MAPPING AND ASSESSMENT OF FLOOD CONTROL STRUCTURES IN BUTUAN CITY, MINDANAO, PHILIPPINES USING LIDAR AND FLOOD SIMULATION MODELS

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ABSTRACT: This paper presents the mapping and assessment of existing flood control structures along Agusan River in Butuan City, Mindanao, Philippines through the combined used of LiDAR topographic datasets and flood simulation models. It can be recalled that several flooding events in Butuan City due to the overflowing of the Agusan River has caused catastrophic damages to both properties and human lives, especially last January 2014 during the onslaught of Tropical Storm 'Agaton', and lately in January 2017 during the torrential rains brought by the tail-end of a cold front. One of the questions raised during the occurrence of these flooding events are the roles and effectiveness of the existing flood control structures which consists of concrete flood walls and dikes. In this study, we utilized LiDAR-derived data products such as Digital Terrain and Surface Models (DTM & DSM) to extract and map existing flood control structures along the Agusan River in Butuan City. An integrated 1D-2D hydrologic and hydraulic models based on HEC HMS and HEC RAS that are capable of simulating detailed and spatially-distributed flood depth were developed using LiDAR-derived topographic datasets (DTMs and DSMs). The integrated HEC HMS and HEC RAS 2D models are then used to simulate the impacts of flooding caused by the recent flooding event in Butuan City caused by the tail-end of the cold front last January 2017. The model's outputs were used to differentiate the impacts of flooding with and without the presence of flood control structures. Finally, an assessment of the effectiveness of the existing flood control structures was conducted by comparing the flooding extent and depths from the two scenarios. The approach presented in this study can be an important reference for undertaking flood control structures assessment in the Philippines.

1. INTRODUCTION

1.1 Background

Flooding in the country is considered as one of the most tremendous phenomenon whose frequency of occurrence in the Philippines have manifested in recent years. This occurrence caused ample dilemma to the community; many houses are submerged, properties devastated and human lives taken by raging waters from the overflowing river (Santillan et al., 2016). It can be recalled that several flooding events in Butuan City due to the spilling over of the Agusan River has caused catastrophic damages, especially last January 2014 during the onslaught of Tropical Storm 'Agaton', and lately in January 2017 during the torrential rains brought by a tail end of a cold front (NDRRMC, 2017). One of the questions raised during the occurrence of these flooding events are roles and effectiveness of the existing Flood Control Structures (FCS) which consists of concrete flood walls and dikes.

Flood control structure are designed to protect coastal and river-bank area, including urban and agricultural communities, homes and other economically valuable areas, and the people located within them (USAID, 2012). To address the urgent needs of the community in preparing for the forthcoming of flood disasters with rains continue to become fiercer, an assessment of the effectiveness of current flood control structures along Agusan River was conducted.

Approaches in assessing the effectiveness of flood control mitigation measures is commonly requires either the use of one- and two-dimensional or a combined one dimensional – two dimensional (1D-2D) numerical simulation models in order to determine whether the existing FCS is an effective way to lessen and controls or prevents the impacts of flooding (Santillan and Makinano-Santillan, 2016); but in this study 2D numerical modeling will only be used.

The objective of this study is to assess the effectiveness of the existing flood control structure along Agusan River in Butuan City, Agusan del Norte, Mindanao, Philippines and generate hazard level and flood depth maps which show the extent of flooding with and without the presence of FCS.

1.2 Study Area

The study covers and focuses the area where flood control structures are located along Agusan River in Butuan City, Agusan del Norte, Mindanao (see Figure 1). Butuan City is one of the areas in the Philippines that always and frequently experience flooding when heavy and extreme rainfall scenario occur in the area. It is located at the northeastern part of the Agusan Valley, Mindanao, sprawling across the Agusan River. It is bounded to the north, west and south by Agusan del Norte, of the east by Agusan del Sur and to the northwest by Butuan Bay. According to the 2015 census (WIKIPEDIA, 2017), it has a population of 337, 063 people. It has an average density of 303 persons per km², higher than the regional average density of 101 persons per km². The existing land use of the city consists of the following: agriculture areas (397.23 km²), forestland (268 km²), grass/shrub/pasture land (61.14 km²) and other uses (90.242 km²) of the total forestland, 105 km² is classified as production forest area while 167.5 km² is protection forest area (WIKIPEDIA, 2017).

