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Flood hazard zones using 2d hydrodynamic modeling and remote sensing approaches

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ABSTRACT

The increasing frequency and severity of flooding demands identification of flood hazard zones in Kalilangan, Bukidnon in response to the echoing need of better disaster preparedness via enhancing the understanding and awareness of the public on flood characteristics by integrating the use of two-dimensional hydrodynamic modeling and remote sensing. Flood simulation was carried out in a two-dimensional hydrodynamic model using hydrologic engineering center-river analysis system to derive the flood inundation area and flood depth of Kalilangan, Bukidnon. Thus, it was preceded by pre-processing of the model using software packages of hydrologic engineering center-hydrologic modeling system and ArcGIS along with interferometric synthetic aperture radar–digital elevation model, Manning's roughness coefficient and precipitation data. Five different rain return flooding scenarios were simulated using rainfall intensity duration frequency data. Three zones of flood hazard were then set as low, medium and high. The result shows that most areas of Kalilangan are within the zones of medium to high hazard with residential buildings as the most flooded type of built-up structures. Flood hazard zone areas could be mapped at an accuracy of 79.51%. Thus, harnessing this potential approach offers cost-effective way of flood preparedness viewing hazard-prone areas with special attention and utmost importance.

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INTRODUCTION

Located along the world's busiest Pacific typhoon belt, Philippines endures an average of 20 tropical cyclones every year which enters the country's area of responsibility causing weather-related or meteorological disasters (Acosta, 2016). According to 2016 World Risk Index which indicates the risk of disaster in consequence of extreme natural events, Philippines ranked third as the most disaster-prone country in the world with the greatest exposure to natural disasters scoring 52.46% and should be understood as a warning to be prepared for a catastrophic events in the future with increased frequency and severity. Hence, the most devastating in terms of their economic and social impact are typhoons and floods accounting for 80 percent of all deaths, 90 percent of the total number of affected people, and 92 percent of the total economic impact (Comes *et al.,* 2016). The most perilous natural threats and principal trigger of calamities (Alcantara-Ayala, 2002) which instigates flooding are related to

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hydro-meteorological phenomena such as typhoons, tropical cyclones, monsoons (Kale *et al.,* 1994), El Niño or La Niña. Typhoon-induced floods are the most common, inevitable and costly large natural disturbances affecting the Philippines annually causing devastation with known loss of over a thousand lives and properties, flood-induced diseases and social disruption hampering economic advancement which may have a serious effect on the quality of life of each people and impact on the social fabric of surrounding community (Jha *et al.,* 2018; Gordon, 2014). Accordingly, as a result of the instability of the Earth's surface features, geomorphic hazards like floods can be viewed as a group of threats to human's lives, properties and natural resources. The municipality of Kalilangan, Bukidnon in Mindanao is no exemption to the distressing effect of floods due to the continuous heavy rainfall instigated by typhoons and/or monsoons. It can be recalled then that the main reason of major flooding in the municipality is the influence of Saguirayan, Malatipay and Maradugao Rivers which overflow due to uninterrupted rains wrought by a low-pressure area in the eastern part of Mindanao making it vulnerable to flooding (Yap, 2011). Attested by the Municipal Disaster Risk Reduction and Management Office (MDRRMO) of Kalilangan, past incidents of flash floods and inundation were only recorded earlier in the year 2003 to 2017 which has incurred damages on infrastructure, agriculture, poultry, livestock and even residential houses. This is affirmed by Secretary Luwalhati Antonino, head of the Mindanao Development Authority stressing that flooding has been viewed as the new normal particularly in the once considered typhoon-free Mindanao region which is attributed to climate change and weather disturbances in the country. Recently, a flashflood transpired in Kalilangan, Bukidnon on September 2, 2017, affecting six barangays with a total of 1,775 families or 8,875 persons. Furthermore, MDRRMO stressed out that three barangays, namely Poblacion, West Poblacion and Pamotolon were submerged in waist-deep floodwaters forcing 1,640 families from their homes. The flooding incident caused a damaging effect to 116.8 ha of rice fields, 48.5 ha of corn fields, 107 heads of livestock and poultry as well as the spillway connecting the two barangays of Kinura and Kibaning (NDRRMC Update, 2017). Consequently, the MDRRMO sought to control and manage the recurrent flooding in a way that it will not be disastrous or its impact will be lessened. However, their disaster management system mostly relies on response and reactive approach based on post-disasters rather than preparedness and preventive approach which is deemed more preferable and effective. Thus, most studies connected with floods have shown the importance of flood hazard zoning and mapping on floodplain management, global disaster preparedness and risk mitigation. Indeed, no fully define mechanism and studies have been directed on the flood hazard zoning of Kalilangan, Bukidnon as a means and tool of LGUs in disaster preparedness and prevention. Hydrodynamic models simulate the motion of water by understanding the conditions derived from applying physical laws to fluid movement with varying degrees of complexity which involves the utilization of one-dimensional (1D) (Brunner, 2016; DHI, 2003), two-dimensional (2D) (DHI, 2012; Moulinec *et al.,* 2011) and three-dimensional (3D) methodologies (Prakash *et al.,* 2014; Vacondio *et al.,* 2011). The concept of applying 2D hydrodynamic models to rivers and floodplain has been successful from large-scale floodplains to small urban areas on a regular basis (Tennakoon, 2004). It was agreed by Liu *et al.* (2012) that the capability of the 2D hydrodynamic model to calculate flood submerged area, flood water depth distribution and flood routing time attracts much attention in flood control management. Thus, the efficiency of flood emergency management could be improved thru provision of flood information which offers more help with risk indications. Its popularity is associated with the recent advancement of geographic information system (GIS) and remote sensing (RS) technology. GIS enhanced the visualization and presentation possibilities due to its capability of exporting the model output files into a raster (Tennakoon, 2004) and need to be used collectively with a hydraulic technique to estimate flood profile with a given recurrence interval. On the other hand, remote sensing provides floodplain topography data to augment the amount and type of information available for effective flood management (Schumann, 2015). Digital elevation model (DEM), a remotely sensed data is one of the most important input data in flood modeling because it determines the topographic information of a particular river basin and/or watershed (Neussner, Obermaier and

