

Hydrologic Model for Flooding in Manupali Watershed and Its Implications to Land-Use Policies

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Abstract

Flooding has become a recurring event in the Province of Bukidnon, causing severe destruction to houses, buildings, infrastructure, and livelihood. Since the province is not exempted in flooding events as an impact of typhoons, understanding the watershed hydrologic behavior is essential for vulnerability and risk assessment as to disaster preparedness and risk reduction. The study aims to analyze the hydrologic response of Manupali watershed through flood hazard maps, hydrologic, and hydraulic models. This paper presents the combination of geographic information system, high-resolution digital elevation model (DEM), land cover, observed hydro-meteorological data, and the combined hydrologic engineering center-hydrologic modeling system and river analysis system models. The hydrologic model assesses the relationship between rainfall and discharge of the watershed and the hydraulic model computes the flood depth and flow pattern in the floodplain. Upon calibration, the over-all performance of the hydrologic model was rated *very good* in its performance based on the standards set by Moriasi et al. (2015) with index values of 0.89, 0.75, 0.46. The calibrated hydrographs were used to produce flood hazard maps in 2, 5, 10, 25, 50, and 100-year return periods, and assessed the number of flooded buildings in each flood hazard level per return period. The flood hazard maps may contribute to science-based land-use policy formulation, land-use zoning, planning, and management to mitigate extreme rainfall-induced flood risks in the affected barangays in the Manupali watershed.

Introduction

Flooding has become a recurring event in the Province of Bukidnon. For the last ten years, two intense tropical cyclones hit some parts of Bukidnon. Typhoon-induced floods and landslides in the province are usually attributed to heavy rainfall or precipitation events. These hydrological disasters cause severe destruction not only to houses, buildings, infrastructures, and livelihood that leave a devastating traumatic experience to humans. Valencia City is one of the localities identified as flood-prone in Bukidnon (Mines and Geosciences Bureau 10, 2008). It

is attributed to its topography and the river systems that drain in the area. In Malaybalay City, areas of Bangcud and the flood plains of Barangays Managok-Simaya areas are identified as flood-prone areas (CLUP-Malaybalay). One of the river systems draining in Valencia and Malaybalay is the Manupali Watershed in Lantapan, Bukidnon. Given these facts, the study assessed the extent of flooding impact to select barangays in Valencia and Malaybalay Cities through flood modeling, simulation and mapping.

Globally, flood hazard mapping and modeling are the recent advances and recommended practices to address risks and disasters (Schumann et al., 2018). Using GIS and other flood simulation tools, these activities are essential in disaster prevention, mitigation, and preparedness following the implementation of the four-priority areas of the Philippine National Disaster Risk Reduction and Management Plan based on RA 10121 (NDRRM Plan 2011-2028). It helps to support the decision-making process of government officials regarding disaster risk reduction, management, land-use planning, and management. In the Disaster Risk and Exposure Assessment for Mitigation (DREAM) Research Program of the University of the Philippines, flood modeling components highlighted the program utilizing the cutting-edge technology such as Light Detection and Ranging (LiDAR), a new spatial data acquisition system. The LiDAR generates updated and high-quality flood maps and models. The use of LiDAR provides an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping with 50cm and 20cm for horizontal and vertical accuracies (Paringit & Puno, 2017). This conforms to the claim of Lindsay & Dhum (2015) that LIDAR-derived DEM is appropriate in flood modeling due to its high vertical accuracy and resolution in capturing details of the modeled terrain and produce high-quality results in the LiDAR-DEM data pre-processing. It is for this reason that flood modeling has become a typical method in simulating flood scenarios and inundation maps to effectively identify areas to be monitored.

In the Province of Bukidnon, Manupali watershed is one of the critical watersheds in the southern Philippines. The watershed provides water for various users (Egnar et al., 2017). It receives an average monthly rainfall of 224.54mm. It has 220 streams traversing a total of 636,000 meters and draining approximately 40,000-60,000 hectares of land into the Pulangi River (Bellows et al. 1995). It covers the entire municipality of Lantapan and portions of Talakag and Valencia (Lantican et al., 2003). Hence, these areas are identified as one of the flood-prone areas in Bukidnon (Mines & Geosciences 10). Various notable flood-risk

studies utilizing the same tools and technologies (i.e. LIDAR) (Puno et al., 2015; Paringit & Puno, 2017; Puno et al., 2018; Oganía et al., 2019; Talisay & Amper, 2019) were conducted in the major watersheds in Bukidnon. The scope of flood risk studies varies from watershed to river basin level. Oganía et al. (2019) assessed the Taganibong Watershed of Bukidnon, while Paringit and Puno (2017) presented flood models and hazard maps in greater scope, the Upper Pulangi River Basin where Manupali is one of its major tributaries. Talisay and Amper (2019) visualize the extent and mitigate the impacts of flood hazards in Malingon River in Valencia City, Bukidnon. Puno et al. (2018) has developed flood models specific for Manupali Watershed using the flood event in Bukidnon in May 23, 2016. It has simulated flood events in three flood return periods detailing the flood extent, inundated sites, and exposure analysis. In 2015, Puno et al. (2015) had a morphometric analysis of the flood prone sites in Bukidnon watersheds including the Manupali watershed. Given these current information and understanding in Manupali watershed and other watersheds and river basins in the Province of Bukidnon, the study addressed the gaps of these studies and provided new information particularly in Manupali watershed using a different and updated flood event. The use of this updated meteorological data and flood event tested the flood model performance of the study. The study also expanded the flood simulation events from three (5, 25, 100-Year) to six flood return periods (2, 5, 10, 25, 50, 100) to see a clear picture of flood extent and depth as the return period increases.