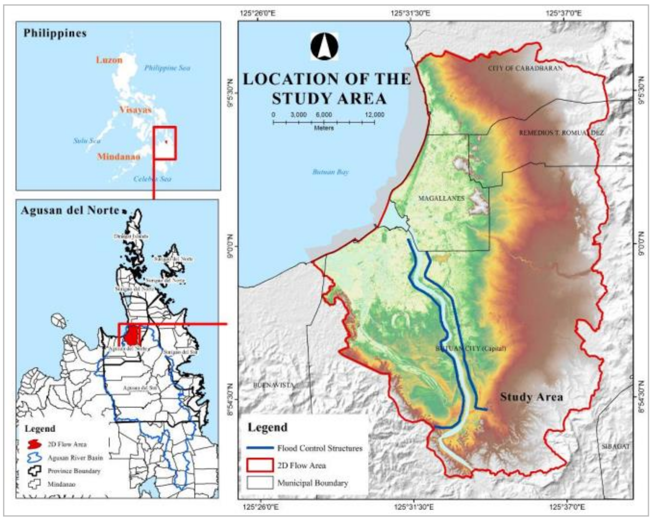

Figure 1. Study Area is within the boundary of 2D Flow Area along Lower Agusan River in Butuan

Agusan River along Butuan City where this study focuses lies on the lower Agusan River Basin (ARB), one of the three subdivided subbasins of ARB, flows from the south to north in the eastern part of Mindanao or mainly from Barangay Amparo to its mouth at Butuan City, Agusan del Norte.

2. METHODOLOGY

2.1 Overview

The methodological flowchart in Figure 2 depicts the summary of procedures involved in assessing the effectiveness of FCS along Agusan River in Butuan City. Form the necessary dataset, numerical model development and simulation, generation of flood inundation maps down to the assessment and analysis of the effectiveness of FCS during extreme rainfall scenario.

Based on the framework shown, the hydrologic model development can be done using the needed parameters that will be inputted upon the development of the model, mainly are the generated landcover map derived using the downloaded satellite images and rainfall values. After which a discharge hydrograph with the simulated discharge values will be used as an input for 2D Hydraulic modelling.

Before simulating the hydraulic model an integration and extraction of FCS in the LiDAR-derived data are needed. The extraction process can be done by manual digitizing from the available LiDAR-derived data (Santillan & Makinano-Santillan, 2016). After digitizing, extraction of FCS was done by using the Inverse Distance Weighted (IDW) technique within ArcMap 10.1 which interpolates a raster surface from points (Santillan, et al., 2016). By then, two Digital Terrain Models (DTMs) will be used for 2D Hydraulic model simulation; which one of it FCS were already extracted. After this, two 2D Hydraulic Models were simulated. Using the time series period during the occurrence of the torrential storm ‘Tail End of a Cold Front’ on January 16-30, 2017 and DTMs with and without the presence of FCS a simulated 2D Hydraulic Models can now be used to assess the FCS and generate an inundation map by converting it to raster which will be done using ArcGIS 10.1 techniques (Santillan, et al., 2016).

In flood control structures assessment 2D Numerical Modeling equipped with the techniques of HEC RAS and HMS was utilized in order to assess the effectiveness of the existing FCS.

