FLOOD MODELING AND HAZARD MAPPING USING HYPOTHETICAL AND EXTREME RAINFALL EVENTS IN BUED-ANGALACAN RIVER BASIN, PANGASINAN, PHILIPPINES

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ABSTRACT: Flood is an obstinate problem that needs to be addressed in a more scientific way in order to prevent or lessen its costly impacts to properties and human lives. This project was proposed and implemented in response for this need. Using the Bued-Angalacan River Basin as the study area, a flood model was developed using a framework that utilized field observations, Geographic Information System (GIS), and Remote Sensing (RS). The flood model consists of two components. The first component deals with the upstream watershed hydrology, wherein a hydrological model based on HEC HMS was developed to estimate how much runoff is produced during a rainfall event. The second component deals with the river and flood plain hydraulics which aims to determine the behavior of water coming from the upstream watershed as it enters the main river and travels downstream towards the sea. This was done using HEC RAS. The combination of HEC HMS and HEC RAS resulted into a flood model that can be used for a variety of purposes, one of this is for simulation of flooding due to hypothetical extreme rainfall events. The outputs of the project are calibrated one dimensional flood hazard maps at different rainfall scenarios. Based on the generated hazard maps results indicate increase in flood affected areas as the return period increases.

1. INTRODUCTION

Natural disasters like typhoons or tropical storms are common incidence in the Philippines due to its geographical location. An average of 20 storms visit the Philippines which causes flooding in many parts of the country especially in low-lying areas. These floods are ruinous natural phenomena which result in copious losses of property, life, and damaging natural environment as well. Bued-Angalacan River is a major river in the island of Luzon located in the province of Pangasinan in the Philippines which contribute flood in the area. It covers primarily the provinces of Benguet and Pangasinan, and a few parts of La Union (Figure 1).

Flood Hazard Mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily-read, rapidly-accessible charts and maps which facilitate the identification of areas at risk of flooding and also helps prioritize mitigation and response efforts (Bapalu & Sinha, 2005). It typically provides a ‘snapshot’ of flood risk at a given point in time.

One of the most commonly used hydrologic and hydraulic modeling systems are the Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS) and HEC RAS (River Analysis System), respectively. HEC HMS is a generalized modeling system designed to simulate the precipitation-runoff processes of dendritic watershed systems with a wide range of applicability large river basin water supply and flood hydrology, and small urban or natural watershed runoff (USACE HEC, 2013). On other hand, HEC RAS is an integrated system of software designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels (Brunner, 2010). HEC RAS provides water surface levels at the cross-sections which can be converted into inundation extents by re-projecting the water levels onto a DEM through the use of GIS techniques (Horritt and Bates, 2002).

The objective of the study was to calibrate and generate one dimensional flood hazard maps through the use of combined HEC HMS and HEC RAS using hypothetical and extreme rainfall events in Bued-Angalacan River. Rainfall Intensity Duration Frequency Curves (RIDFs) of extreme rainfall events in Pangasinan areas have been generated by the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) through statistical analysis of historical data.

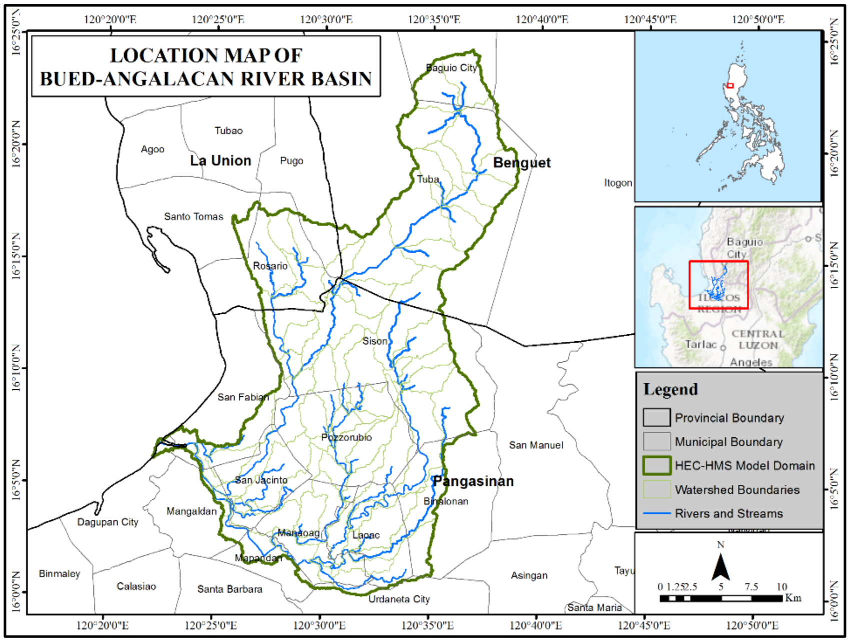

Figure 1. Location of the Bued-Angalacan river basin relative to the Philippines.