To address these gaps, the hydrologic response of Manupali watershed through flood hazard maps, hydrologic and hydraulic modeling, and simulation were undertaken using the combined tools of GIS, HEC-HMS, HEC-RAS, high resolution DEM, land cover, and updated hydro-meteorological data.

Objectives of the Study

Generally, the study aimed to assess the flood hazards in Manupali Watershed through combined hydrologic, hydraulic modeling, and

Geographical Information Systems. Specifically, the study aimed to:

- (1) simulate a synthetic hydrograph model and delineate inundated sites in the identified flood-prone areas using HEC-GeoHMS, HEC-GeoRAS, and GIS tools;
- (2) assess the interaction between a flood hazard and the spatial and built environment; and
- (3) recommend land-use policy vis-à-vis flood-affected areas.

Materials and Methods

Study Area

The Manupali watershed covers the Municipality of Lantapan, a portion of Talakag, and few parts of Valencia City in Bukidnon. This 50,553-hectare watershed is geographically situated between $7^{\circ}58'38.93''$ to $8^{\circ}13'50.16''$ north latitudes and $124^{\circ}55'7.81''$ to $125^{\circ}14'26.85''$ east longitudes (Puno et al., 2018). The watershed consists of four major tributaries, namely Tugasan, Maagnao, Alanib, and Kulasihan. Manupali watershed, shown in Fig. 1, is tributary of a relatively more significant Pulangi watershed and Rio Grande de Mindanaos (Pradhan et al., 2016; UPLB, 2017). Kalatungan and Kitanglad mountains ranges declared as protected areas and prominently known as the ancestral domain of three major indigenous tribes, the Talaandig, Higaonon, and Bukidnon, serve as a headwater source for Manupali watershed (DENR & B+WISER, 2015; Canoy & Suminguit, 2001; DENR-FMB & Asian Development Bank, 2018).

The watershed of Manupali traverses the City of Valencia within barangays of Mailag, Colonia, San Carlos, Lurogan, and Mt. Nebo, Municipality of Lantapan within the barangays of Lantapan, Kulasihan, Bantuanon and Poblacion, and the City of Malaybalay, Bukidnon within barangays of Sto. Niño and Bangcud. As a core agri-based center of the province, the large-scale plantations of corn, banana, pineapple, and sugarcane consume the downstream portions of the watershed. Generally, the economy of the province of Bukidnon relies on farming, fishing, trade, and commerce. Rice, corn, sugar coffee, and cassava

are the provinces' primary produce (Province of Bukidnon Brief Information, 2014). Furthermore, the river provides irrigation to immense rice fields in Valencia City. With the increasing population and land use conversions follows increased runoff and flood hazards in the river along with the neighborhood, river channels and floodplains.

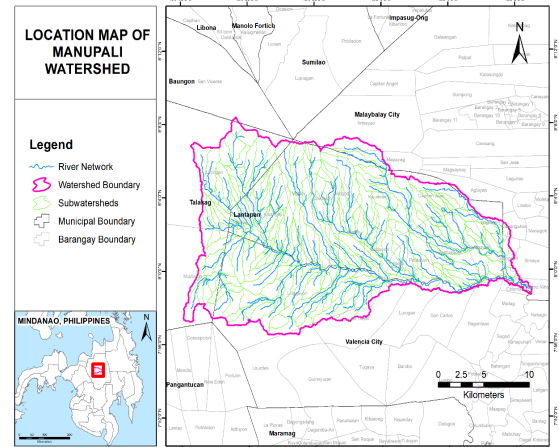


Fig. 1. Generated map of the Manupali Watershed.

Affected by flooding in the past years are barangays of Bangcud, Colonia, Aglayan of Malaybalay City, considered floodplains of Manupali River. Among the recent flood incidents comprise August and December 2007 events, Typhoon Pablo in December 2012, in October and September of 2012, and October of 2013 (NDRRMC, 2012). The tail-ends of the cold front on January 19, 2017 triggered floods in the parts of Mindanao, including eight (8) barangays in the City of Valencia in Bukidnon (Lagsa, 2017). A total of 52,350 residents in the barangays in Lantapan, Malaybalay, and Valencia were among the vulnerable people as they reside within the immediate vicinity of the river, according to the Philippine Statistics Authority (PSA) 2015 National Census.

Flood Modeling Framework

This flood modeling study covers two distinct models: hydrologic and hydraulic models using the Hydrologic Engineering Center- Hydrologic Modeling System (HEC-HMS) and HEC- River Analysis System (RAS)

for Manupali watershed, respectively. The HEC-HMS, created by the US Army Corps of Engineers (2015), is a numerical modeling system designed to simulate watershed and channel behavior.

The hydrologic model determines the amount of rainfall-runoff processes of watershed runoff (USACE-HEC, 2010). The actual hydrologic data, such as rainfall and discharge, were utilized to calibrate the hydrologic model. The accuracy of the hydrologic model was also examined. HOBO RG3 Data Logging rain gauge was used for rainfall data.

A 2D hydraulic model was then performed in the study. The hydraulic model simulates the flows and precipitation into the river basin system and floodplain areas (USACE, 2015).

The hydraulic model that deals with the flow of water along the terrain was developed using the Light Detection and Ranging (LiDAR) Digital Elevation Model (DEM) extracted by the RAS layers of HEC-Geographical River Analysis System (HEC-GeoRAS). The RAS layers compose the geometry of the model. The HEC-GeoRAS, an extension in ArcGIS, was utilized to create the HEC-RAS 2D flow geometry consisting of the river storage areas and break lines that were exported to HEC-RAS in a RAS file format. Using the calibrated hydrologic model, a 2D hydraulic simulation

was conducted to create a flood depth grid. Validation points for the accuracy test of the 2D hydraulic model in predicting floods were used to validate the generated flood depth grid. Flood simulations were then conducted using different return periods such as 2, 5, 10, 25, 50, and 100-year. Maximum flood depths were determined from each return period flood simulation. The depth grid was then exported as a raster file, processed, and converted into flood hazards by classifying depth grids ranges that correspond to flood hazard levels. The depth grids range from <0.5, 0.5- 1.50 m, and >1.5 m for low, medium, and high flood hazards.