Sanchez, 2012; Konadu and Fosu, 2009). The DEM incorporated in the present study was obtained from Interferometric Synthetic Aperture Radar (IFSAR), a technology which uses two radar antennae mounted on an aircraft called as the interferometric baseline and is displaced by a known distance. IFSAR-DEM has a 5-m resolution which is essentially cost-effective in providing data with accuracy and offers more strategic substitute for immediate response during the occurrence of a disaster especially for LGUs during tropical storms and flood (Suarez *et al.,* 2014). The use of GIS and RS datasets have been broadly used in facilitating flood hazard modeling and mounted its application in the areas of flood management such as flood inundation mapping, floodplain zoning, and river morphological research (Ng *et al.,* 2017; Khanna *et al.,* 2018). However, along with RS and GIS, Hydrologic Modeling System (HMS) and River Analysis System (RAS) are the two computer models used to analyze the behaviors of a river basin and/or watershed (Chatterjee *et al*., 2014; Zope *et al*., 2015). HEC-HMS is used for rainfall-runoff modeling while HEC-RAS is intended for 2D hydrodynamic modeling (Tahmasbinejad *et al.,* 2012). In recent years, the burgeoning interest in the application of modern technology in flood management is the unique capabilities of space technology in providing the basic information needed in the space, time and frequency domain of monitoring and managing flood dynamics. Flooding is frequent in Kalilangan, Bukidnon attributed by climate change which urged the Provincial Disaster Risk Reduction and Management Office of Bukidnon to ensure timelier, efficient and coordinated disaster preparedness among the local government units in the province by proposing a uniform alarm system in floodprone rivers. The advancement in hydrodynamic models and GIS techniques along with hydrologic model has paved a way for remote sensing to play a significant role in providing valuable information in flood assessment, mitigation and preparedness phases of floods (Khanna *et al.,* 2018). Maximum flood inundation and water depth may be adequate for hazard mapping, environmental evaluation and water resources planning (Teng *et al.,* 2011). So, as the frequency and severity of flooding increases, the need of flood hazard zonation remains wanting in response to societal demand and echoing need of better disaster preparedness via enhancing the understanding and awareness of flood characteristics. Integrating the use of two-dimensional hydrodynamic modeling and remote sensing along with GIS techniques, the present study focuses on demarcating and zoning potential flood hazard-prone areas of Kalilangan, Bukidnon which will guide in setting evacuation routes, rescue actions and defining safe areas to allocate affected people. This study has been carried out in Maradugao River of the Municipality of Kalilangan, Bukidnon, Philippines in 2017.

MATERIALS AND METHODS

Study area

Geographically, Kalilangan, Bukidnon lies between the coordinates of 7° 37′ 47.58″ to 7° 56′ 2.42″ north latitude and 124° 36′ 7.03″ to 124° 48′ 26.31″ east longitude which is bounded by the Municipality of Talakag on the north; by the Municipality of Pangantucan on the east and south; and by the Province of Lanao del Sur on the west. Further, the municipality of Kalilangan was selected as the focus of the study since Mines and Geosciences Bureau of Region 10 identified the location as susceptible to floods where there are several reports on flooding incidence in the area greatly influenced by Maradugao, Malatipay and Saguirayan River. Attested by the MDRRMO of Kalilangan, the root causes of flooding in some areas of Kalilangan are its basin-like geographical structure, non-sustainability on watershed management, denuded forest, land conversion, non-compliance of proper zoning, encroachment of easement and many others. The aforementioned causes of riverine flooding are triggered by continuous rain with high rainfall intensity and heavy rainfall at the neighboring municipality which drains to Kalilangan because of its low elevation profile which will then cause inundation of the area. Hence, the MDRRMO recognized Barangay Poblacion, West Poblacion, Ninoy Aquino, Kinura, Macaopao, and Pamotolon as susceptible to and heavily flooded areas which may be isolated during heavy rains. Fig. 1 shows the location of the study area.

Datasets preparation

Several datasets and parameters were acquired and prepared on the month of September 2017 to achieve realistic flood simulations and outputs, as well as, to satisfy the objective of the study. Remotely sensed data like Synthetic Aperture Radar (SAR)

Digital Elevation Model (DEM) with a 10-m resolution is used to delineate sub-basin and extract model topographic parameters like slope and elevation while the 5-meter Interferometric SAR-DEM is primarily used for flood depth simulation as base topography. Other input datasets to be supplemented in flood modeling are digitized river networks from Google Earth™; Rainfall Intensity Duration Frequency (RIDF) obtained from Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA); and 2D hydraulic model using IFSAR derived digital terrain model (DTM) associated with the actual river geometry obtained from the bathymetric field survey; Manning's surface roughness coefficient derived from generated land use land cover; and the simulated flow hydrographs. As such, river discharge and rainfall data from field survey and sensors were obtained, respectively by deploying a rain gauge, flow meter and depth gauge for basin model initial simulation and calibration.

Flood modeling

Integrating two computer models, this research involves the use of Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) version 3.5 and HEC-River Analysis System (RAS) Beta version 5.0 for hydrologic and hydraulic modeling of Maradugao River, respectively. HEC HMS, created by US Army Corps of Engineers (2015), is a numerical modeling system designed to simulate watershed and channel behavior; precipitation-runoff processes of a watershed and/or river basin systems with an extensive variety of application in flood hydrology, and small urban or natural watershed runoff (USACE-HEC, 2010). On the other hand, a hydraulic simulation through two-dimensional (2D) hydrodynamic flow routing was performed within the interface of HEC-RAS in unsteady flow analysis (USACE, 2015). HEC-RAS is commonly used in mapping flood extent with the availability of inflow data (e.g., from hydrological simulations or actual flow measurements) to fill in the model's boundary conditions (Hicks and Peacock, 2005).

