Acquiring LiDAR Validation and Bathymetric Data as Input for Agno River LiDAR DEM

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Key words: GNSS, LiDAR , River Bathymetry

SUMMARY

Typhoon Parma struck the Philippines in September 2009 which brought incessant rains and massive inundation causing an estimated US$570 million damage. Among the river systems that swelled in Luzon is the Agno River Basin, which is the fifth largest system in the country. Determining its river bathymetry is essential for computing discharge which could be used for flood modelling and eventually, early warning systems for its communities. A GNSS network was established in the province on August 1-13, 2012 by occupying first and second order reference points using GNSS receivers. Riverbed elevation data was acquired by mounting a single-beam echo sounder paired with a roving GNSS receiver in a continuous topo mode utilizing PPK survey technique on a boat while traversing the river. Additionally, validation points for LiDAR DEM was acquired using Continuous Topo mode in PPK survey technique. The data was used in order to complete the LiDAR DEM of the basin for hydraulic analysis. Aside from early warning systems derived from its hydrologic model, the LIDAR DEM with river bathymetry data could be used by the local key agencies for resource management, improved urban planning, and disaster mitigation.

The paper explains how bathymetric data is acquired and its importance for improved hydraulic analyses for the major river basins in the Philippines. The survey is part of the Nationwide DREAM Program funded by the Department of Science and Technology.

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1. INTRODUCTION

The Philippines is an archipelagic country situated along the Pacific Ring of Fire. It is subject to a number of natural hazards brought by volcanic activities and tropical cyclones and each year, an average of 19 tropical cyclones enter the Philippine Area of Responsibility (PAR) inducing flooding, storm surges, and landslides.

Yusuf and Francisco (2009) in their paper Climate Change Vulnerability Mapping for Souheast Asia identified the Philippines as among the most vulnerable countries in the region. The country is also consistently among the top ten countries impacted by extreme weather events from 1994-2015 according to the Global Climate Change Index (Kreft, Eckstein, & Junghans, 2015). The index focused on the first-hand impacts of weather events such as fatalities and economic loss for the 20-year period. The country rose to the top of the list in 2013, the same year Typhoon Haian struck the country.

Riverine flooding is the most destructive natural hazard present in the country. Reduction of fatalities is imperative since it is a continuous threat for the entire population. Key measures done by the government includes strengthening the NDRRMC responses by developing flood early warning systems for the major river systems in the country.

National initiative to address this constant threat include the implementation of the Nationwide Disaster Risk and Exposure for Mitigation (DREAM) Program funded by the Department of Science and Technology in 2012. The program to gather national elevation dataset and to develop three-dimensional (3D) hazard maps for the 18 major river systems in the country.

Datasets utilized in the program were acquired locally. The program acquires elevation data using Airborne Terrain Laser Mapper (ALTM) systems which are calibrated using ground and bathymetric data from because it cannot penetrate through silted rivers. The LiDAR point cloud and validation data acquired are processed into DEMs by and eventually, into 3D flood hazard maps.

2. STUDY AREA

The Agno River Basin is the fifth largest basin in the Philippines with an estimated area of 5,852 square kilometers Philippines. It is situated in the island of Luzon encompassing the provinces of Benguet, Ifugao, Tarlac, and Pangasinan. The Agno River Basin location map is delineated by the Flood Modelling Component (FMC) of the DREAM Program as shown in Figure 1.

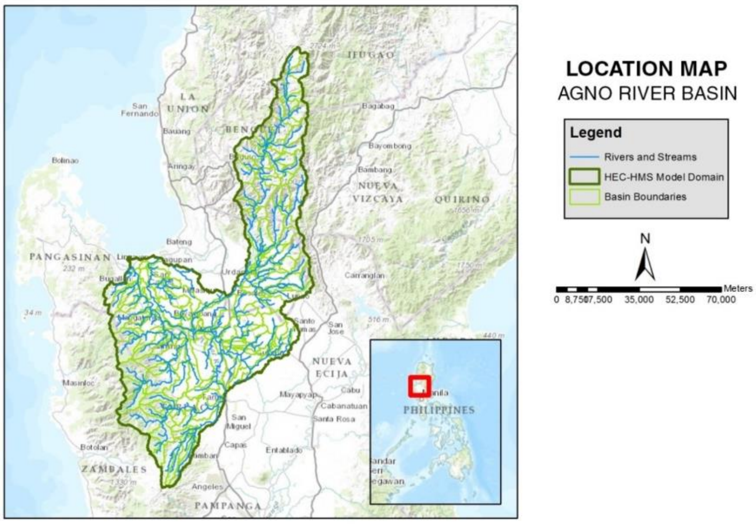


Figure 1 Agno River River Basin location map (UP-TCAGP, 2015, p.6)

The catchment properties of the watershed were delineated based on mean elevation with the aid of RADARSAT DTM by FMC (UP-TCAGP, 2015). The area of interest is the Agno River Stem running from the Municipality of Santa Maria down to Alcala as identified to be part of the flood plain of the basin (see Figure 2 and Figure 3).