Exposure assessment (i.e., number of affected buildings) then followed. Shown in Fig 2 is the flood modeling framework adapted from Talisay et al. (2019). The oval-shaped indicates the input, rectangular-shaped as a process, and the hexagonal shaped as output.

Hydrologic Model Development and Model Calibration

The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) is an application that simulates the rainfall-runoff relationship in a watershed with an existing condition. The same software application of version 4.0 was utilized to generate the hydrologic model of Manupali watershed. The model comprises the basin model of the

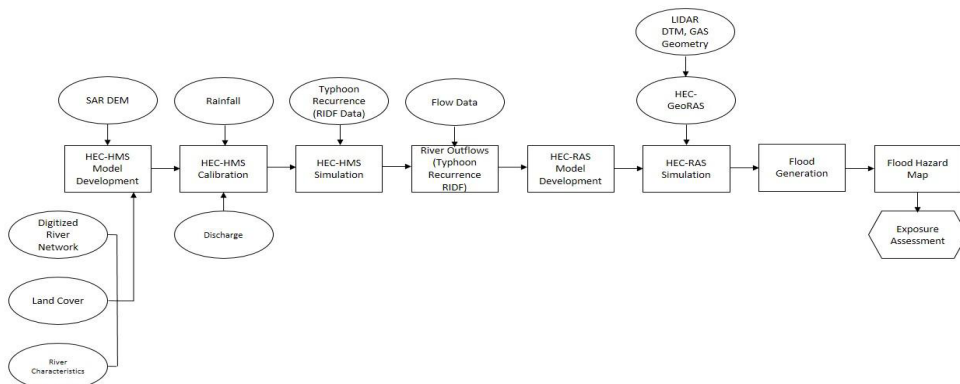


Fig. 2. Process flow of flood modeling.

physical watershed, a meteorological model for weather data, and a set of control specifications representing the computational time settings and simulation periods.

To create the basin model of the Manupali physical watershed, the following data inputs were utilized, namely (i) 10-meter Synthetic Aperture Radar- Digital Elevation Model (SAR-DEM) secured from National Mapping and Resource Information Authority (NAMRIA), (ii) digitized Manupali watershed networks using Google Earth for watershed delineation, (iii) classified land cover map from Sentinel-2 image of United States Geological Survey (USGS) Earth Explorer (CMU LiDAR, 2016) and (iv) river characteristics from LiDAR 1 Data (CMU LiDAR 1, 2016). Classification of the land cover using the satellite image from USGS Earth explorer follows the processing framework of Mueller-Wilm (2017). The generation of the classified land cover map follows the process of error analysis to assess the accuracy of land cover classes.

For the meteorological model, the observed hydro-meteorological data such as rainfall and discharge were used as inputs for the model. The same sets of data were used for hydrologic model simulation. The rainfall data were obtained using recorded data from HOBO RG3 Data Logging rain gauge pre-installed at the upstream of the Manupali watershed, particularly at Barangay Songco, Lantapan, Bukidnon. The discharge data were gathered using the mechanical flow meter and automatic HOBO U20 water level data logger installed at Manupali bridge. The Manupali bridge is a boundary of Barangays Bangcud and Colonia, and this area serves as a catch basin of the Manupali watershed. These actual hydrologic data were collected during the rain episodes of July 31 to August 1, 2018.

The August 31, 2018 data recorded at 12:20, 14:40, and 16:00 hours were used for the hydrologic model calibration. Three accuracy measures were used to evaluate the model calibration, and these are the (i) Nash Sutcliffe Coefficient of Model Efficiency (NSE), (ii) Percentage Bias (PBIAS), and the (iii) root mean

square error-observations standard deviation ratio (RSR).

The NSE is a normalized measure (-integer to 1.0) that compares the mean error generated by the particular model calibration to the variance of the target output sequence. A value of 1.0 NSE specifies perfect model performance where the model completely simulates the target output. A value of 0 NSE indicates the model is performing similar to the mean target value as a prediction on the average (Nash & Sutcliffe, 1970).

Gupta et al. (1999) describe how PBIAS accuracy measure works. The PBIAS measures affinity of the simulated values to be larger or smaller than the observed ones. The optimal PBIAS value is 0.0. Low magnitude PBIAS values indicate model overestimation bias, while negative values indicate underestimation bias.

The root mean square error (RMSE), as described in Golmohammadi et al. (2014) indicates a perfect match between observed and predicted/simulated values when it equals 0. However, increasing RMSE values indicate an increasingly poor match. RMSE values less than half the standard deviation of the observed (measured) data that are considered low and indicative of a good model prediction (Singh et al., 2004). The RMSE-observations standard deviation ratio (RSR) is calculated as the ratio of the RMSE and standard deviation of measured data. RSR fluctuates from the optimal value of 0 to a large positive value. The lower RSR and the lower the RMSE, the better the model simulation performance (Golmohammadi et al., 2014; Moriasi et al., 2007).

Hence, these three quantitative statistics, NSE, PBIAS, and RSR, are the recommended measures for the accuracy of model calibration and model performance evaluation (Moriasi et al., 2015). These statistical measures were used to assess the accuracy of a hydrologic simulation comparing the simulated and observed hydrographs. The statistical criterion for model performance evaluation is shown in Table 1.