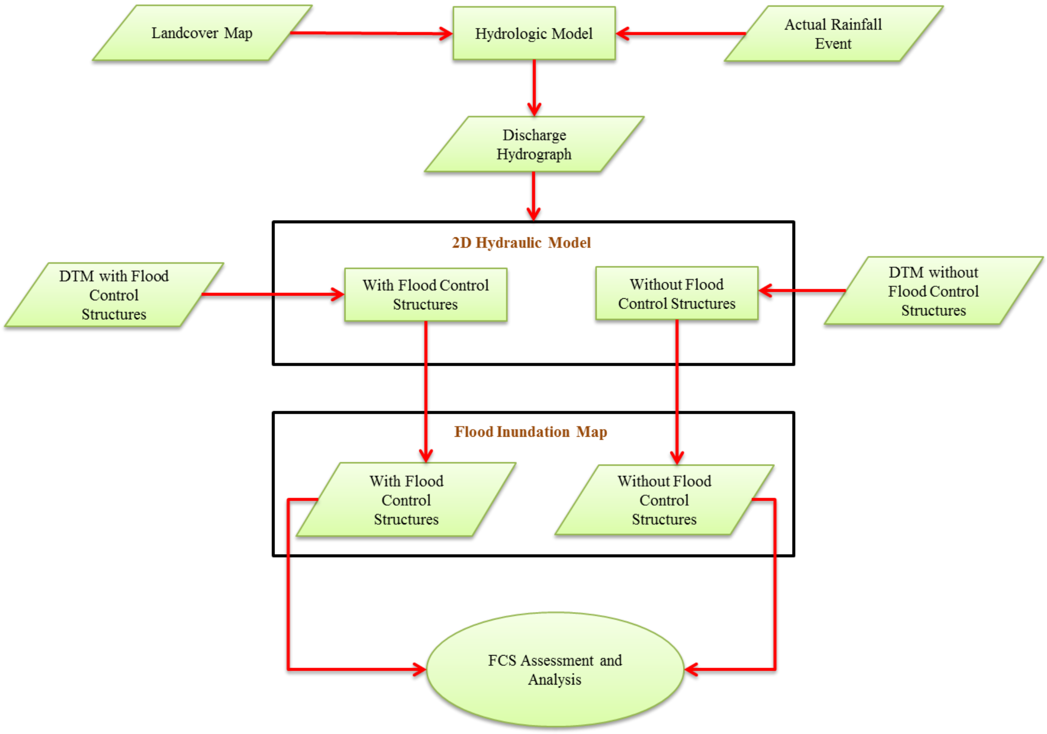

Figure 2. An illustration of the approach applied for FCS assessment and analysis

2.2 Datasets Used

The hydrologic model simulates flow hydrographs for specific locations in the river basin based on the downloaded rainfall data. The downloaded satellite images from the https://earthexplorer.usgs.gov/ were utilized for the generation of Landcover Map where eleven classes are classified (i.e., Built-ups, Barren, Palm, Cropland, Grassland, Shrubs & Fishpond, Forest, March Vegetation, Fishpond, Exposed Riverbed and Water). The generated landcover map information was used for the parameterization of the HEC RAS model by extracting the Manning's roughness coefficients and was assigned to the cross-section segment. After which, another dataset will be used as an input for the simulation of the model which are the downloaded rainfall values.

In the Philippines, LiDAR-derived Digital Terrain Model (DTM) through the UP DREAM Program (UP DREAM, 2016), provides appropriate detailed topographic information and other necessary physical ground features that can be utilized for flood risk assessment, most particularly in assessing the effectiveness of the existing FCS (Santillan & Makinano-Santillan, 2016) . This dataset was utilized for the simulation of 2D Hydraulic model and Synthetic Aperture Radar Digital Elevation Model (SR DEM). Extraction of FCS in the DTM was done using IDW where it assumes that distances between points are inversely proportional to the weight that each point influences to each other (Santillan, et al., 2016). Which means that as the distance between points increases, the influence of the points to each other decreases and the nearer the points, the more are they to resemble each other. The DTM extracted the FCS and not was utilized for the simulation of the model.

2.3 Rainfall Data Collection

Time series data of historical rainfall events were acquired from Automated Rain Gauges (ARGs) installed and maintained by the Philippine's Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) and can be accessed through http://fmon.asti.dost.gov.ph. Rainfall data from stations (see Figure 3) within and around the Agusan River Basin during the hit of the tail-end of the cold-front (January 16-30, 2017) was considered.

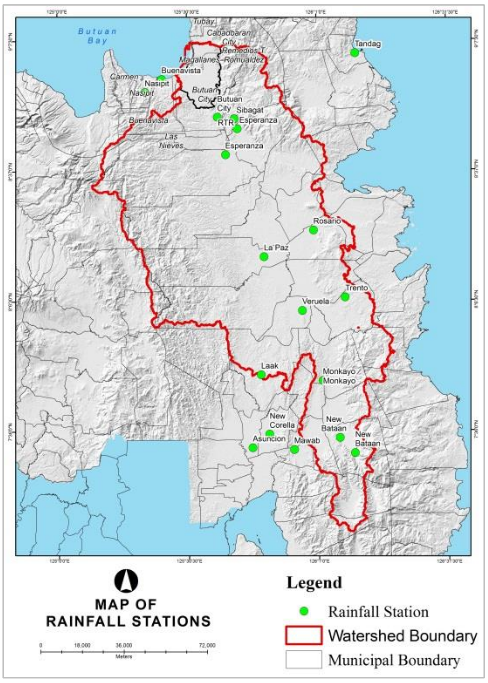

Figure 3. Map showing the location of rainfall station for Agusan River Basin

2.4 Hydrologic Model Development

The hydrologic model of Agusan River Basin was based on the Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS), simulation software specifically designed to simulate the precipitation-runoff processes of watershed systems (USACE, 2010). HEC HMS modeling is dependent on the three components: the basin model, meteorological model and the set of control specification. For Agusan River basin, the basin model, which is the physical representation of the watershed, was developed by utilizing a 10-m SAR DEM and the river networks in the delineation of watersheds.