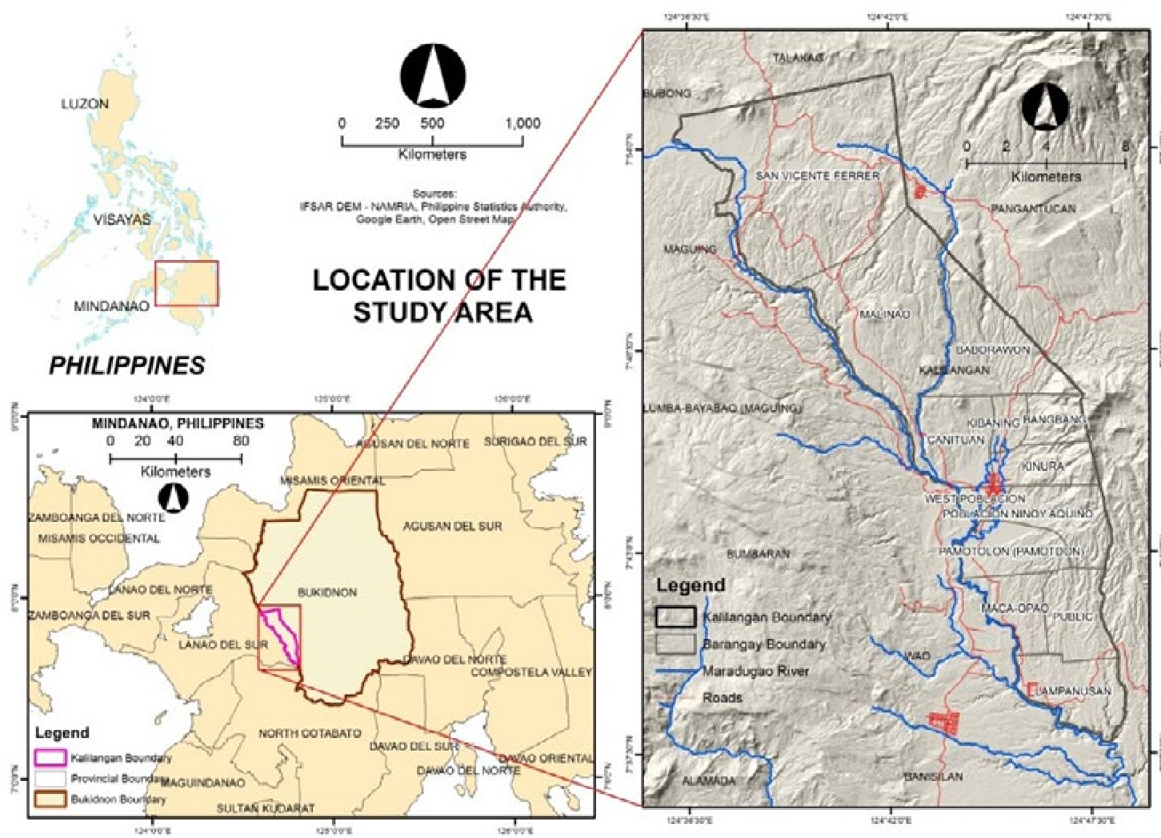

Fig. 1: Geographic location of the study area in Kalilangan, Bukidnon of Philippines

Hydrologic model development and calibration

Development and generation of Maradugao basin model is the initial step to flood modeling which involves the use of HEC- Geospatial HMS, a pre-processor of HEC-HMS software attached as an extension in ArcView GIS software. The watershed which is physically represented by a basin model was delineated using a 10-m SAR DEM and digitized river networks. It undergoes parameterization using the information derived from the land use land cover map that was generated from object-based image classification of Sentinel 2 images using support vector machine (SVM) algorithm. Additionally, selected model components in HEC-HMS were SCS for loss method, Clark UH for direct runoff, Recession for base flow and Muskingum-Cunge for channel routing method as shown in Table 1. Whilst, initial abstraction, curve number, storage coefficient, time of concentration, initial base flow, recession constant, and Manning's N are considered as the calibration parameters. This parameters are well established, stable, widely accepted, used and recommended by various researchers dealing with flood modeling studies (Udhavrao (2014). The basin model was then exported to HEC-HMS version 3.5 for further model calibration and hydrologic simulations of a rainfall-runoff model. The created model was calibrated for the event-based simulation using one event of localized rainfall and discharge collected on October 8 to 10, 2017 recorded for a duration of 71.75 hours and 52 hours, respectively. Event-based simulation uses individual event with high precipitation causing peak discharges and water level rise on the basis of storm event (Duhan and Kumar, 2017) which was also employed in the studies of (Puno and Amper, 2016; Santillan *et al*., 2016; Udhavrao, 2014). The duration of the event may range from few hours to days which reveals the response of a basin to an individual event (Udhavrao, 2014). The calibration process of the model involved adjusting or tuning the model parameters used in HEC-HMS such as Curve Number, Initial Abstraction, Time of Concentration, Storage Coefficient, and Recession Constant by evaluating the observed flow against the simulated flow produced by the model until the two closely fit each other which was used extensively in the field of flood modeling studies. The acceptability and accuracy of the model and the calibration procedure was evaluated and validated using various quantitative statistics such as Nash Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), and the observation standard deviation ratio (RSR), an error index computed as the ratio of the root mean square error (RMSE) and standard deviation of measured data. These measures were calculated by comparing the measured and simulated hydrographs based on the comprehensive model evaluation guidelines developed by Moriasi *et al.,* 2007 to facilitate systematic quantification of accuracy in hydrological simulations. NSE measures the certainty of the model indicating how well the plot of modeled discharge versus observed data matches the 1:1 line with an optimal value of 1 as the perfect match. RSR, on the other hand, is a standardization of RMSE which integrates the benefits of error index statistics and includes a scaling/normalization factor. Lower RSR designates lower RMSE which signifies better model simulation performance – a zero value means perfect model simulation. PBIAS gives an indication on the average tendency of the model results to be under- or overestimated compared to the observations with an ideal value of 0.0 (Moriasi *et al.,* 2007). Consequently, the established rainfall-runoff model was used to simulate the flow for the five return periods, namely, 5-, 10-, 25-, 50-, and 100-year RIDFs.

Table 1: Input parameters for event-based hydrological modeling

Model	Parameter
Loss-SCS	Initial abstraction Curve number (CN)
Transform-clark's UH	Storage coefficient Time of concentration
Base-flow-exponential recession	Initial base flow/discharge Recession constant Ratio to peak
Routing-Muskingum-Cunge	Manning's N

Hydrodynamic modeling

HEC-RAS was used in creating 2D hydrodynamic model of Maradugao River with IFSAR DTM as the primary source of elevation data for the model simulations. However, the development of 2D model was preceded by the pre-processing procedure of geometric input data (2D flow area that defines the boundary of 2D computation, break lines and inflows) using HEC-Geospatial-RAS extension in ArcGIS interface and then, exported to RAS file format. Riverbed morphology gathered through a bathymetric survey using single beam echo sounder was integrated into DTM through bathymetric data burning to ensure that the 2D model can account for the effects of riverbed in flow simulation. The 2D flow modeling was accomplished by adding a 2D flow area representing the entire floodplain of the watershed; developing a 2D computational mesh and connecting the boundaries to the 2D areas in HEC-RAS environment. Hence, the 5 m spatial resolution IFSAR-derived DTM and the Manning's roughness coefficients given to every land use land cover classes were the necessary data to set the model's geometric information to anticipate or estimate flood depths and extents in Kalilangan, Bukidnon. Result of simulation is viewed under RAS Mapper, then exported and analyzed in ArcGIS environment and a spatially-distributed grid of maximum flood depths was created for each flood scenario.