Table 1.
Model Performance Evaluation (Moriassi et al., 2015).

Remarks	Statistical criterion		
	NSE	PBIAS (streamflow)	RSR
Very good	$0.75 < NSE < 1.00$	$PBIAS < \pm 10$	$0.00 < RSR < 0.50$
Good	$0.65 < NSE < 0.75$	$\pm 10 < PBIAS < \pm 15$	$0.50 < RSR < 0.60$
Satisfactory	$0.50 < NSE < 0.65$	$\pm 15 < PBIAS < \pm 25$	$0.60 < RSR < 0.70$
Unsatisfactory	$NSE < 0.50$	$PBIAS > \pm 25$	$RSR > 0.70$

The Rainfall Intensity Duration Frequency (RIDF) data from Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) were used to simulate hypothetical rainfall events. RIDF is a set of information on the likelihood of a rainfall event or referred to as return periods with different rainfall amounts and durations. For instance, the two-year return period likelihood of a rainfall event was computed as $(1/2) * 100\% = 50\%$ chance probability that a typhoon could occur in a given year. For the hydrologic simulation of hypothetical scenarios in the model, the RIDF of PAGASA Weather Station of Malaybalay was utilized (Table 2). Table 2 shows that the volume of rainfall increases as the return period increases. For instance, in a two-year return period, the minimum and maximum rainfall amount for a rainfall duration of five minutes and 24 hours of continuous rain are 9.0 mm and 112.8 mm, respectively. While a 100-year return period of the same rainfall duration shows a higher amount of rainfall, 5-min rain has 25.4mm while the 24h shower has 265.3mm of rain.

Manupali watershed, the Hydrologic Engineering Center River Analysis System (HEC-RAS) was used. It is designed to perform one-dimensional (1D), two-dimensional (2D), or combined 1D and 2D hydraulic calculations for the constructed channels and complex river systems (USACE, 2016). The model is comprised of four boundary conditions in which one inflow representing the discharge from the upstream river. The use of break lines or the abrupt changes in elevation, denotes the roads and river banks, the 2D flow

Table 2.
Values of the Different Hypothetical Rainfall Events Based on Malaybalay RIDF Data.

Return periods (Year)	Rainfall Amount in different duration (mm)							
	5 min	15 min	1 h	2 h	3 h	6 h	12 h	24 h
2	9.0	21.4	47.8	63.7	73.5	90.2	103.4	112.8
5	13.4	34.0	78.4	100.8	114.3	130.2	143.2	153.6
10	16.3	42.4	98.6	125.3	141.4	156.7	169.6	180.7
25	20.0	52.9	124.1	156.3	175.5	190.1	202.8	214.8
50	22.7	60.8	143.0	179.3	200.9	214.9	227.5	240.2
100	25.4	68.6	161.8	202.2	226.0	239.5	252.0	265.3

Two-dimensional Hydraulic Model Development

To create the hydraulic model of the

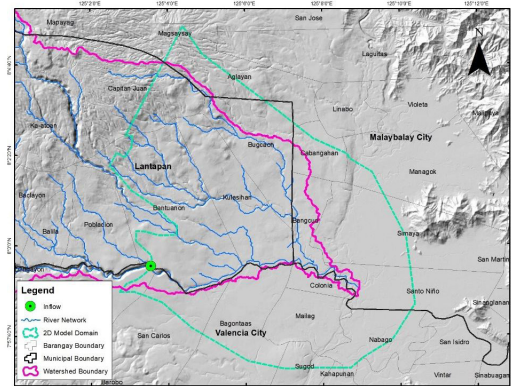


Fig. 3. Generated 2D floodplain domain of Manupali Watershed.

area was computed to create the computational mesh or cells. The 1-m resolution terrain model was utilized as the primary source of elevation data. Parameterization of the HEC-RAS model utilized the land cover information by extracting the Manning’s roughness coefficients that were used to calculate the hydraulic table properties of the flood simulation area. Figure 3 below shows the 2D floodplain domain of the Manupali Watershed generated through HEC-RAS.

Flood Depth Generation and Hazard Classification

Representing the flow hydrograph that enters the hydraulic model is one inflow boundary condition location. The flow analysis module of HEC-RAS was applied, and the unsteady simulated flow hydrographs coupled with the precipitation data were used to generate flood depth and extent. In every simulation of each return period, maximum flood depth grids were created. The flood depth created were exported into the GIS software and categorized into flood hazards which corresponds to various levels (low hazard: less than 0.50 m, medium hazard: 0.50 to 1.5 m, and high hazard: greater than 1.5 m).

Scenario flood simulation and flood exposure assessment

Using different rainfall scenarios, output hydrographs from the calibrated HMS model of Manupali watershed were utilized as input from the validated 2D RAS model together with a land cover map for the roughness coefficient. The generated flood depth grids were classified according to varying flood hazards that repeat the process.

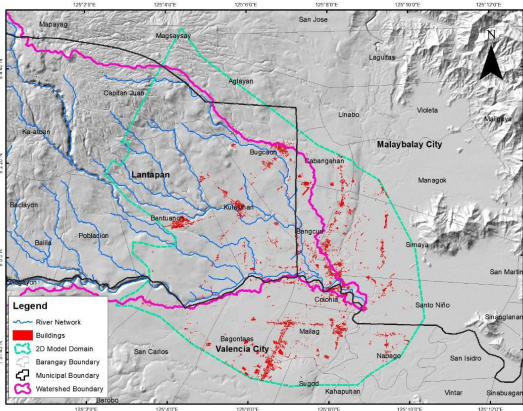


Fig. 4. Extracted building features within the generated 2D floodplain domain of Manupali Watershed.