2. METHODOLOGY

2.1. Overview

Figure 2 shows the overview of the project's methodology. The SAR DEM, land cover and hydrologic data (discharge, river flow, water level and rainfall) are the major inputs in HEC HMS model calibration. The purpose of the HMS model was to determine the volume of water coming from the various sub-basins due to extreme rainfall events. After calibrating the HMS model, the RIDF's was used as an input parameters to compute discharge hydrograph at different return periods. Furthermore, 1m LiDAR DEM, land cover and calibrated discharge was then the primary inputs in HECRAS model. The purpose of this model is to determine the maximum flood extent and inundation levels due to rainfall events of different rainfall intensity. The output of the model is a flood hazard map.

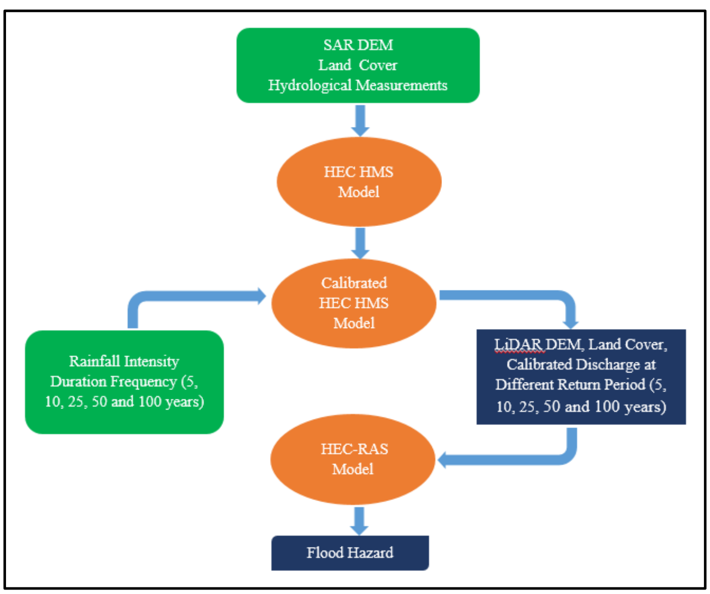

Figure 2. Framework for application of combined HEC HMS-HEC RAS for flood hazard mapping in Bued-Angalacan River Basin.

2.2. HEC HMS Model Development

The development of the HEC HMS model primarily involved the physical representation of watershed and streams within Bued-Angalacan river basin into hydrologic elements namely watersheds, reaches, and junctions interconnected in a network to simulate rainfall-runoff processes.

Modeling in HEC-HMS relies in three specific components: a basin model, a meteorological model, and a set of control specifications. HEC-HMS's preprocessor, HEC-GeoHMS, was used to prepare the basin model. The basin utilized the 10-m Synthetic Aperture Radar Digital Elevation Model (SAR DEM) acquired from University of the Philippines, Diliman, soil shape files from the Bureau of Soils and Water Management (Figure 3), land cover shape file from the National Mapping and Resource Information (Figure 4).

The basin model generated was exportedinto HEC HMS for final model set-up. The components of HEC HMS such as a meteorological model, time series data (rainfall and outflow/discharge) and set of control specifications indicating the simulation periods were constructed.

2.3. Calibration of HEC-HMS Model

The model simulates flow hydrographs was based on rainfall data recorded by Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) rain gauges located at the Municipality of Laoac and Binalonan, Pangasinan (Figure 5). The parameters of the model were calibrated by relating the simulated flow hydrographs to the actual measured flow (in m^3/s) in the river. The station utilized during HEC HMS model calibration was on Don Calimlim Bridge (16°1' 45.5118"N, 120° 27' 24.8499"E). Hydrological data necessary for calibration was gathered from this station last 10/01/2015 to 10/05/2015 with the use of water level and velocity meter with data logger together with the river cross-sectional data (Figure 6).