Flood hazard validation

To evaluate the accuracy of the produced flood hazard maps, the performance of the model was checked using the real flooding information obtained from the field through flood validation survey. Flood validation survey was carried out in predetermined points evenly scattered within the floodplain of the river whether they were flooded or not during typhoon Sendong (Washi) event in December 2011. The resulting flood map of historical events from numerical simulation was compared to the actual flooding information. Using the confusion matrix approach based on Ambiental (2013), the accuracy of the produced flood hazard map was assessed. Measure of fitness known as "F Measure" was also utilized to determine if the flooding extent generated in the map is the same as on the ground and it can be computed using Eq. 1 (Aronica *et al.,* 2002; Horritt, 2006).

$$F = \frac{A}{A + B + C} \quad (1)$$

Where; A is the number of points correctly anticipated as flooded by the model, B is the number of points anticipated as flooded while being not flooded in the real observation (over-prediction) and C is the flooded points not anticipated by the model (under-prediction). F is equivalent to 1 when observed and anticipated areas overlap exactly and equivalent to 0 when no overlap between observed and anticipated areas exists. Breilh, *et al.* (2013) subjectively assessed good fit measurements for F-values ≥ 0.7, intermediate fit measurements for 0.5 ≤ F-values < 0.7 and bad fit measurements for F-values < 0.5.

Flood hazard zoning

A total of 5 scenarios were identified and simulated during hydrologic and hydraulic modeling in this study. Flood inundation map shows areas which could be flooded complemented with flood extent and depth associated with flood hazard. In the current study, color coding of the three zones of flood hazard were set as yellow for low flood hazard (> 0.5 m flood depth), orange for moderate or medium flood hazard (0.5< flood depth <1.5 m), and red for high flood hazard (< 1.5 m flood depth). Flood layers were overlaid with exposure datasets to quantify the number of the affected building.

RESULTS AND DISCUSSION

Calibrated hydrologic model

The observed and calibrated hydrograph as displayed in Fig. 2 shows a close fitness with each other having a simulated discharge of 7.771 m^3/s and observed discharge of 8.199 m^3/s. Rainfall peak of 15.8 mm was observed at 14:00 h (2:00 P.M.) of October 9, 2017 before the occurrence of observed peak discharge at 17:30 h (5:30 P.M.) of the same day. It can be inferred then that there is 3 h and 30 min. lag time before the highest discharge to arise. This delay in time between the maximum precipitation and peak river discharge gives time for the communities to prepare and evacuate their area to reduce possible damages and casualties it may incur.

In hydrologic modeling studies, reasonable adjustment and approval of the model is imperative to decrease the uncertainty in model simulations (Engel *et al.,* 2007) where model output is contrasted against the measured data with the assumption that all error variance is contained inside the anticipated values and that determined values are error free (Moriasi *et al.,* 2007). However, Willmott (1981) and ASCE (1993) found out the measured facts are not error free; hence, a model validation must be carried out using defined and accepted statistical measures. Generally, the fitness between the observed and simulated variables shows an unsatisfactory rating based on the initial values of hydrologic parameters before the calibration event because it exceeds the optimal value of each quantitative statistics defined by Moriasi *et al.,* 2007. The simulated data as predicted by the model must be computed with the observed data and statistical tests of error functions must be performed to study the suitable performance of calibrating and validating the model. The goodness-of-fit was achieved by manual adjustments through trial-and-error changes of the model parameters which was also employed in the studies of (Puno and Amper, 2016; Santillan *et al.*, 2016; Yu, 2015; Choudhari, 2014; Udhavrao, 2014). As a result, statistical indicators of the validated model as shown in Table 2, confirms a very good model performance based on the NSE, RSR and PBIAS values of 0.77, 0.48 and -9.34, respectively as shown in Table 2. The model has a Pearson correlation coefficient (r^2) of 0.9438 which indicates that the actual and simulated values have the best fit (r^2 close to 1.0). Nonetheless, the negative estimation of PBIAS suggests model overestimation bias while the positive demonstrates underestimation. Test results must at least be satisfactory to be considered acceptable and valid for future simulations. This implies that the model can be used in simulating discharge hydrographs with an acceptable accuracy level and has a tendency towards over prediction due to negative PBIAS values.

Generated models of flood hazard were based on the 5-, 10-, 25-, 50-, and 100-year extreme rainfall data gathered from PAGASA in the form of RIDF curve (Fig. 3) from Malaybalay City synoptic rainfall station as chosen based on its proximity to the study area. RIDF curve provides the anticipated intensity of

Table 2: Maradugao basin model performance rating

Statistical measures	Values before Calibration	Rating	Values after Calibration	Rating
NSE	-27.57	Unsatisfactory	0.91	Very good
RSR	5.35	Unsatisfactory	0.29	Very good
PBIAS	-99.27	Unsatisfactory	-1.13	Very good

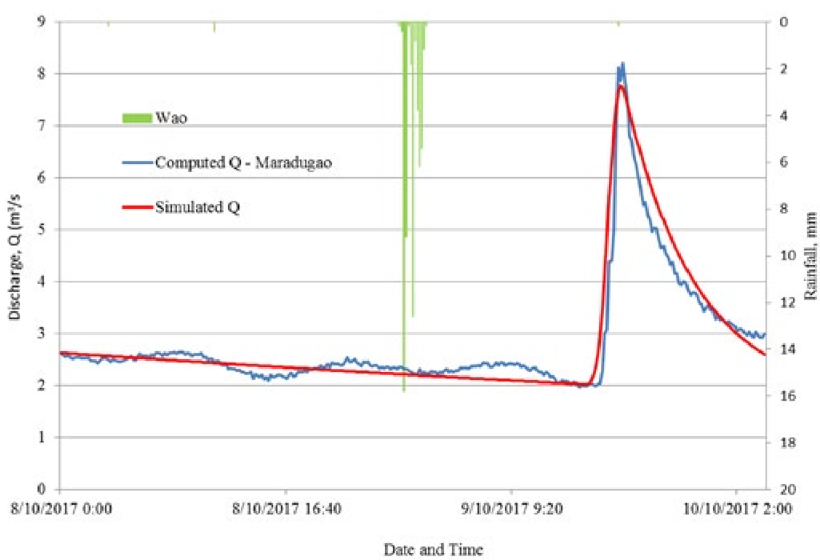

Fig. 2: Comparison of simulated and observed discharge with rainfall data

rainfall of a given duration of a storm with a desired frequency of occurrence. It is normally presented in graph to describe the relationship between the rainfall intensity plotted in the x-axis, the duration (time) in the y-axis and the return period (Nhat *et al.,* 2006). On the other hand, the computed extreme rainfall value as presented in Table 3 was based on 31 years of historical rainfall data of Malaybalay rain gauge. The use of RIDF data to estimate river discharges is one of the most common methods used in estimating designs for flood hydraulic structures and bases of flood hazard or risk mitigation related programs (Botero and Frances, 2010). Return periods are utilized to quantify the outcomes of flood with the end goal to a give a thought of the characteristics the flood may have (magnitude) and how frequently it is probably going to happen (recurrence) (Alcantara-Ayala, 2002). It is expected then that there is a significant increase in outflow magnitude as the rainfall intensity increases for a range of duration and return periods because an amount of water is added to the stream flow of the river. Thus, the quantity of precipitation is highly dependent on the recurrence interval of a specific rainfall event which has a great effect on the river outflow (Urias *et al.,* 2007).