The extracted features of the Manupali watershed from the 1m high-resolution LiDAR-derived DSM and the flood hazard maps of different rainfall scenarios were used for flood exposure assessment. The extracted features

refer to ground structures that include buildings or houses only. A total of 11,532 buildings structures were extracted within the 2D floodplain domain of the Manupali watershed (Figure 4). Overlay analysis was performed to determine the number of buildings exposed to the flood hazards. The 1m high-resolution LiDAR data was gathered by UP Diliman in 2016 (CMU LiDAR Project Report).

Results and Discussions

Manupali Watershed HEC-HMS Model

Rainfall and discharge data are significant data requirements for HEC-HMS Modeling. The actual rainfall and discharge data within the Manupali watershed were gathered during the rainy months of July and August 2018. The lower part of the Manupali watershed is characterized by high relative humidity and with rainy season from May to October (Rola et al. 2004). Figure 5 shows the actual data on rainfall and discharge observed during these months. Three rainfall peaks were recorded on July 31, 2018 : 12:20h at 1.2 mm, 14:40h at 1.4 mm, and 16:00h at 1 mm. Peak discharge was recorded on August 1, 2018, at 1:10 h at 19.1536 m³/s. These actual data were used as input for hydrograph (precipitation-runoff) simulation through the HEC-HMS model.

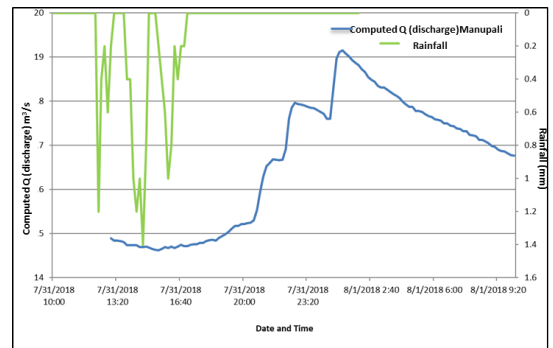


Fig. 5. Hydrograph for observed rainfall and discharge data collected with in Manupali watershed.

The rainfall and discharge data were gathered from Barangay Songco, Lantapan, and river sites under Manupali Bridge, respectively. The same data sets were used for HMS model calibration. Prior to the calibration of the hydrograph model, the observed and simulated

discharge data shows a great difference (Fig.6). This explains the unsatisfactory performance rating (values exceeds the optimal value) of the model after subjecting it to three quantitative accuracy statistics and model performance evaluation defined by Moriasi et al. (2007). Hence, the need for HMS model calibration to have an accurate hydrograph discharges simulation.

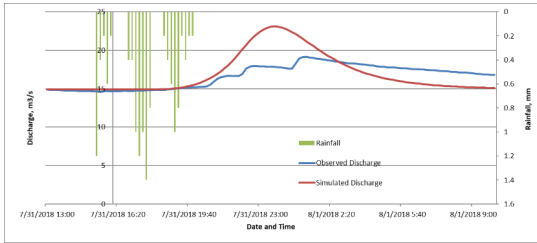


Fig. 6. Hydrograph of observed and simulated discharge in an uncalibrated HMS model.

Upon calibration, the efficiency of the model improved to a *very good* performance rating with index values of 0.89, 0.75, and 0.46 for NSE, PBIAS, and RSR, respectively. A value close or equal to 1.0 NSE specifies perfect model performance where the model completely simulates the target output (Nash and Sutcliffe, 1970). The optimal PBIAS value is 0.0. Low magnitude PBIAS values indicate model overestimation bias, while negative values indicate underestimation bias (Gupta et al., 1999).

The root mean square error (RMSE), as described in Golmohammadi et al. (2014) indicates a perfect match between observed and predicted/simulated values when it equals 0. The RMSE-observations standard deviation ratio (RSR) is calculated as the ratio of the RMSE and standard deviation of measured data. RSR fluctuates from the optimal value of 0 to a large positive value. The lower RSR and the lower the RMSE, the better the model simulation performance (Golmohammadi et al., 2014; Moriasi et al., 2007).

The very good performance rating of the HMS model prompts for rainfall-discharge simulation using the different hypothetical

rainfall events based on Malaybalay RIDF data against the actual data. As assessed, the simulated discharge data are close to the observed discharge data (Fig. 7). A lag time of 11 hours and 10 minutes was recorded before the highest discharge occurred. This explains why the maximum rainfall and peak river discharge is significant information in a given community. This is when the community prepares for possible evacuation and other disaster risk mitigation measures.

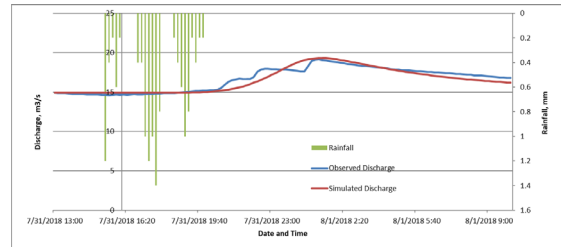


Fig. 7. Calibration Result of Manupali Watershed HEC-HMS model using the observed discharge.

Manupali Watershed HEC-RAS Model

HEC-RAS was used for hydraulic simulations to obtain flood depth information and converted to flood hazard categories, i.e., low (depth < 0.5 m), medium (0.5 m < depth < 1.5m), and high (depth > 1.5 m). The maximum rainfall in 24 hours and the probability of occurrence for each return period in a year of Malaybalay RIDF data was used for hydraulic modeling and simulations (Table 3).

Table 3.