2.4.HEC RAS Model Development

Hydrologic Engineering Center River Analysis System (HEC RAS) model of Bued-Angalacan river was developed by first constructing a geometric representation of the rivers and their flood plains. This includes cross-sections, river banks, centerline, and the flood plain boundaries. The high resolution 1-m LIDAR DEM integrated with river bed data was used as the primary source of the cross-section data. The Manning's roughness coefficients *n*, were assigned to the cross-section segments using land-cover information from Bureau of Soils and Water Management. River banks, flow paths and centerlines were digitized from Google Earth.

HEC GeoRAS is the pre-processor of HEC RAS, and it basically prepares the model's geometric data. It is also used to assign basic model parameters. This geometric data is then imported in HEC RAS for further model setup.

The unsteady flow module of HEC RAS was used to determine the water surface profiles for flood inundation mapping. This type of simulation is made for varying flows in the river with respect to time. The boundary conditions used for the unsteady flow simulation were the discharge hydrograph for the upstream reach boundary and normal depth for the downstream reach boundary.

The calibrated HEC-HMS discharge generated from the 24-hour Rainfall Intensity Duration Frequency (RIDF) curves for Bued-Angalacan river provided by PAGASA would be the input parameters in HEC RAS modeling.

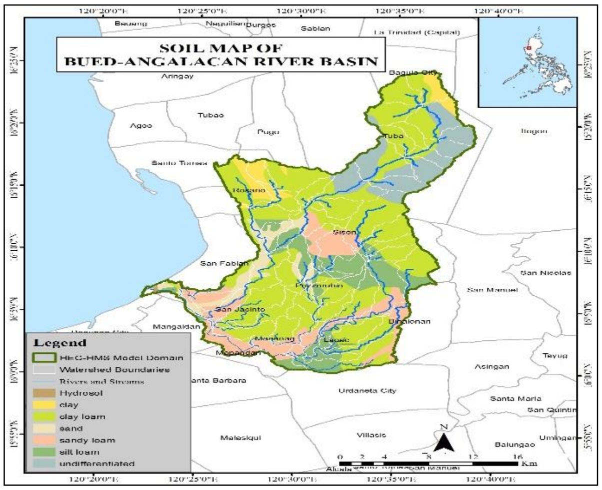

Figure 3. Soil map of the Bued-Angalacan River Basin. (Source of data: Digital soil map of the Philippines published by the Bureau of Soil and Water Management Department of Agriculture)

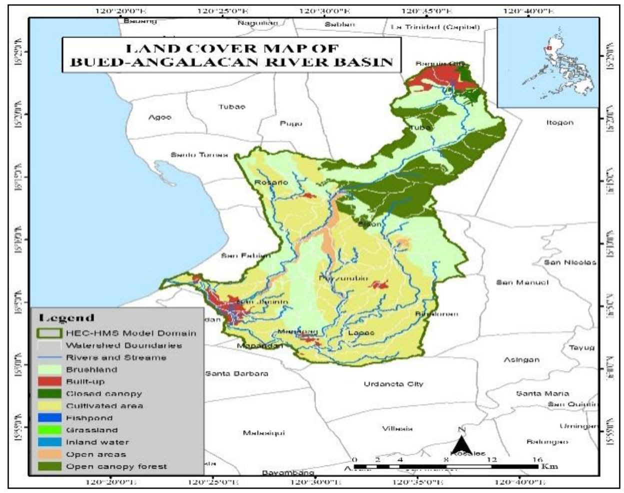

Figure 4. Land cover map of the Bued-Angalacan River Basin. (Source of data: National Mapping and Resource Information Authority)

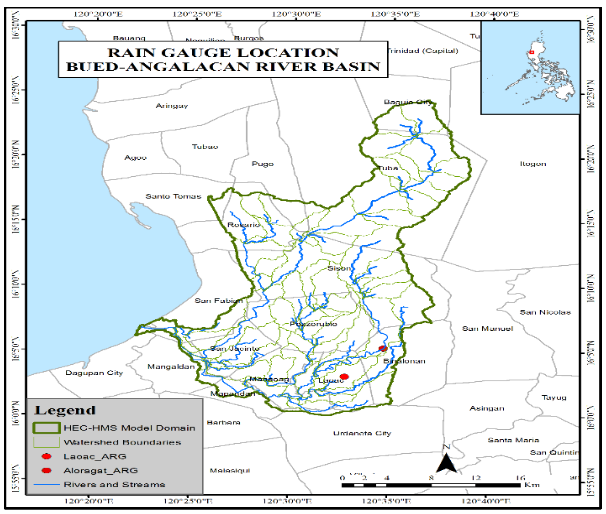

Figure 5. The location map of rain gauges used for the calibration of the Bued-Angalacan HEC-HMS model.

