year rain return period. For the 25-year rain return period, the E and the RSR values were 0.74424 and 0.505727, respectively, which are satisfactory values with an RMSE of 0.924195. For the 100-year rain return period, E and RSR values were 0.66442 and 0.579293, respectively, which are also satisfactory with RMSE value of 1.058634.

2.7 Flood Exposure Assessment

Intersecting the two-dimensional (2D) 5-year rain return flood hazard and barangay boundary vector files, it was identified that the Lasang River will inundate structures built in 10 barangays. These barangays are Alejandra Navarro in Davao City and Cagangohan, Datu Abdul Dadia, Gredu, JP Laurel, Katipunan, Kauswagan, Little Panay, Maduao, and New Visayas in Panabo City. In this rain return period, the most exposed structures susceptible to high flooding (1.51m and above) is situated in Barangay Alejandra Navarro having a total of 139 structures out of 296 or 47%. In a moderate flood (0.51-1.5 m flood), Barangay Cagangohan was identified as the most exposed in this flood category having a share of 1,031 structures out of 3,484 or 30%. Lastly, the barangays of Cagangohan (583 structures) and Datu Abdul Dadia (583 structures) was identified as the most exposed to low flooding (0-0.5m flood) with 1,166 identified structures in total out of 2,380 or 49%. For this rain return flooding, there are a total of 6,160 exposed structures out of 18,594 structures within the Lasang River floodplain. Flood exposure can be defined as the assets and values situated in flood prone areas. It primarily considers the density of the structures in built-up areas. Intersecting the two-dimensional (2D) 100-year rain return flood hazard and barangay boundary vector files, it was identified that the Lasang River will inundate structures built in 11 barangays. These barangays are Alejandra Navarro in Davao City and Cacao, Cagangohan, Datu Abdul Dadia, Gredu, JP Laurel, Katipunan, Kauswagan, Little Panay, Maduao, and New Visayas in Panabo City.

Table 7 shows the summary of the number of structures per barangay within the Lasang floodplain that are exposed to a 100-year rain return flooding. In this rain return period, the barangay that is greatly exposed to a high flooding is the barangay of Cagangohan with 721 inundated structures out of 1,702 or 42%. In addition, Datu Abdul Dadia is the greatly exposed barangay when it comes to a moderate flooding with 1,408 inundated structures out of 5,103 or 28%. Finally, JP Laurel is the greatly exposed barangay when it comes to a low flooding having 462 inundated structures out of 1,675 or 28%. For this rain return period, there are a total of 8,480 exposed structures out of 18,594 structures within the Lasang River floodplain. Figure 20 shows the 2D flood hazard maps in 100-year rain return period of the Lasang floodplain with structures. It can be seen that the flood extent is wider than that of 5-year and 25-year rain return period, thus, inundating more structures.

Table 7. Summary table of the total exposed structures of each barangay within the Lasang floodplain for every flood level in 100-year rain return period.

Watershed	Barangay	Location	100-Year Return Period						Total Exposed Structures	Total Structures
			Low	%	Moderate	%	High	%		
Lasang	Alejandra Navarro	Davao City	380	22.7%	512	10.0%	352	20.7%	1,244	2,007
	Cacao	Panabo City	2	0.1%	-	0.0%	-	0.0%	2	284
	Cagangohan		149	8.9%	1,144	22.4%	721	42.4%	2,014	3,355
	Datu Abdul Dadia		234	14.0%	1,408	27.6%	182	10.7%	1,824	2,122
	Gredu		7	0.4%	199	3.9%	96	5.6%	302	4,041
	JP Laurel		462	27.6%	983	19.3%	238	14.0%	1,683	1,963
	Katipunan		44	2.6%	43	0.8%	5	0.3%	92	470
	Kauswagan		11	0.7%	3	0.1%	-	0.0%	14	300
	Little Panay		251	15.0%	204	4.0%	55	3.2%	510	794
	Maduao		116	6.9%	64	1.3%	3	0.2%	183	557
	New Visayas		19	1.1%	543	10.6%	50	2.9%	612	2,701
Total Structures			1,675	100%	5,103	100%	1,702	100%	8,480	18,594

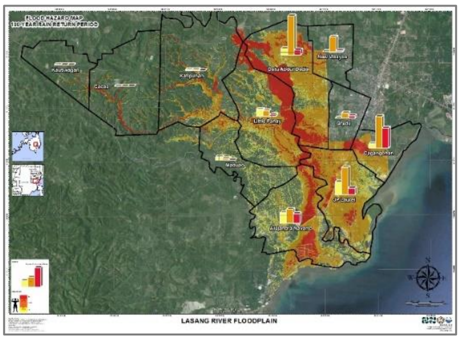

Figure 20. 2D structure exposure flood hazard maps in 100-year rain return period of the Lasang floodplain.

Overall, it was observed that there is a change in the coverage of hazards per barangay when exposed to the three different flood levels for each rain return period. For example, the barangay of Alejandra Navarro was identified as the most exposed to a high flooding in 5-year and 25-year rain return floods. On the other hand, it was the barangay of Cagangohan that is mostly exposed when it comes to a 100-year rain return flood. One of the reasons is that Barangay Cagangohan has more structures compared to Barangay Alejandra Navarro. The high level inundated areas of Lasang River in a 100-year rain return flood became wider reaching the barangay of Cagangohan with denser buildup. This observation also applies to the changes in moderate and low flood levels.

3. CONCLUSION AND RECOMMENDATION

There were 10 LiDAR blocks processed for Lasang floodplain, covering a total of 1,415.57 km^2. The Digital Elevation Models (DEMs) were calibrated and were integrated with the bathymetric data gathered from the field. Salient features were extracted from the generated LiDAR Digital Surface Model (DSM). The extracted features were given additional attributes taken during field validation. Hydrological measurements including rainfall, river velocity, and water level were conducted in the field. Subsequently, the relationship between the observed water levels and outflow known as rating curve were calculated to ensure the goodness of fit of the data. The calculated discharge, with an acceptable rating curve value, was used in calibrating the hydrologic model. Undergoing these processes, the Lasang hydrologic model has achieved the acceptable calibration result. Simulation of hypothetical scenarios were also prepared for this river. For the development of the model, the edited and calibrated LiDAR DTM of the river floodplain along with the base flow, event flow, and simulated hypothetical scenarios in 5-year, 25-year, and 100-year rain return periods were processed resulting to the production of 1D flood maps in 5-year and 100-year of the Lasang river floodplain. Two-dimensional (2D) flood maps were also produced in 5-year, 25-year, and 100-year rain return periods and validation of these maps were conducted to verify the reliability of the generated hazard maps. At least 180 field validation points were selected based on the 2D flood depth maps of the Lasang River for three scenarios which got a descriptive equivalent of Very Good for the 5 year; Good for the 25 year, and Good for 100 year return period. Lastly, flood exposure assessment showing 8,480 exposed structures out of 18,594 structures within the Lasang River affecting eleven (11) barangays within the floodplain in 100-year rain return period.

4. ACKNOWLEDGEMENT

Department of Science and Technology (DOST); Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIEERD); Disaster Risk and Exposure Assessment for Mitigation (DREAM); Phil-LiDAR 1 Program; TCGAP, UP Geodetic Engineering, University of the Philippines Diliman; and College of Science and Mathematics, Phil-LiDAR 1.B.13 University of the Philippines Mindanao