2.5 2D Hydraulic Model Development

Hydrologic Engineering Center River Analysis System (HEC-RAS) Version 5.0.3 was used for the development of the 2D hydraulic model of the Agusan River Basin. This software is designed to perform one- and two-dimensional hydraulic calculations for a full network of natural and constructed channels, overbank/floodplain areas and levee protected areas (Santillan et al., 2016). The 2D HEC RAS of the Butuan City floodplain area was develop by first creating geometric representations of the rivers and the floodplain area. These geometries are: the 2D flow area, which represents the floodplain portion; the breaklines, which sets the model on the location of sudden drop or rise in elevation; and the boundary conditions wherein the hydrologic values are inputted. Two hydraulic models were developed with different cases; (1) model with existing FCS, and (2) model without the FCS. To simulate the actual scenario, boundary conditions (Figure 4) were identified in the 2D flow area that are inputted with inflow data generated from outflows of the hydrologic model, tidal data at the sea portion, and the actual precipitation .

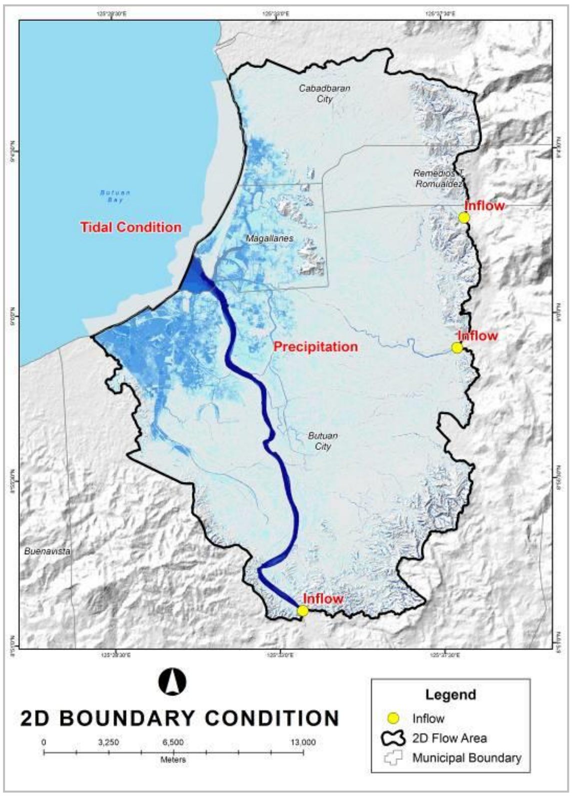

Figure 4. Boundary condition locations of the 2D hydraulic model within the Butuan City floodplain area.

2.6 Flood Inundation Map Generation

For generating the flood inundation maps for an extreme rainfall scenario, the internal flow boundary condition locations were and the inflow and internal flow condition locaitons' maximum flow rate were attained from the simulated discharge hydrographs and utilized as an input for HEC RAS steady flow estimation (Makinano-Santillan, et al., 2015). Flood Depth grid was generated by having the maximum depth in each cell even without the time when that depth was reach the period of simulation (Santillan J. R et al., 2016) and categorized based on its corresponding hazard level. The categorization 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 (Makinano-Santillan, et al., 2015).

2.7 Flood Control Structure Assessment and Analysis

The HEC RAS 2D Hydraulic Model integrated with the discharge values using the HEC HMS model were utilized to compute the estimated flood depths and extents in Butuan City's floodplain area during the onslaught of the tail-end of the cold front with and without the presence of FCS. The outputs were exported in a raster file format and loaded in ArcGIS for spatial analysis. The analysis involved the comparison of the possible maximum depths and extent experienced by Butuan City during the simulation period with and without the FCS. Also, from the outputs of flood models which are the flood depth and categorized hazard level will be used for the assessment of the effectiveness of flood control structures.