Flood hazard zonation

Flood hazard zonation maps provide an overview of the area where the flood hazard could occur and should be taken into consideration before planning any other use. The generation of these maps usually combines topographic, hydrologic, geomorphic, land use land cover and demographic data (Knutsson, 2012). Thus, the focus of the zonation is on river flood hazard caused by Maradugao River on Kalilangan, Bukidnon. Based on the result of hydraulic simulations, the generated flood depth and inundation information were converted into zones of flood hazard which is categorized into three: low (depth > 0.5 m), medium (0.5 m< depth< 1.5 m), and high (depth < 1.5 m) that may happen in 24 h term rainfall events of differing return period. In

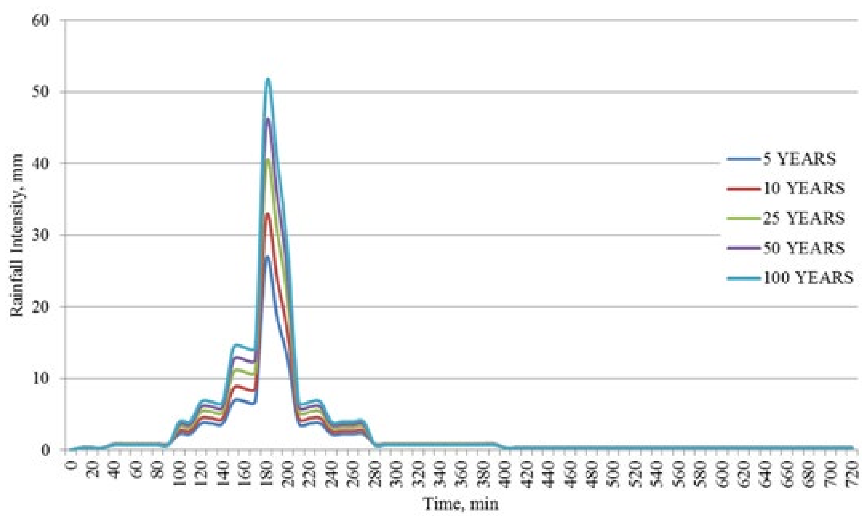

Fig. 3: RIDF curve of Malaybalay City Synoptic Rainfall station

Table 3: Computed extreme values of precipitation (mm)

Return Period (y)	Precipitation								
	10 min.	20 min.	30 Min.	1 h	2 h	3 h	6 h	12 h	24 h
5	26.7	45.3	57.9	78.4	100.8	114.3	130.2	143.2	153.6
10	32.5	56.5	72.7	98.6	125.3	141.4	156.7	169.6	180.7
25	39.9	70.6	91.3	124.1	156.3	175.5	190.1	202.8	214.8
50	45.4	81	105.1	143	179.3	200.9	214.9	227.5	240.2
100	50.8	91.4	118.8	161.8	202.2	226	239.5	252	265.3

this study, the set parameters were color-coded into yellow for low (Zone 1), orange for medium (Zone 2) and red for high (Zone 2). The resulting flood hazard maps are in accordance with the different probability of occurrence and flood magnitude produced by corresponding rainfall intensity. Figs. 4 to 8 presents the flood hazard maps generated in HEC-RAS model using the defined hazard level categorization for 5-,