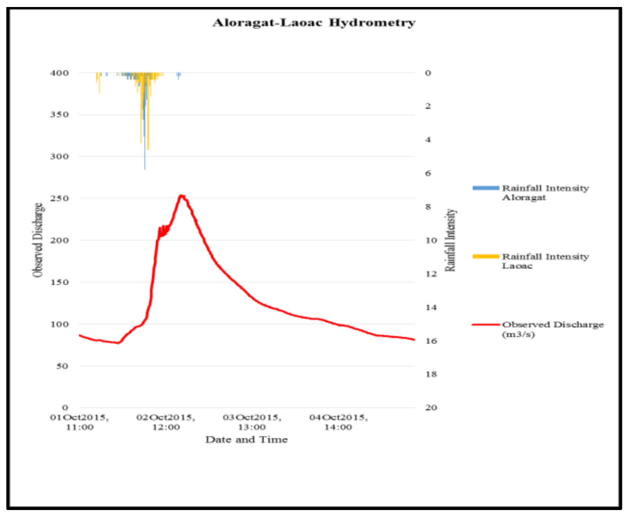

Figure 6. Rainfall and outflow data used for modeling at Mapandan.

2.5. Flood Hazard Map Generation for Different Rainfall Events

The simulated results was then post-processed in the RAS Mapper. The RAS Mapper option provides the maximum flood extent and inundation levels based on the hypothetical rainfall events. The generated depth float was then categorized based on its corresponding hazard level. The categorizations are: low hazard for depths of less than 0.50 m, medium hazard for depths from 0.50 m to 1.50 m, and high hazard for depths of greater than 1.50 m.

3. RESULTS AND DISCUSSION

3.1. Generated Basin Model

The basin model consisted of 69 watersheds (sub-basins), 34 reaches, and 34 junctions (including the main outlet). The delineated watersheds range from0.0428 to 29.817 km^2 in area, and with an average area of 8.879 km^2. Figure 7 shows the basin model map of Bued-Angalacan river basin.

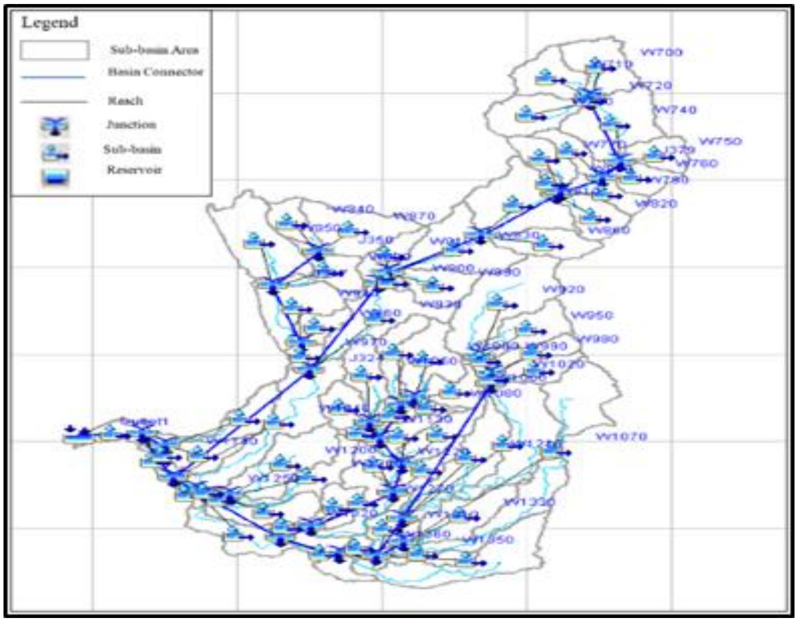

Figure 7. The Bued-Angalacan basin model showing the delineated watersheds/sub-basins, reaches and junctions.

3.2. HEC HMS Model Performance

After calibrating the Bued-Angalacan river basin HEC-HMS model, its accuracy was measured against the observed values. Figure 8 shows the comparison between the simulated and actual discharge data. The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 4.5 m^3/s. The Pearson correlation coefficient (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. The computed value of r^2 = 0.992 was acquired in this model. The Nash-Sutcliffe (NSE) 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 1.00.A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction and the optimal value is 0. In the model, the computed value for PBIAS is 0.50. The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0when the error in the units of the valuable are quantified. The model has an RSR value of 0.07. The results revealed that the three measurements of accuracy are within the limit of "very good" performance.