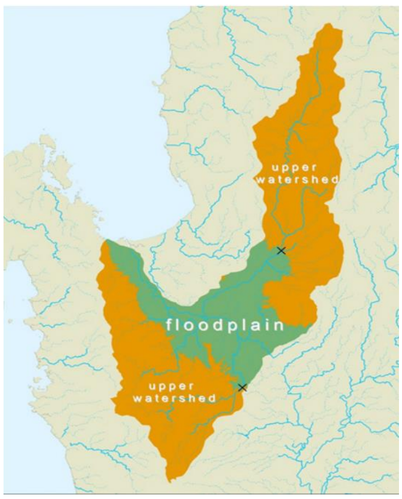


Figure 2 Delineation of upper watershed for Agno flood plain discharge computation (UP-TCAGP, 2015, p. 25)

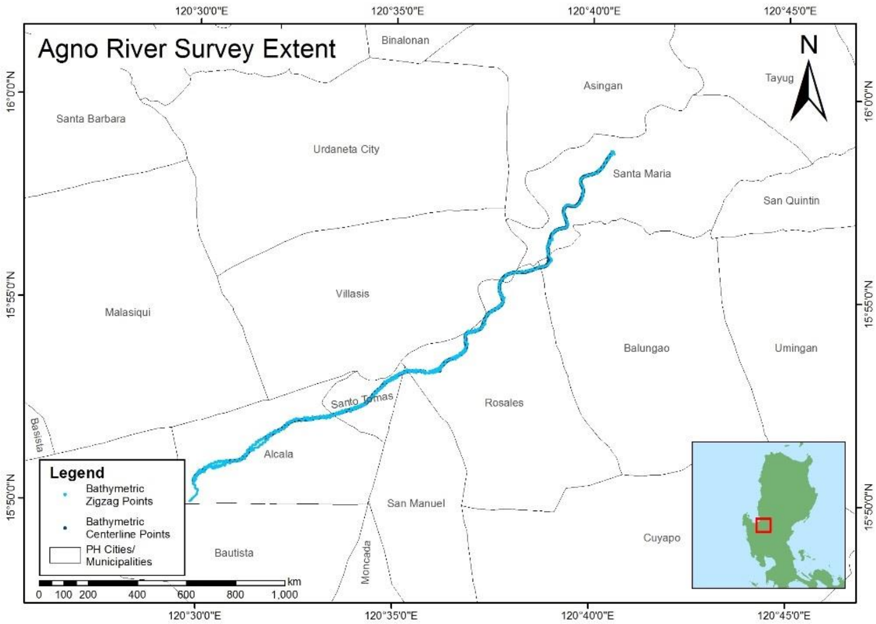


Figure 3 Agno River survey extent

3. METHODOLOGY

3.1 Acquiring bathymetric and validation points field data

Datasets acquired are ensured to have have ±20 cm and ±10 cm for horizontal and vertical accuracy, respectively. The task of the component could be divided into two – (1) acquisition of topographic data for calibrating and validation of airborne LiDAR of DAC and (2) acquisition of bathymetric data to define the underwater terrain of rivers.

3.1.1 Validation Points Acquisition Survey

Validation points acquisition survey were conducted for quality checking of the aerial LiDAR acquired by the Data Acquisition Component (DAC) of the Program. Points were gathered along concrete roads and open spaces at the end of each flight strips utilizing PPK survey technique.

Figure 4 Validation points acquisition in continuous topo mode (UP-TCAGP, 2015, p.50)

Two types of techniques were used to acquire validation points. A vehicle setup employs PPK survey technique in a continuous topo mode wherein a Trimble®SPS882 dual frequency GNSS receivers were attached to the side of the vehicle while traversing roads at around 10-15kph cutting across LIDAR flight strips by DAC. Each flight strip across the flood plain must be cut across perpendicularly at both ends.