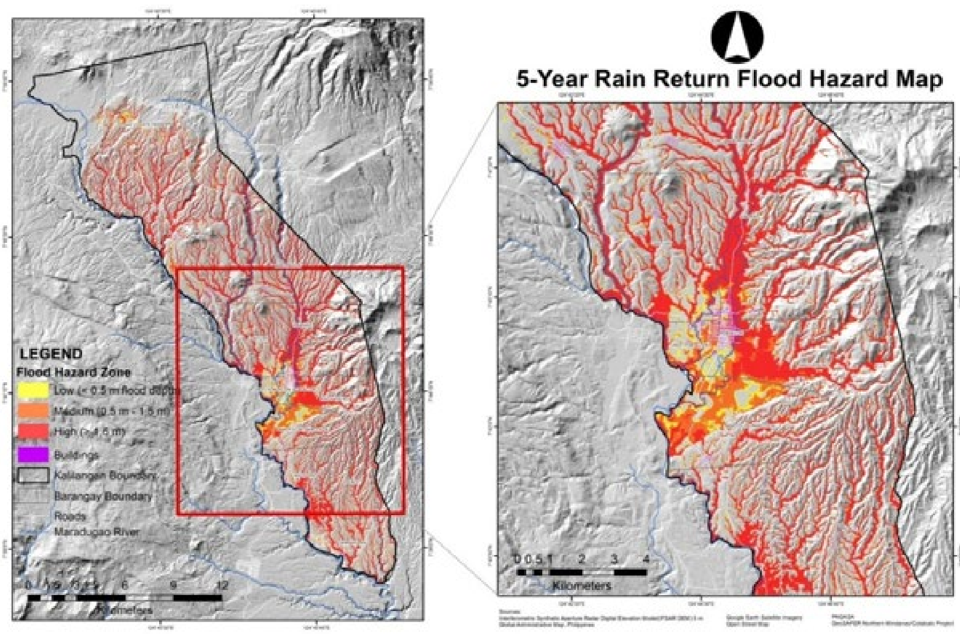

Fig. 4: Flood hazard map of 5-year return period

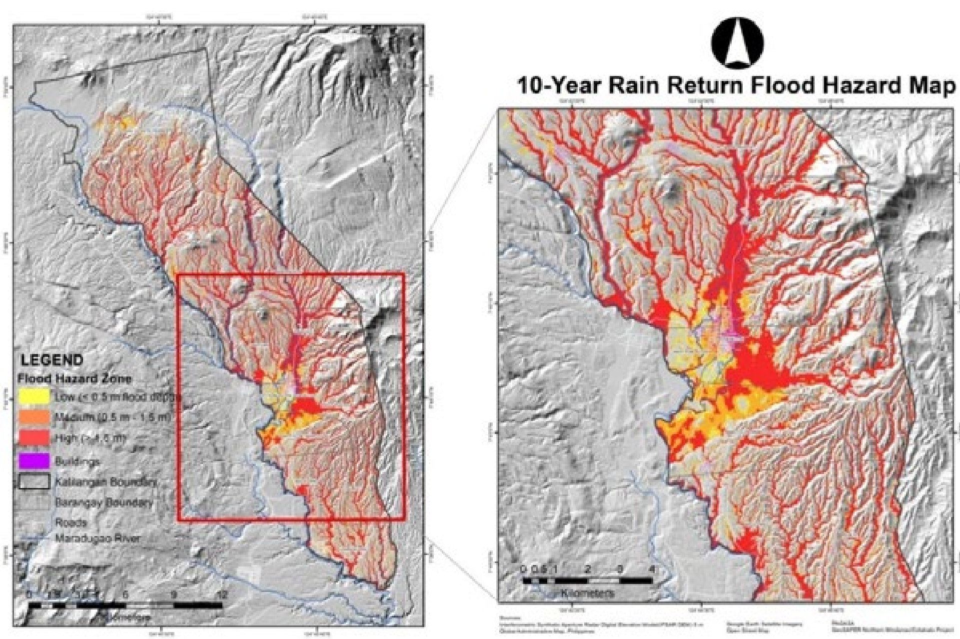

Fig. 5: Flood hazard map of 10-year return period

10-, 25-, 50-, and 100-year flood events with 20%, 10%, 4%, 2%, and 1% probability of occurrence in a year, respectively, which clearly shows the area that is potentially inundated by flood instigated by overflowing of Maradugao river and its tributary within the boundary of Kalilangan, Bukidnon. Flood map shows that at low recurrence period events, some areas are already susceptible to high hazard

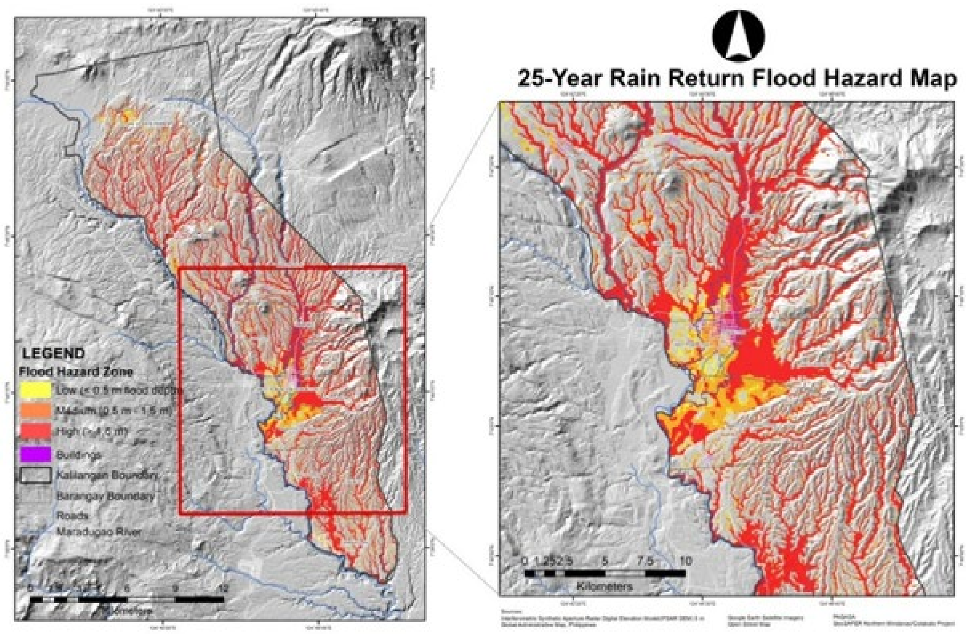

Fig. 6: Flood hazard map of 25-year return period

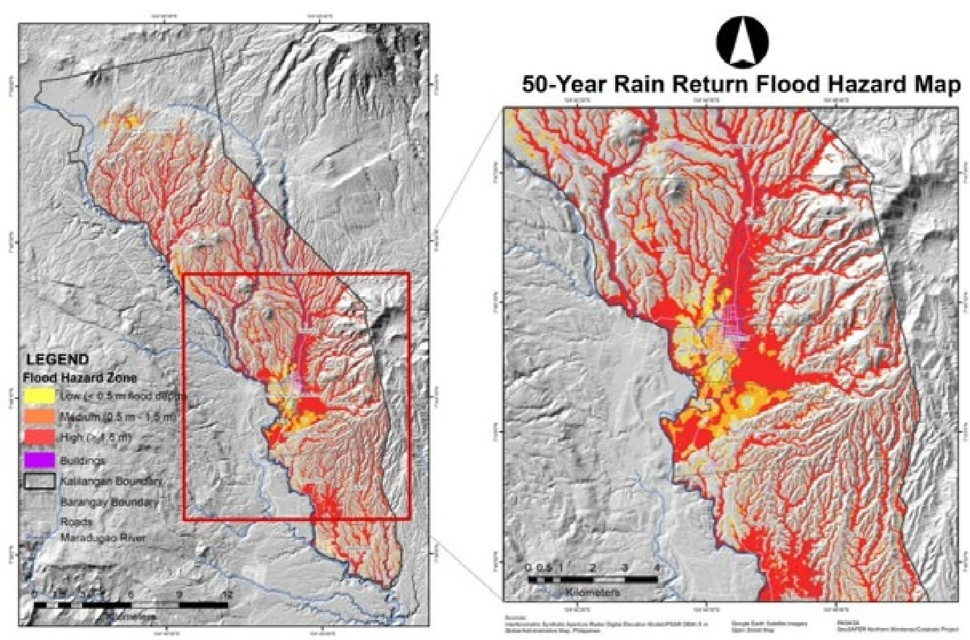

Fig. 7: Flood hazard map of 50-year return period

of flooding for a 5-year return period, among them are those residential building constructed in the floodplain of the river. In addition, it is depicted in Fig. 9 that in all flooding scenarios, areas within the zone of low hazard only constitutes 6% to 9% of the total inundation area which is evident in the map shown. Areas in low hazard zone are only apparent to Barangay Poblacion, West Poblacion, Pamotolon, Kinura, Macaopao and some parts of Ninoy Aquino and Canituan which is also prominent to medium to high hazard zone attributed to its slope profile that is within 0% to 3% (expressed in percent rise), flat terrain and low lying profile. Slope within that range is categorized by the Bureau of Soil and Water Management as severe to flooding hazard. The flood hazard analysis carried out in the aforesaid barangays