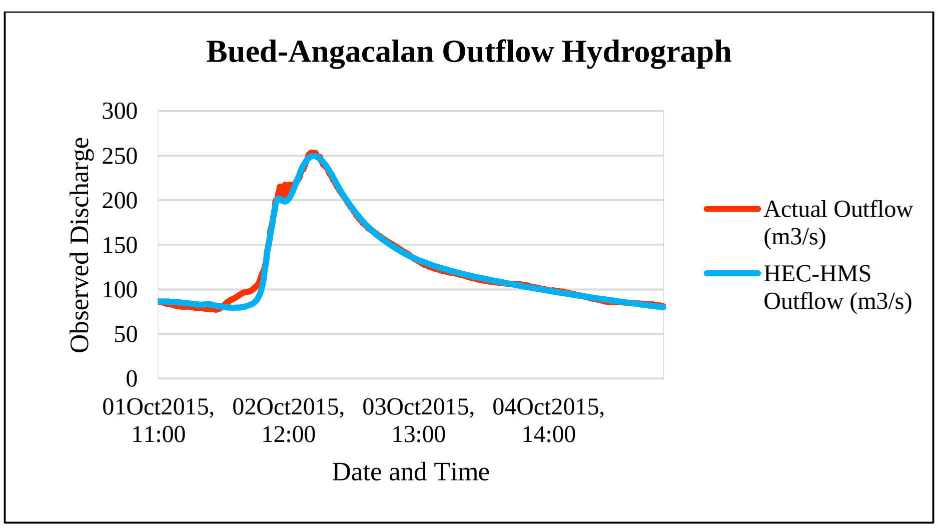

Figure 8. Outflow Hydrograph of Bued-Angalacan produced by the HEC-HMS model compared with observed outflow.

3.3. Model Outflow using Rainfall Intensity-Duration- Frequency (RIDF) Analysis Data

3.3.1. Pangasinan RIDF

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) computed the Rainfall Intensity Duration Frequency (RIDF) values for the Pangasinan Rain Gauge. This station was chosen based on its proximity to the Bued-Angalacan watershed. The extreme values for this watershed were computed based on a 48-year record.

Five return periods were used, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs as shown in Figure 9. All return periods were registered for 24 hours and the peak periods are noted after 12 hours.

3.3.2. Results using Rainfall Intensity Duration Frequency

The summary graph (Figure 10) shows the Bued-Angalacan outflow using the Pangasinan rainfall Intensity-Duration-Frequency curves (RIDF) in 5 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 (PAG-ASA) data. The simulation results showed significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

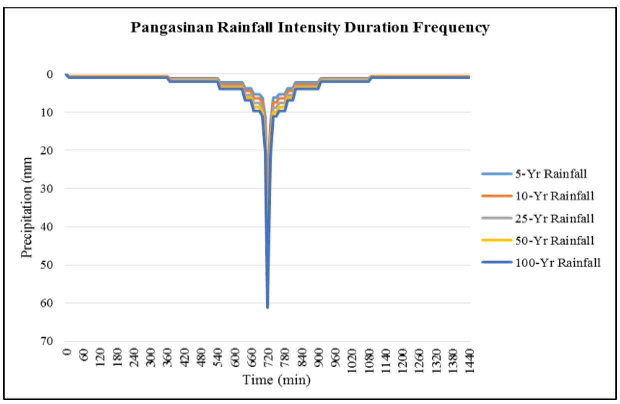

Figure 9. Pangasinan Rainfall-Intensity Frequency Duration (RIDF) curves.

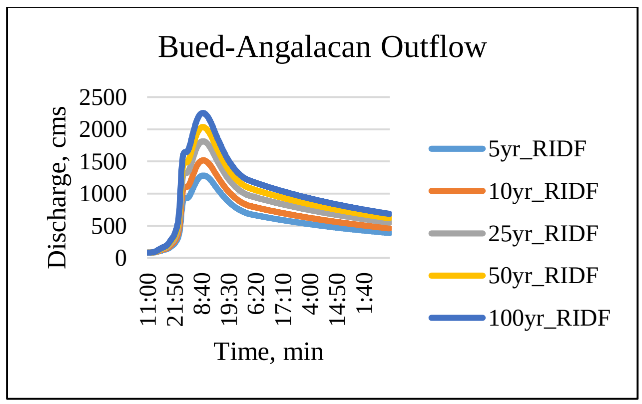

Figure 10. Bued-Angalacan Outflow -Using the Pangasinan Rainfall Intensity Duration Frequency (RIDF) Curves

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Bued-Angalacan discharge using the Dagupan RIDF in five (5) different return periods is shown in Table 1.