Manual acquisition of validation points were also gathered using a Trimble®SPS882 in Topo Surveying mode in PPK survey technique logging at every second along concrete open spaces such as basketball courts and parking lots at the end of select flight strips. A minimum of twenty (20) points were gathered for each open space. This was done to in order to determine if data gathered in a vehicle setup in continuous topo mode is comparable with the elevation data acquired using Topo Surveying method. The setup for both surveys is illustrated in Figure 4 and Figure 5, respectively.

Figure 5 Validation points acquisition in Topo Surveying technique (UP-TCAGP, 2015, p.49)

3.1.2 Bathymetric Surveys

Bathymetric survey was conducted using a Trimble®SPS882 dual frequency GNSS receiver in PPK continuous topo mode mounted on a 2m pole with a Hi-Target™ HD-370 Digital VF single-beam echo sounder transducer attached to its bottom for rivers navigable by boat (see Figure 6).

Figure 6 Bathymetric survey setup using a single-beam echo sounder (UP-TCAGP, 2015, p.53)

The GNSS receiver acquires (x,y,z) coordinates up to the bottom of the pole whereas the transducer acquires depth from the transducer to the river bed. Hence, the depth value read by the transducer must be subtracted from the transducer elevation read by the GNSS rover as described in the formula:

$$RBE\ (t) = TRE(t) - Depth\ (t)$$

Where:

RBE(t)	= elevation of the riverbed during time t
TRE (t)	= transducer elevation (from EGM 2008)
Depth (t)	= depth recorded by the echo sounder at time t, where depth is measured from the bottom of the transducer down to the riverbed.

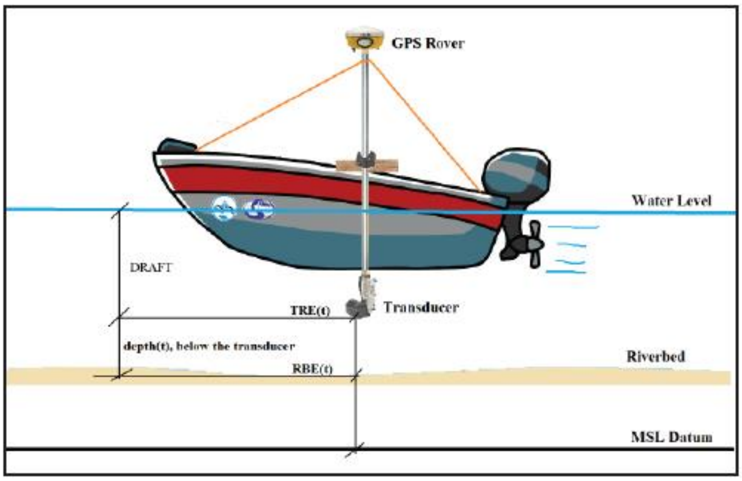


Figure 7 Echo sounder and GNSS rover setup (UP-TCAGP, 2015, p.30)

Data were logged on a one (1) second interval for both instruments and its processed data were time-stamped to give each point a corresponding (x,y,z) data.

Bathymetric survey was conducted in two ways, navigating the both in the centerline of the river and in a zigzag fashion. This was done in order to fully capture the topography of the riverbed.

3.2 LiDAR DEM Calibration and Bathymetric Data Integration

The LiDAR point cloud was acquired by the Data Acquisition Component (DAC) of the program using Airborne Lidar Terrain Mapper (ALTM) Systems. Flight strips were designed to acquire point cloud data to have a minimum 25% overlap with an average density of 2 points per square meter.

The point cloud data acquired underwent rectification to give each individual point coordinates by merging its trajectory, accuracy, and range files. Horizontal and vertical misalignments between contiguous strips were also corrected by matching points from overlapping strips using the LiDAR Mapping Suite (LMS) software. This ensures that the average point density is met and that the elevation difference of strips does not exceed 20 cm in flat areas.

After which, the point cloud data were divided into 1km by 1km blocks for easier data management. Points were then classified either as ground, low vegetation, medium vegetation, high vegetation, and buildings. Air points were also identified by assigning a 5m search radius and filtering out points that are 5 standard deviations away. Cleaned point cloud data were rasterized into 1m by 1m grid to produce Digital Terrain Model (DTM) and Digital Surface Models (DSM)

This dataset was calibrated using validation points acquired by the field to ensure its homogeneity with actual ground data. The prescribed accuracy of the LiDAR DEM is ±50 cm and ±20 cm for horizontal and vertical positions, respectively.