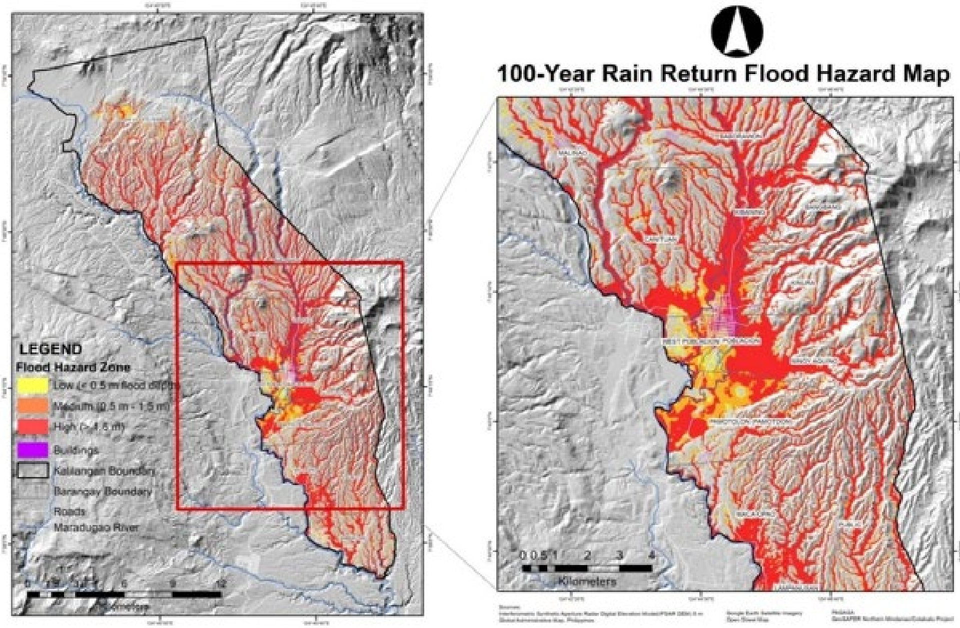

Fig. 8: Flood hazard map of 100-year return period

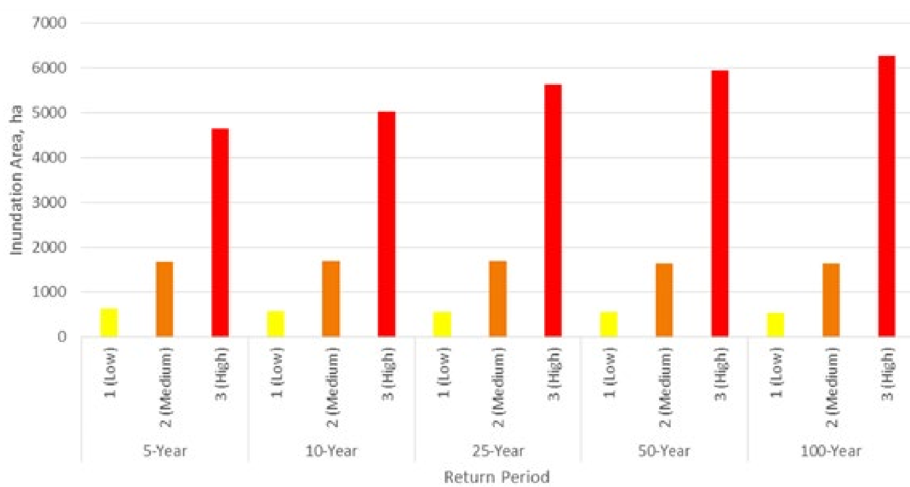

Fig. 9: Flood inundation area of Kalilangan, Bukidnon in varying return periods

highlight the fact that the high flood hazard zone is influenced by Saguirayan and Malatipay River, a tributary river of Maradugao which traverses the said area making it a basin-like geographical structure and its watercourse is already disturbed due to extensive human activity. Zone 3 or high hazard level inundated 65% to 75% of Kalilangan relative to its return period which may cause disruption to the municipality. However, the zone of high hazard in other barangays is confined to the area along the watercourse with small streams or channel and does not affect the number of communities and buildings. Whilst, as the rainfall return periods increases, the areas previously within the zone of low hazard became susceptible to moderate to high level of flood hazard. Change of zone from low to high hazard level is observable in the increasing trend of the inundation area of the varying rainfall return periods as being shown in Fig. 9. A significant increase of flood extent and hazard level can be explained by the considerable increase in the rainfall intensity from 5 to 100-year return period. In parallel to the produced flood hazard maps, there was a high flood hazard threat to floodplain in relatively lowland compared to other location considering its slope and elevation profile. Thus, the escalation of flood event due to rain return scenarios leads to the increase of magnitude of the generated runoff which contributes to the enlargement of the flood inundated area and boosts flood hazard classes.

For the validation of flood hazard zonation map, its accuracy can be estimated using the validation outcomes of typhoon Sendong flood map generated by the same models. Accuracy of the produced flood hazard maps were evaluated using the confusion matrix approach as presented in Table 4 which consist of records of flooded and no flooded points predicted by model-generated flood hazard maps. In confusion (error) matrix, a number of correct and incorrect predictions will be determined by comparing two data sources (Cwik, 2017) which in this case are a modeled flood from actual flood data. The result of the confusion matrix analysis of the model reveals that flood hazard areas could be mapped at an accuracy of 79.51% which gives us an assumption that what the models generate is approximately 79.51% accurate. Hence, this implies that the flood hazard zonation produced by the model has correctly predicted more than 75% of the actual-flooded points during the event of Typhoon Sendong. Measurement of fitness (F) was computed as 0.716 indicating that the flooding extent generated by the model in the map is a good fit, almost the same as on the ground.