Table 1. Peak values of the Bued-Angalacan HEC-HMS Model outflow using the Pangasinan RIDF.

RIDF Period	**Total Precipitation (mm)**	**Peak rainfall (mm)**	**Peak outflow (m^3/s)**	**Time to Peak**
5-Year	246.7	33.9	1282.3	10 hrs. 20 min.
10-Year	293.6	40.5	1518.6	10 hrs. 20 min.
25-Year	352.9	48.9	1815.1	10 hrs. 20 min.
50-Year	396.8	55.1	2034.9	10 hrs. 10 min.
100-Year	440.5	61.2	2253.1	10 hrs. 10 min.

3.4. Geometric Representation

The geometric representation of Bued-Angalacan river has a total of 81 cross-section lines with an interval of 200 m as shown in Figure 11.

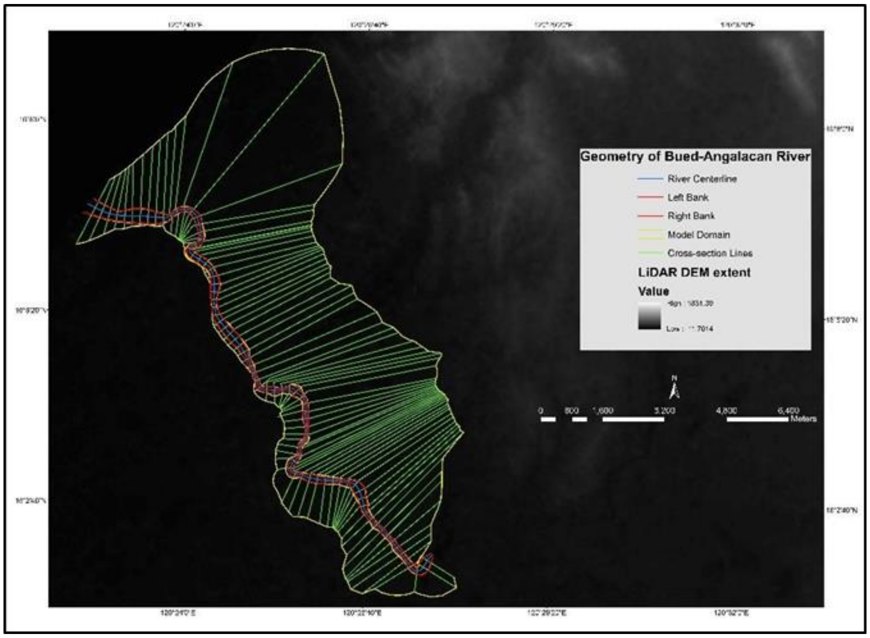

Figure 11. Geometric representation of Bued-Angalacan River

3.5. 1-D Simulated Flood Hazard Maps due to Hypothetical, Extreme Rainfall Events

The flood hazard maps of Bued-Angalacan River according to the rainfall return periods are shown in Figures 12-16. Most of the barangays affected by flood were found in the downstream portions of Bued-Angalacan river located in municipality of San Fabian province of Pangasinan. Flooding in these areas was found to be significant with 5-100 year return period, particularly in barangays Poblacion, Nibaliw Vidal, BonuanBinloc, Langos-Amagonan, Cayanga, Nibaliw Central, Tempra-Guilig, Tocok, Sobol, Cabaruan, Sagud-Bahley, and Lekep-Butao. These areas have low to high flood hazard levels. Result revealed that the municipality of San Fabian dominated the largest area affected by flood in all return periods as presented in Table 2. A news published on July 19, 2015 stated that 35 barangays in 9 towns and cities in Pangasinan including San Fabian were flooded caused by two weeks of continuous monsoon rains (Locsin, 2015). Typhoon Pepeng in October, 2009 devasted Northern Luzon wherein many houses in Pangasinan were washed out from the destructive typhoon which forced a number of families to flee their homes (Merueñas, 2009). Figure 17 shows the flooded subdivision in San Fabian, Pangasinan captured through Storm watch.