3. RESULTS AND DISCUSSION

3.1 Flood Model Development and Simulation

A developed hydrologic model of Agusan River Basin is shown in Figure 5. Agusan River basin consists of 538 subbasins, 309 reaches and 309 junctions. The hydrologic model was simulated using an actual and historical event by using the downloaded rainfall data from January 16 to 30, 2017.

The 2D flow area of the simulation model has an approximate area of 368.53 km^2 and was meshed using a 60-m by 60-m cell size. The simulation of the HEC RAS model utilized the DTMs with and without the presence of the flood control structures which were computed with 102,648 and 101,937 cells respectively. Manning's roughness map (Figure 4) derived from Landsat satellite image classification was also incorporated in the model. The simulation period used was from January 16 to January 30, 2017.

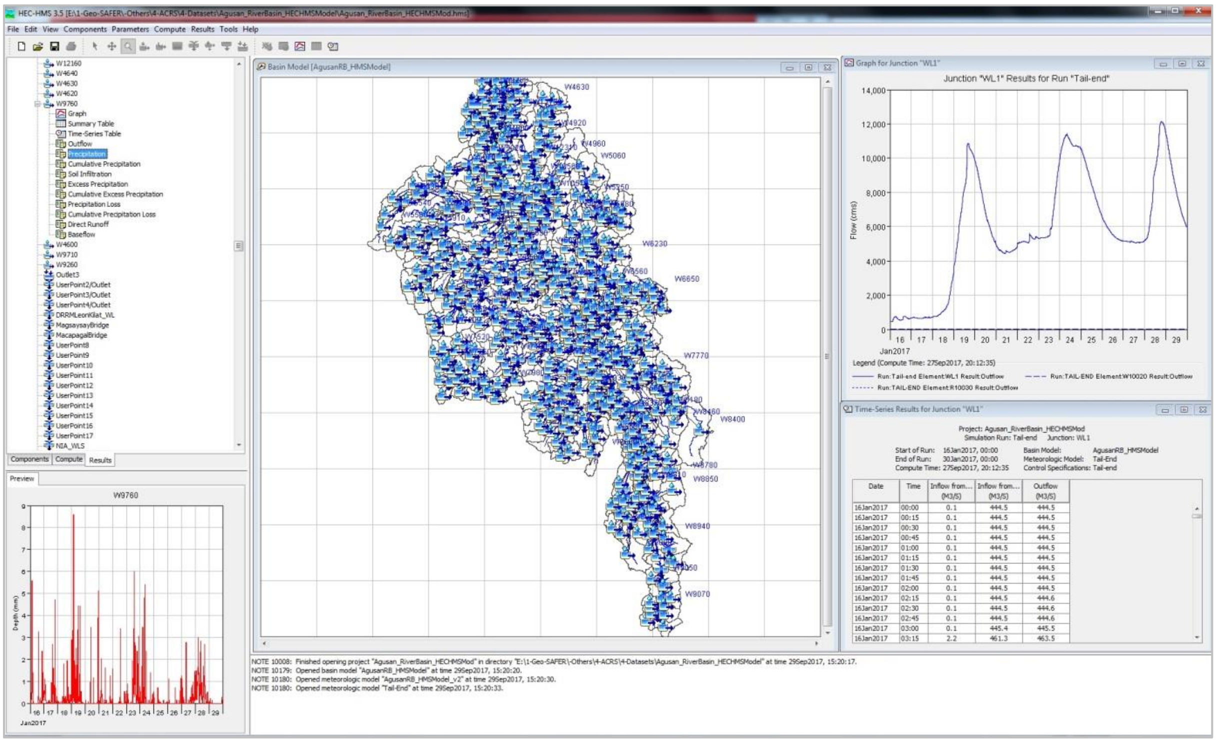

Figure 5. The interface of the HEC HM-based hydrologic model of Agusan River Basin