Maximum rainfall and probability of occurrence in each flood return period

Flood Return Period	Maximum rainfall (mm) in 24 hours	Probability of occurrence in a year
2-year	112.8	50%
5-year	153.6	20%
10-year	180.7	10%
25-year	214.8	4%
50-year	240.2	2 %
100-year	265.3	1%

Flood scenario-building interaction was done using the flood hazard maps through

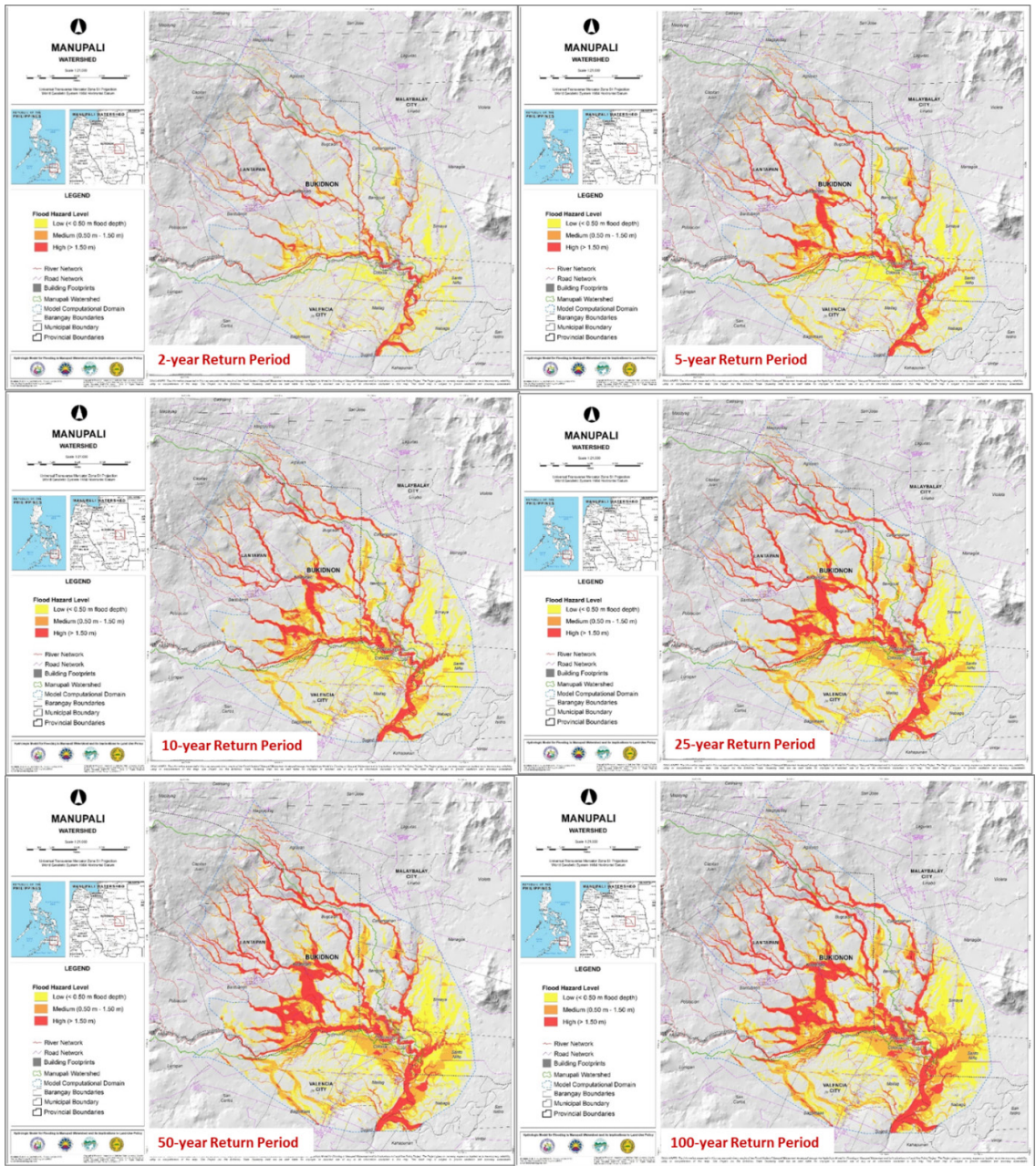


Fig. 8. Flood hazard maps generated in this study at different flood return period scenarios

HEC-RAS and subject to different flood return periods. The flood hazard categories were color-coded into yellow, orange, and red for low, medium, and high flood depth levels. Different flood hazard levels are indicated in flood hazard maps generated in all six flood return period scenarios (Fig. 8).

The HEC-RAS 2D floodplain domain of the Manupali watershed has a total area of 141.49 km². In the flood hazard maps produced through HEC-RAS, an increasing flood extent and depth were observed as the return period increases. As to hazard levels, most areas within the Manupali watershed progresses from low to medium, medium to high, and low to high hazard categories. The low to high flood hazard levels (marked with a blue circle) is already evident from a two-year to five-year return period scenario, which progresses to the 100-year return period scenario. Valencia and Malaybalay City areas show low to high flood hazard levels as the return period increases.

The flood extent in the model was expressed in terms of flooded land area in km². The two-year return period scenario had the least flooded area covering 23.04km² that accounted for 16.28% against the total area. In comparison, the 100-year return period scenario showed the largest flooded area covering 57.69 km² or 40.77% of the total area in the floodplain domain of Manupali Watershed. A summary of the flooded land area within the watershed at different flood hazard levels under different return period scenarios is shown in Figure 9.