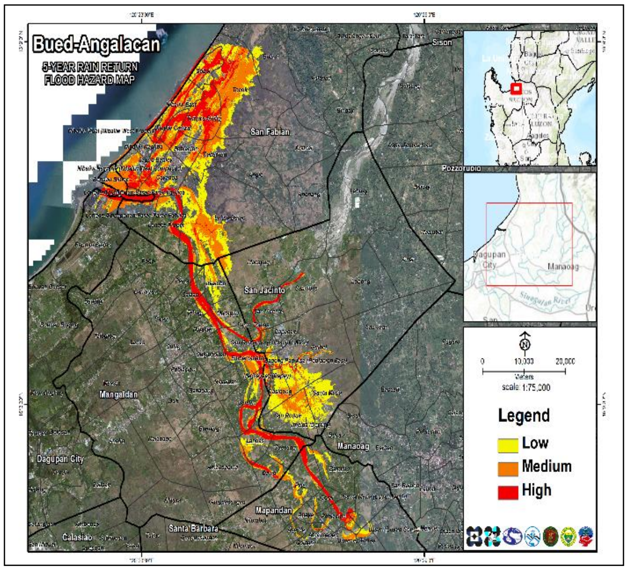

Figure 12. 1D-Simulated flood hazard map of Bued-Angalacan River Basin for a 5-year rainfall event

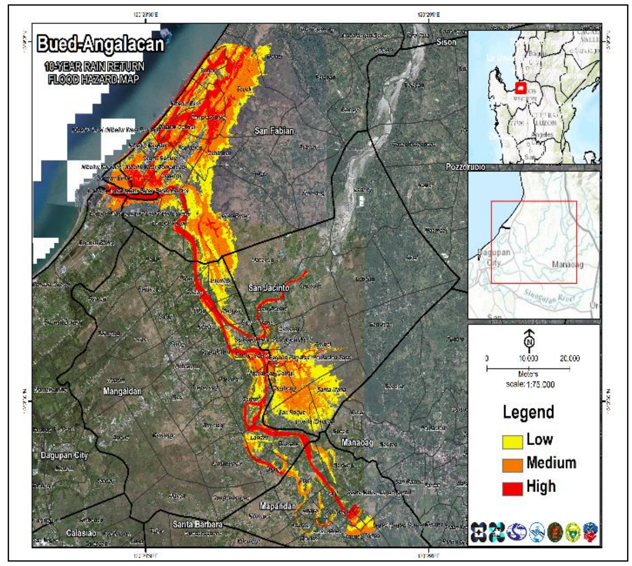

Figure 13. 1D-Simulated flood hazard map of Bued-Angalacan River Basin for a 10-year rainfall event

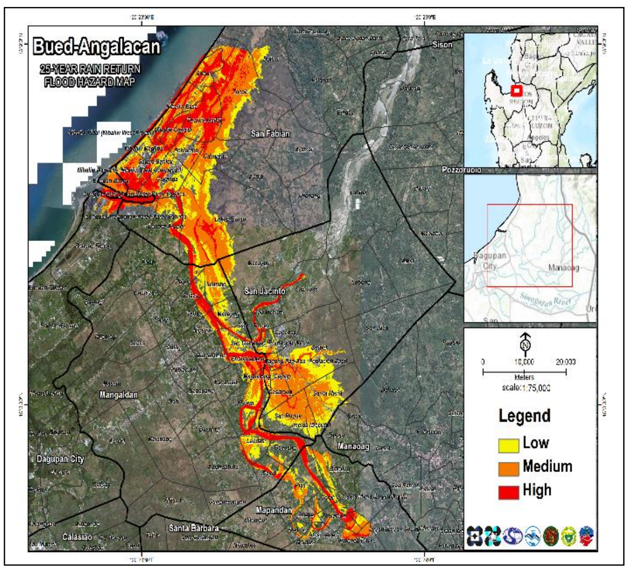

Figure 14. 1D-Simulated flood hazard map of Bued-Angalacan River Basin for a 25-year rainfall event