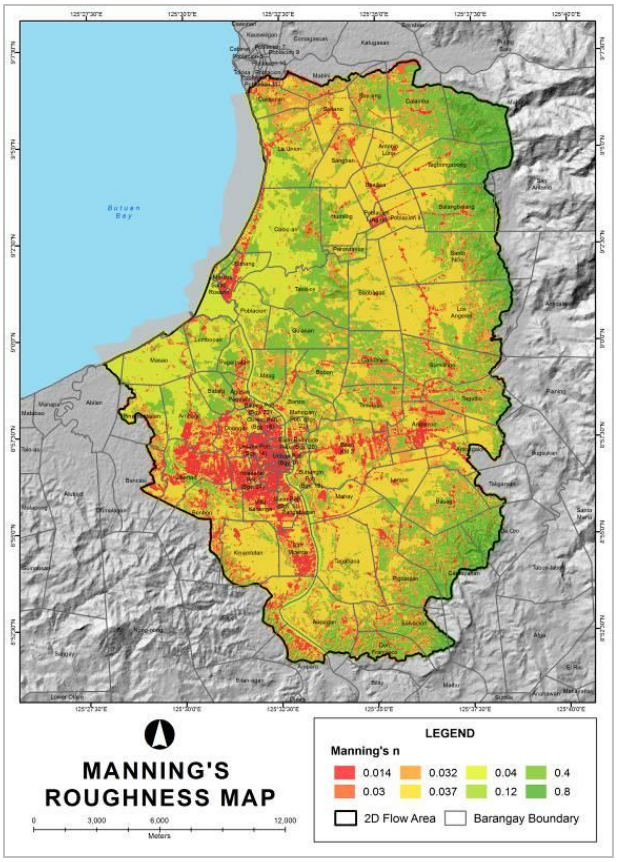

Figure 6. Manning;s Roughness Map of the Butuan City floodplain area

3.2 Flood Inundation Map Generated

The generated flood depth and hazard level maps of Agusan River Basin for ‘Tail End of a Cold Front’ event are shown in Figure 7 and Figure 8, respectively.

Area of the flood extent with and without the presence of FCS and categorized its depths into hazard levels with their corresponding area is shown in table 1. It depicts an approximate total area of extent. Simulated 2D numerical models with FCS have an approximate total area of 154.71 km^2 and have a total of 163.76 km^2 without FCS.