Parangit and Puno (2017) discussed that on December 27, 2007, the areas of Bangcud, Malaybalay City was affected by a low-pressure area (LPA). The LPA incident caused much rainfall that resulted in an overflow of the Manupali River draining from Lantapan area. Residents claim that a *buhawi*, a local term for a tornado, might have aggravated the area's flooding. Accordingly, the flood depth reached up to 6 feet (1.83 meters) in the floodplain areas of Bangcud and took overnight before the flood subsided. This incident explains the result of a flood map subject to a 100-year return period scenario where most areas in Bangcud,

Malaybalay City were flooded at different flood hazard levels.

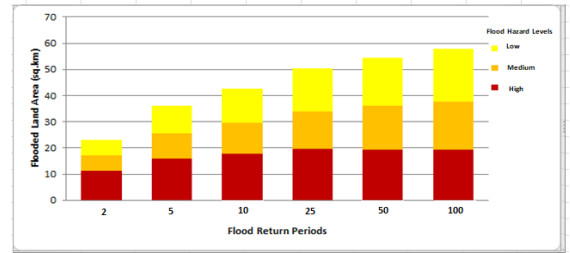


Fig. 9. Flooded land area within Manupali Watershed at different flood hazard levels under different return period scenarios.

Exposure Assessment

The interaction of flood hazard and the ground structures within the Manupali watershed was assessed through the generated flood hazard maps. The same trend of results was observed; that is, the number of flooded buildings increases as the return period increases. This result is similar to the findings of Puno et al. 2018, where flood hazard in the Manupali watershed was assessed using only three return periods. It revealed that the 25-year and 100-year return periods have an increasing coverage of flood inundation with highest hazard category of medium affecting other several residential houses.

A total of 11,532 buildings were sampled within the Manupali watershed. The highest number of flooded buildings was recorded at 6,906, or 59.89% of the total number of building extracted was under the 100-year return period. The least number of flooded buildings was 3,267 or 28.33% of the total number of building extracted recorded under the two-year return period scenario. Among the flooded building structures sampled, majority are exposed to low flood hazard level, followed by structures with medium hazard, and only a few are vulnerable and at-risk to high flood hazard levels (Fig. 10).

As assessed, the most vulnerable building structures were residential and commercial buildings. Most of these buildings were located in the downstream vicinity or situated near the river banks. A similar pattern of flood

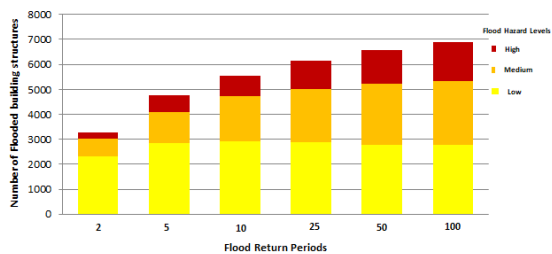


Fig. 10. Number of building structures exposed to flood at different hazard levels under different return period scenarios.

risk exposure of building structures was also revealed in the study of Puno et al. (2020) in the Solana watershed, where areas susceptible to flooding were mostly near the river, extending towards the floodplain of the watershed.

The Manupali traverses in areas under the Municipality of Lantapan and Cities of Valencia and Malaybalay. As indicated in the Comprehensive Land-Use Plan of Malaybalay City, Barangays Mailag and Simaya of Malaybalay City have the most considerable number of buildings exposed to flood hazards with 2,014 and 2,013 buildings respectively. In Valencia City, Barangay Bagontaas has the highest accounting for 1,578 buildings.

Table 4 shows the state of building structures located in areas where Manupali traverses exposed to different flood scenarios.

In a two-year return period scenario, most of the building structures in the affected barangays were categorized under low hazard. Barangays under Valencia City had the most buildings affected, especially the Barangays of Bagontaas (n=456) and Mailag (n=533), followed by Barangay Simaya, Malaybalay City with 410 affected buildings.

In a five-year return period scenario, the number of affected buildings increased in all three hazard categories. Low hazard buildings were still predominant. The same barangays in Valencia and Malaybalay had the most affected buildings. Notably, Barangay Simaya (n=269) and Bangcud (n=191) in Malaybalay had the greatest number of medium-hazard buildings in all affected areas. The greatest number of

high hazard buildings was located in Barangay Kulasihan, Lantapan (n=179).

In a 10-year return period scenario, Barangays in Valencia still had the highest number of buildings affected but mostly were low hazard categories mostly located in Mailag (n=686) and Bagontaas (n=601). Barangays in Malaybalay had the highest number of medium-hazard buildings located in Simaya (n=340) and Bangcud (n=214). High hazard buildings were slightly increasing in all areas.

In a 25-year return period scenario, the number of affected buildings increases but showing the same pattern of the locations of the predominant low-hazard, medium-hazard, and high-hazard buildings to that of the 10-year return period.

In a 50-year return period scenario, the same highly affected Barangays in Valencia had decreased low-hazard buildings, while the medium and high-hazard buildings increased. Valencia had the highest number of medium-hazard affected buildings (n=1093), while Lantapan had the highest number of high-hazard affected buildings (n=579) and Malaybalay had 526 high-hazard affected buildings.

In a 100-year return period scenario, high hazard buildings were mostly located in Barangays Kulasihan, Lantapan (n=454); Barangays Bangcud (n=231); Simaya (n=205), and Sto Niño (n=178) in Malaybalay; and Mailag (n=114) in Valencia City. Medium hazard buildings were also mostly located in Mailag (n=468); Simaya (n=388); Bagontaas (n=381); Kulasihan (n=290); Sto Niño (n=268); Colonia (n=248); and, Bangcud (n=229).

Table 4.

Exposure Assessment to Building Structures in Areas within Manupali Watershed.