The barangays recognized by MDRRMO of Kalilangan as susceptible to flooding correlates to the result of flood hazard zonation which has the highest population density of approximately 20,917 based on 2015 census residing along the indicated hazard zone. Hence, it is alarming knowing that most of the affected buildings are in the zone of high hazard which increases as per return period constituting 30% to 60% of the total number of affected buildings as illustrated in Fig. 10. As such, 90% of that affected buildings were residential type of built-up structures with known number of families and properties which may bring psychological and health impact to the affected person, dreadful condition and even worst, loss of life. Attested by the MDRRMO, a total of 1196 households are affected by floods or at risk of flooding from the above-mentioned barangays. Additionally, according to the records of MDRRMO on flood historical events that incurred damages, the extent of damage to houses, roads, and bridges were from partially to totally damage costing hundreds of thousand pesos. The floods also inflict damages on agriculture (crops), livestock, poultry and fisheries in the aforementioned barangays. They stressed out that no casualties were encountered so far in those areas but the possibility of damages to houses, structures, and yields along agrarian regions may result to a financial disability of the occupants, ranchers and

Table 4: Result of the flood map accuracy analysis in Maradugao River Basin for Typhoon Sendong (Washi) event

		Actual Flooding Scenario			User's accuracy (%)
		Flooded	Not flooded	Total	
Flood model simulated flooding	Flooded	63	15	78	80.77%
	Not Flooded	10	34	44	77.27%
	Total	73	49	122	-
Producer's Accuracy (%)		86.30%	69.39%	-	-
Overall Accuracy (%)		79.51%	-	-	-

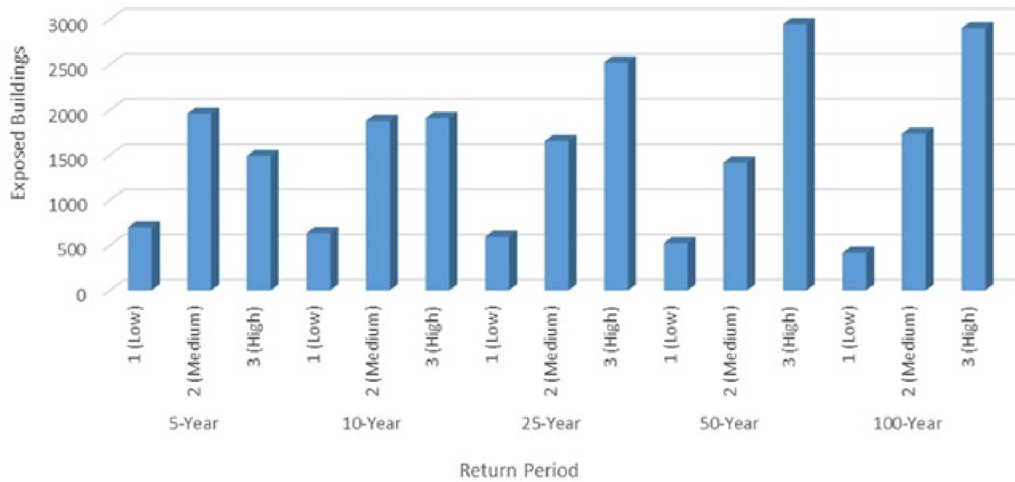

Fig. 10: Number of exposed building per return periods

their families as well as the municipality.

The MDRRMO of Kalilangan affirmed that flooding was worsened by inadequate and mushrooming of informal settlers in the floodplain of the river, land conversion, non-compliance to proper land use zoning, silted drainage system, clogged waterways, improper waste disposal and denuded forest. The increasing trend of exposed built-up structures to flooding is associated by enlargement of the area of river flood hazard due to the increase of rainfall event magnitude. The decrease and increase of the aforementioned level or classes can be observed by an increase of rainfall event magnitude from 5 to 100 year return period. This is in congruent to the result of flood inundation area in Kalilangan in various return periods as presented in Fig. 9 denoting a direct relationship with each other.

CONCLUSION

The integrated approach of hydrodynamic modeling and remote sensing with the aid of GIS techniques provides a potential and efficient way to increase the capability to model, predict and manage flood events for a reliable flood hazard zonation. Thus, harnessing this potential approach offers cost-effective way of flood hazard zone mapping in Kalilangan, Bukidnon to an acceptable accuracy level as regulated to restrict damages and casualties it may incur. The result shows that the generated flood hazard zonation is more influenced by flood depth and inundation area that shows hazard level and its corresponding extent. The proliferation in the magnitude of rainfall event (return period) from 5- to 100-year leads to an increase of river discharge, thus significantly intensify flood inundation area and hazard level. The identified barangays of Poblacion, West Poblacion, Pamotolon, Kinura, Macaopao and some parts of Ninoy Aquino and Canituan falls into the zone of low to high hazard of flooding of which greater area of medium to high hazard zone constitutes the total inundation area of the aforesaid barangays. Residential buildings which can be linked to household and community were the most flooded-type and exposed built-up structures in all flooding scenarios and the majority falls into the zone of high hazard. Identification of flood hazard zones gives awareness to the community and Local Government Units of Kalilangan, Bukidnon in understanding flood characteristics coupled with disaster preparedness. Flood hazard zonation plays a significant role in updating the comprehensive land use plan of the municipality of Kalilangan, Bukidnon, to serve as a guideline for any development and construction of infrastructures of the areas within the hazard zones which should be viewed with special attention and utmost importance. Hence, combined non-structural and structural flood preventing strategies should be adopted in the identified barangays where high hazard level is prominent, with high population density and development exists. This could be an underlying advance for action and strategic planning for disaster preparedness, reduction and prevention via incorporating the flood overlay zones on the land use plan, establishing necessary procedures as to operational communication and disaster response and public information and warning (Mohammed, 2018). Thus, harnessing this potential approach could set the evacuation routes and safe sites during flooding condition for flood control, disaster reduction and prevention considering that there is an appropriate actions administered towards its realization.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. In addition, the ethical issues; including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy have been completely observed by the authors.

ABBREVIATIONS

2D	Two-dimensional
DEM	Digital elevation model
DTM	Digital terrain model
F measure	Measurement of fitness
GIS	Geographic information system
h	hour
ha	Hectare
HEC-GeoHMS	Hydrologic engineering center-Geospatial hydrologic modeling system
HEC-HMS	Hydrologic engineering center-Hydrologic modeling system
HEC-GeoRAS	Hydrologic engineering center-Geospatial river analysis system
HEC-RAS	Hydrologic engineering center-River analysis system
IFSAR	Interferometric synthetic aperture radar
m	meter
MDRRMO	Municipal Disaster Risk Reduction and Management Office
Min.	minute
mm	millimeter
m^3/s	Cubic meter per second
NDRRMC	National Disaster Risk Reduction and Management Council
NSE	Nash-Sutcliffe Efficiency
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PBIAS	Percent bias
P.M.	Post meridiem
RAS	River analysis system
RIDF	Rainfall intensity duration frequency
RMSE	Root mean square error
RS	Remote sensing
RSR	Ratio of the root mean square error to the standard deviation
SAR	Synthetic Aperture Radar
SCS	Soil conservation service
SVM	Support vector machine
UH	Unit hydrograph
USACE	US Army Corps of Engineers
y	year

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