Water surface from the DTM was removed to integrate bathymetric data from the field. Bathymetric data provides riverbed elevation to make it suitable for hydraulic analyses. The step-by-step procedure for this is illustrated in Figure 8.

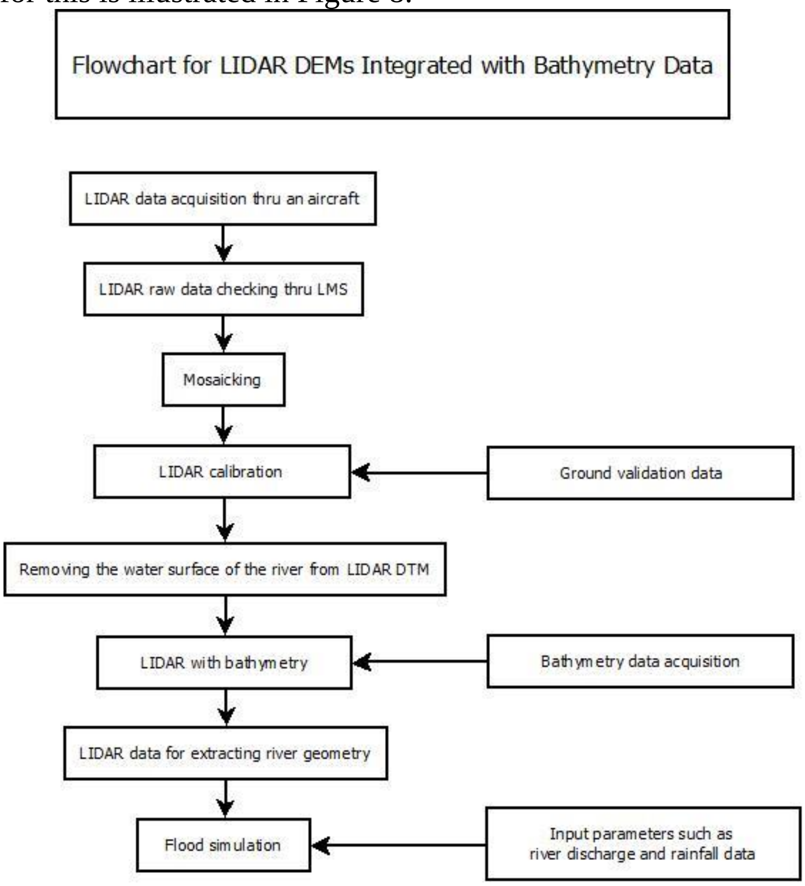


Figure 8 Workflow for LiDAR DTM calibration and bathymetric data integration

3.3 Flood Simulation

River geometry such as riverbank and centerline profiles and cross sections were extracted from the LiDAR DTM using HEC GeoRAS, an extension in ArcGIS. This data is exported in Hyrdrologic Engineering Center – River Analysis System (HEC-RAS) 4.1.

Discharge data from the field were combined with a 5-year Rainfall Intensity Duration Frequency (RIDF) of the river from the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). This was done in the Hydrologic Modeling System (HEC-HMS) to generate 5-year, 25-year, and 100-year rainfall scenarios.

Flood simulation was done in HEC-RAS by encoding these hypothetical rainfall scenarios to determine the maximum extent of flooding given these varying rainfall intensities. The simulated results were processed in RAS Mapper in HEC-RAS.

4. RESULTS AND DISCUSSIONS

4.1 LiDAR DEM Calibration

The two types of validation methods employed using vehicle validation in Continuous Topo mode and Topo method in PPK survey technique were compared and resulted to an R^2 of 0.997 and an RMSE of 3.53 cm (see Figure 9).