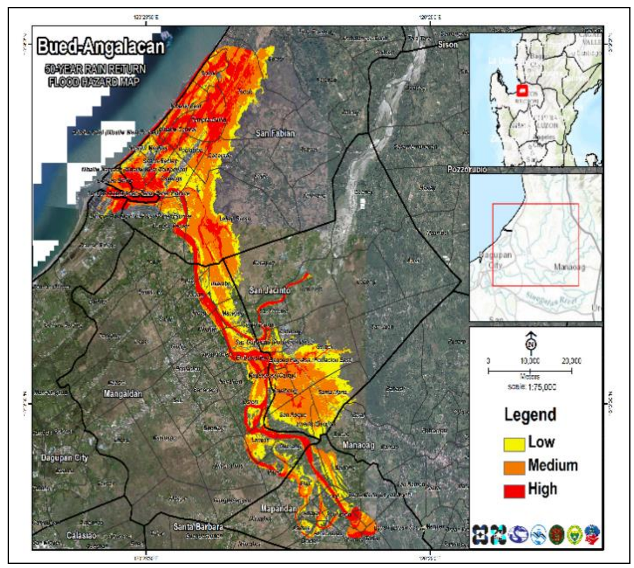

Figure 15. 1D-Simulated flood hazard map of Bued-Angalacan River Basin for a 50-year rainfall event

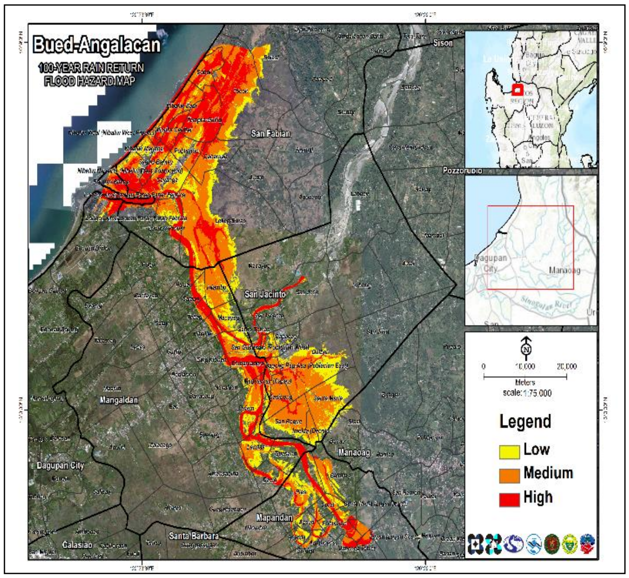

Figure 16. 1D-Simulated flood hazard map of Bued-Angalacan River Basin for a 100-year rainfall event

Figure 17. Floods triggered by Pepeng swallow a Subdivision in San Fabian, Pangasinan. Pablo Erfe (Merueñas, 2009)

Table 2. Area (Km^2) of Municipalities affected by flood at different return period.

RIDF	**Category**	**Municipalities of Pangasinan**					
		Dagupan City	Manaoag	Mangaldan	Mapandan	San Fabian	San Jacinto
5 - year	**Low**	0.06	0.00	0.95	0.44	3.59	2.25
	Medium	0.40	0.00	0.75	0.43	4.65	0.99
	High	0.08	0.00	1.43	0.37	2.70	0.34
10 - year	**Low**	0.05	0.01	1.38	0.58	3.53	2.29
	Medium	0.40	0.00	1.01	0.65	5.45	1.92
	High	0.10	0.00	1.55	0.42	3.27	0.41
25 - year	**Low**	0.05	0.03	1.74	0.78	3.14	2.25
	Medium	0.31	0.00	1.44	0.93	6.33	2.87
	High	0.21	0.00	1.70	0.56	4.02	0.52
50 - year	**Low**	0.05	0.06	1.77	0.91	2.74	2.15
	Medium	0.24	0.00	1.82	1.09	6.70	3.48
	High	0.29	0.00	1.81	0.71	4.66	0.61
100 - year	**Low**	0.05	0.09	1.67	1.01	2.35	2.02
	Medium	0.20	0.00	2.22	1.28	6.90	3.98
	High	0.35	0.00	1.93	0.84	5.28	0.72

4. CONCLUSIONS AND RECOMMENDATION

The model was found to have a "very good" performance in predicting discharge hydrographs at the upstream station located in Mapandan, Pangasinan.

The hazard maps of Bued-Angalacan river indicate increase in flood affected areas as the return period increases. Most of the areas that will be affected by the flood is in the town of San Fabian which is located at the downstream portion of the river basin.

The flood hazard maps would provide important information for preparation, evacuation, and damage estimation. The maps also indicate which areas are to be avoided if such flood events are expected to occur.

Validation of generated flood hazard maps at different return periods is recommended to make it more reliable.

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