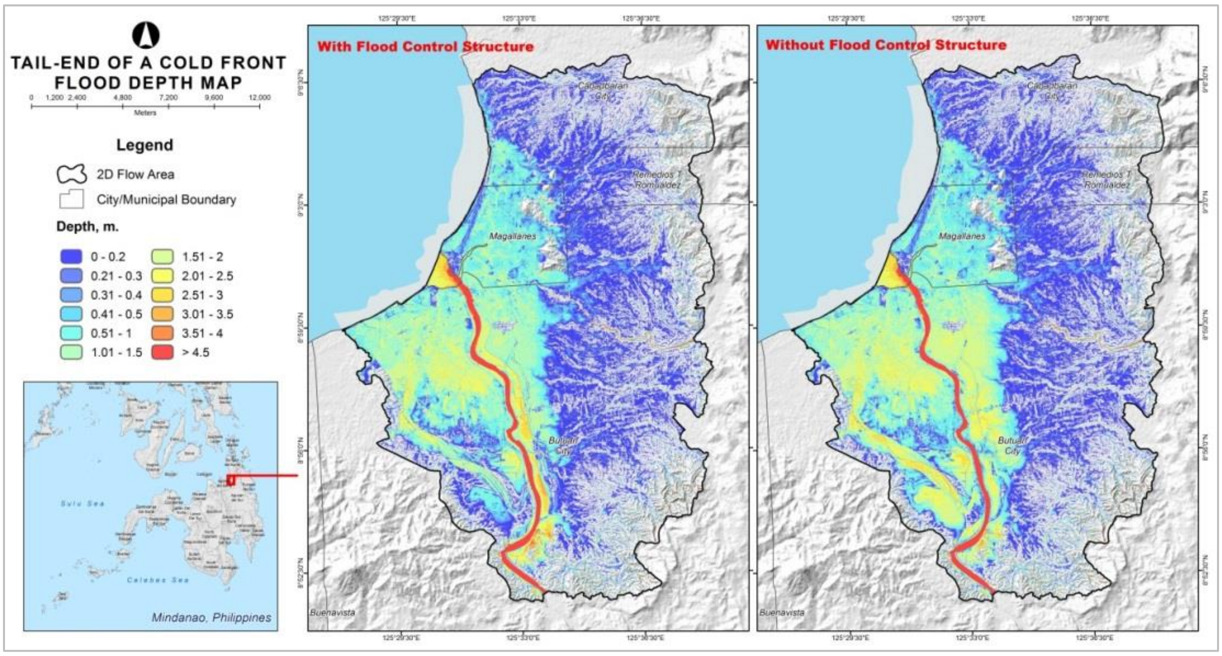

Figure 7. Flood Depth Map during Tail End of a Cold Front event

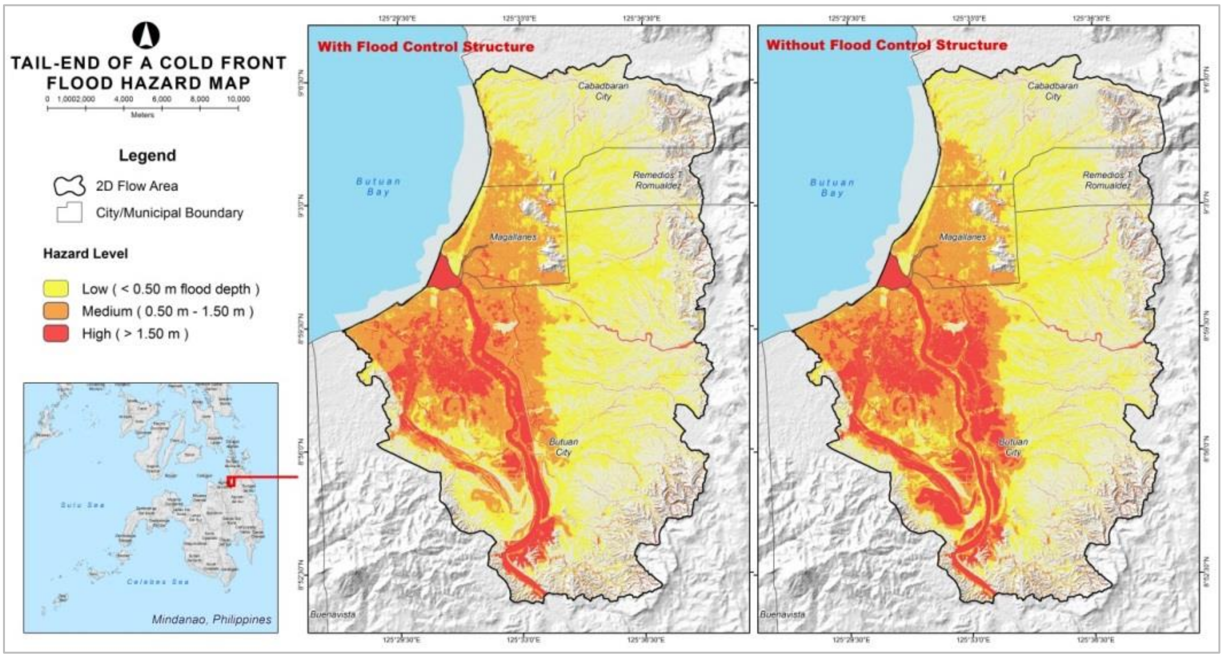

Figure 8. Flood Hazard Map during Tail End of a Cold Front event

3.3 Assessment of Flood Control Structures

The difference when it comes to the area of its flood extent will be shown in Figure 9, Figure 10 and Figure 11. Area of flood extent with the presence of FCS has an approximate total area of 154.71 km^2 (see Figure 1).

Meanwhile, flooding without the presence of FCS shows that flooding in the area is much greater than with presence of FCS which has an approximate area of 163.76 km^2. Flood hazard maps depict that, though inundation can be seen anywhere yet if we would take a look to its level of hazard we can differentiate to that map (see figure 11; left map) where FCS has its presence that it lessens the vulnerability of flooding unlike to that map in figure 11 on the right side.