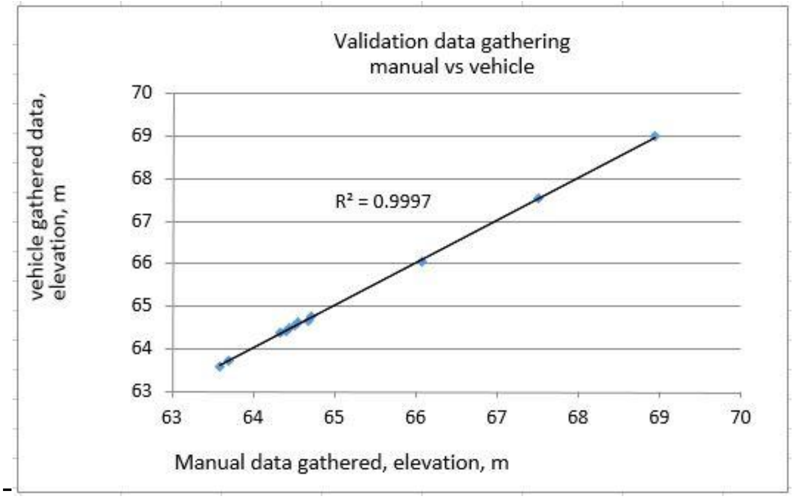


Figure 9 Comparison of continuous topo and topo method in validation points acquisition

Hence, acquisition of validation points using continuous topo mode were primarily utilized for because of it is both time and cost efficient.

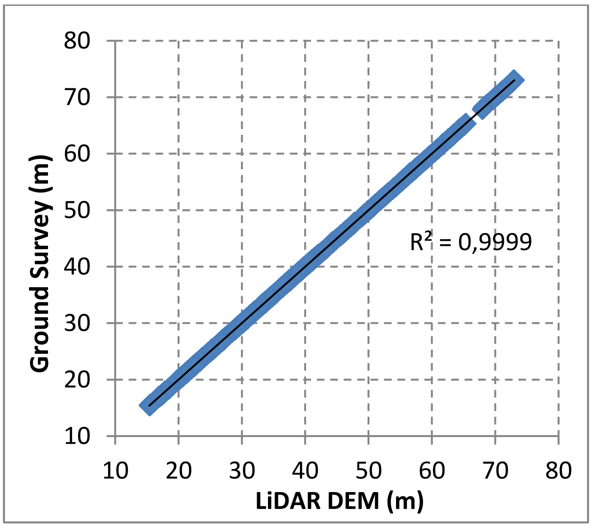


Figure 10 Correlation of LiDAR DTM and validation points acquired

The linear correlation of LiDAR DTM and validation points data were determined and its RMSE computed which resulted to an R^2 of 0.9999 and an RMSE of 7.8284 cm for a total of 8,669 validation points used. This RMSE value was used to calibrate the Agno River DTM in ArcGIS10. The image in Figure 11 shows the extent of validation points acquired and its respective flight strips.

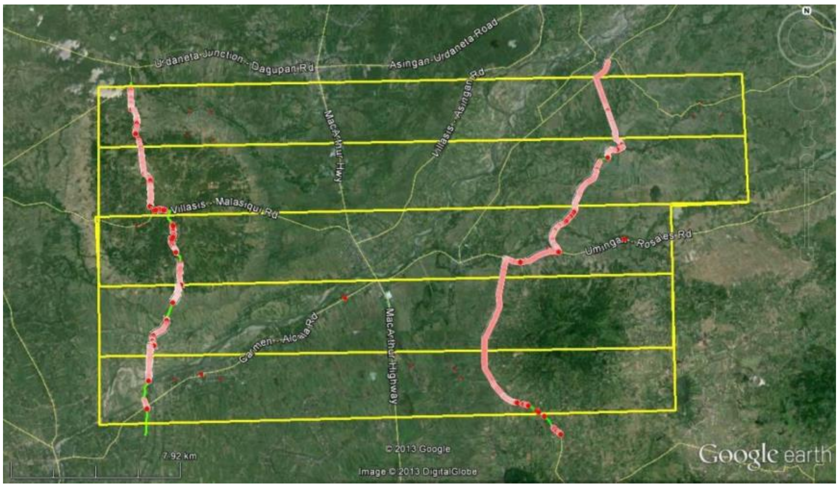
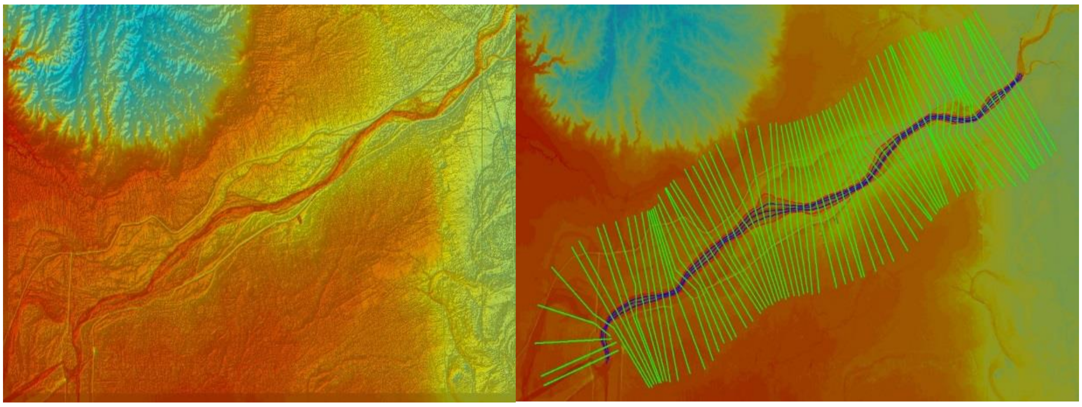