Barangays	Flood Return Period																		
	2-Year			5-Year			10-Year			25-Year			50-Year			100-Year			
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	
Lantapan																			
Bantuanon	84	42	42	111	55	76	121	65	91	122	77	108	130	90	110	126	90	122	
Bugceon	95	15	20	109	33	45	124	32	55	145	39	62	146	48	58	159	49	97	
Kulasihan	167	53	34	227	142	179	220	284	199	180	296	299	109	354	381	135	290	464	
Valencia																			
Bagontaas	456	71	5	593	122	22	601	195	24	610	268	35	593	339	38	616	381	47	
Cabangahat	80	41	2	84	53	17	73	68	19	77	72	21	64	85	26	60	90	31	
Colonia	145	32	16	209	57	36	165	150	44	130	218	50	115	237	65	108	248	78	
Lurigan				1							2							3	
Mailag	533	80	5	640	143	13	686	232	33	741	312	58	779	383	92	756	468	114	
Matago	111	8		133	16		151	21		164	26	2	166	35	3	164	44	5	
San Carlos	10	5	3	9	12	7	16	6	14	19	7	16	15	12	17	16	13	19	
Bugod	4			7			4	3		3	4		3	2	2	3	2	2	
Malaybalay																			
Bangcud	131	144	53	127	191	116	119	214	157	99	222	193	81	220	217	70	229	231	
Mailag				6	1		7	1		8	1		12	1		12	1		
Simaya	107	78	39	146	149	80	181	177	113	136	227	139	96	256	157	66	266	178	
Simaya	410	141	20	456	269	62	464	340	80	457	376	137	457	390	162	466	388	205	

The flood scenario results above conform to Valencia City's Comprehensive Land Use Plan (CLUP). The Barangays of Bagontaas, Sugod, and Mailag of Valencia City are identified as areas vulnerable to low flood hazard levels. These barangays experienced increasing flood incidences from 2008 to 2011. Bagontaas falls under the urban area category, while Sugod and Mailag are categorized as urbanizing. These are areas that may reconsider land-use planning concerning mitigating flood hazards, especially those near the riverbanks.

In the CLUP of Malaybalay City, Barangays Sto. Niño and Bangcud are identified as flood-prone areas. The classification conforms to the flood scenario results given that Bangcud, Sto. Niño and Simaya barangays were found to have the most number of buildings exposed to flood hazards. As described in the CLUP, Bangcud falls under the urban areas while Sto Niño and Simaya are rural areas of Malaybalay. It is acknowledged that aside from Manupali, Sawaga River also drains to these areas contributing to the intensity of flood problems. It has been recorded that moderately turbid flash flood is very common at Puroks 1, 2, 3, 4 and 7 in Barangay Bangcud. The December 2007 flood greatly affected Puroks 1, 2, and 7 near the Kulasihan creek and river banks.

Based on the CLUP, barangays Sto. Niño and Simaya are mostly used and prospected for agricultural land. As assessed, buildings categorized under high and medium-flood hazard level were primarily located near the vicinity of river and creeks, and flood plain areas evident in Bangcud, Colonia and Sto. Niño. Colonia is a barangay boundary of Valencia City and Malaybalay City.

Land-uses present in Bangcud are residential settlements along the highway, light industries, institutional, agricultural, and forest land. An area of 44.96 hectares is added to its existing 84.7 hectares of settlements for future development. There is also an increase in the agricultural protection area, which is delineated as part of the Network of Protected Areas for Agriculture and Agro-Industrial Development Map (NPAAAD). Given these future land-use

plans for Bangcud, the local government may reconsider planning to avoid high flood hazard areas in expanding settlements and other developments. Agricultural area development may also include proper and/or climate-resilient irrigation and dikes systems.

Science-based land use planning is important to support hydrological performance of watersheds as well as the mitigation of flooding. Furthermore, the network of interconnected ecosystems has to be strategically planned concerning land development, growth management and physical infrastructure planning (Schuch et al., 2017). Therefore, this study recommends that the three affected LGUs coordinate and network among themselves for the above stated goals.

Conclusion

High-resolution digital elevation model, land cover and observed hydro-meteorological data provide a clear picture of the hydrologic behavior of the Manupali watershed through the use of combined tools: Hydrologic Modeling System (HMS), River Analysis System (RAS) and Geographic Information Systems. A synthetic hydrograph model was simulated and delineated inundated sites of flood-prone areas. The model is essential for hydraulic simulations to map out flood depth and extent, and to generate flood hazard maps of the Manupali watershed. Simulation results revealed that flood extent and the number of flooded buildings within the watershed increases as the return period increases. Hence, the generated flood hazard maps are a good reference tool for a science-based policy formulation in land use planning, zoning, and management. This information is essential in the vulnerability assessment of the area preparatory to disaster preparedness and risk reduction

Recommendation

The study results would help improve disaster risk reduction and management in flood-affected areas within the Manupali Watershed. Local governments can utilize the hazard maps for science-based policy formulation in land-use

zoning, land development, growth management and physical infrastructure planning to mitigate flood risks. Specifically, the study recommends the following:

1. It is recommended that the local government put necessary action and policies for the affected barangays that are mostly agricultural land-use to adapt interventions for flood mitigation such as dikes and irrigation and climate-resilient crops. Crop insurance may also be considered for post-flood interventions for farmers. Local governments should also consider proper site selection for the expansion of settlements in barangays categorized as urbanizing in Valencia City and Malaybalay City.
2. The three concerned LGUs may organize a network to protect the Manupali Watershed through PES (Payments for Environmental Services) since these areas depend on the health of the hydrology of Manupali. This recommendation can also be a basis for future research intervention with regards to PES for the watershed.
3. Hazard map validation survey on-site using the 2007 low pressure area incident is recommended to improve accuracy of the study. Further study to assess land-use based flood hazard may be done in the future as a basis for forest protection and regeneration of denuded areas to reduce flood risks.

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