Figure 11 Extent of validation survey conducted along Agno River

4.2 Bathymetric Data Integration and Flood Simulation

The acquired bathymetric points were used to delineate the width of the river to remove the water surface from the DTM. After removing the water surface, the elevation values of the bathymetric points were interpolated with the LiDAR DTM.



a b

Figure 12 (a) Agno DTM with integrated bathyetric data and (b) extraction of river geometry using HEC-GeoRas in ArcGIS 10

River geometry was extracted from the DTM using HEC GeoRAS, an extension in ArcGIS10. A total of 74 cross sections of about 4 km in length, riverbank profile, and bathymetric centerline were generated for the river. These data were exported to HEC-RAS 4.1 for flood simulation.

Manning's coefficient and flow data were also prepared. The vicinity of the river is mostly grassland which has a corresponding Manning's coefficient of 0.030. The result of the 5-year and a 25-year simulation is illustrated in Figure 13.

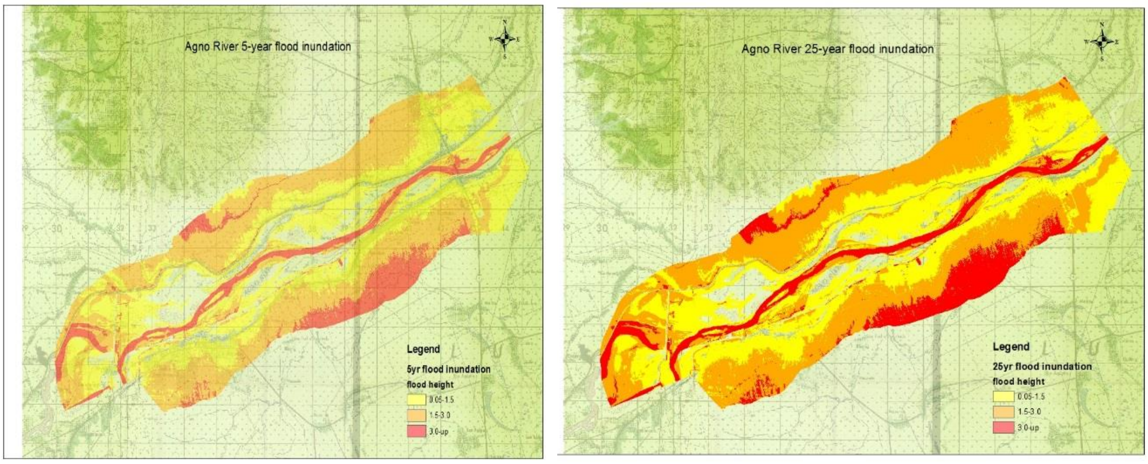


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Figure 13 (a) 5 year and (b) 25 year flood event caused by Typhoon Parma

a b

Figure 14 Flood simulation without bathy data (a) and without bathy data (b) for Agusan River

The difference of flood simulation with and without bathymetric data is shown in Figure 14. Note the difference of flood extent after three (3) hours for Agusan River in Mindanao.

5. Conclusions and Recommendations

Merging airborne LiDAR DTM with ground data such as validation and bathymetric points produces more realistic flood simulations. The output of this methodology is currently being utilized in a national level as aid for the local government's early flood warning systems in the 18 major basins in the country.

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BIOGRAPHICAL NOTES

Louie P. Balicanta is currently a faculty of the U.P. Department of Geodetic Engineering teaching land surveying and planning. He graduated B.S. Geodetic Engineering at the UP Department of Geodetic Engineering and M.A. in Urban and Regional Planning at the U.P. School of Urban and Regional Planning in UP Diliman. He is a licensed geodetic engineer involved in several industry and research projects. His research interests include land administration, urban and regional planning, GNSS application and surveying instrumentation.

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