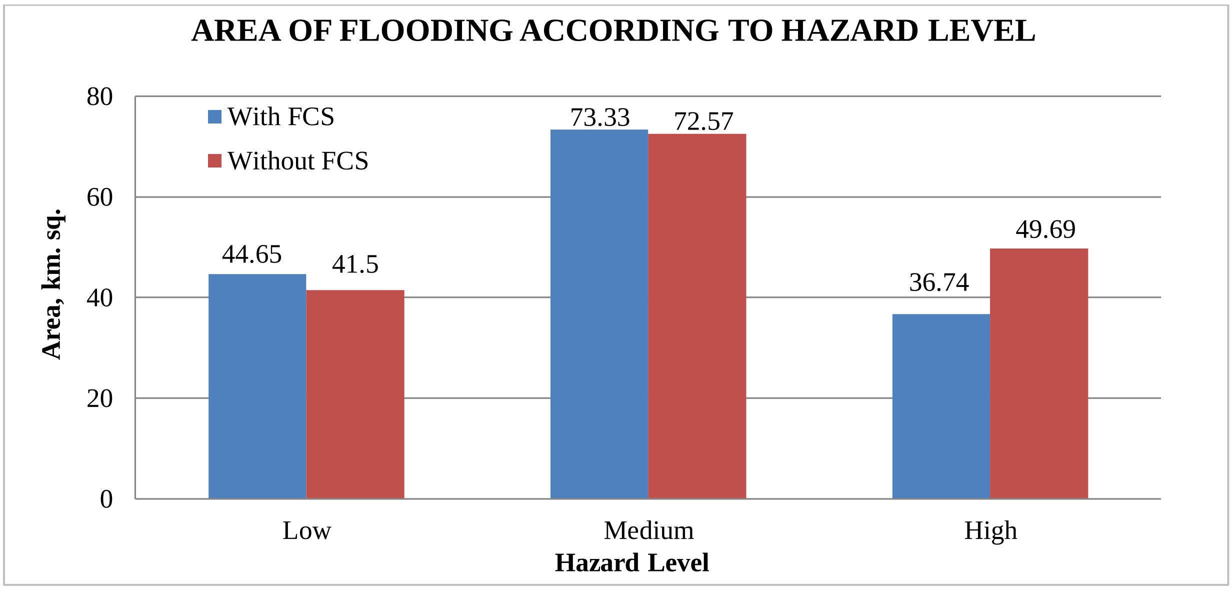

Figure 9. Graph of the calculated area of flooding in Agusan River Basin according to hazard level

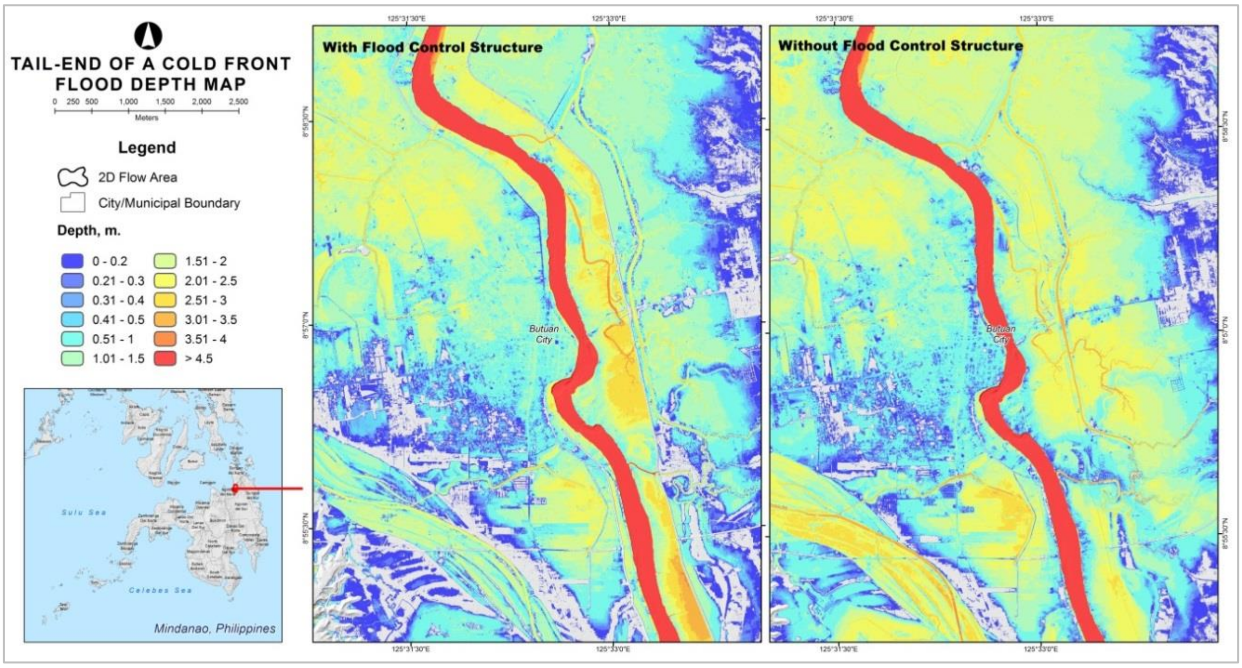

Figure 10. Comparison of the flood depth maps with and without the presence of FCS

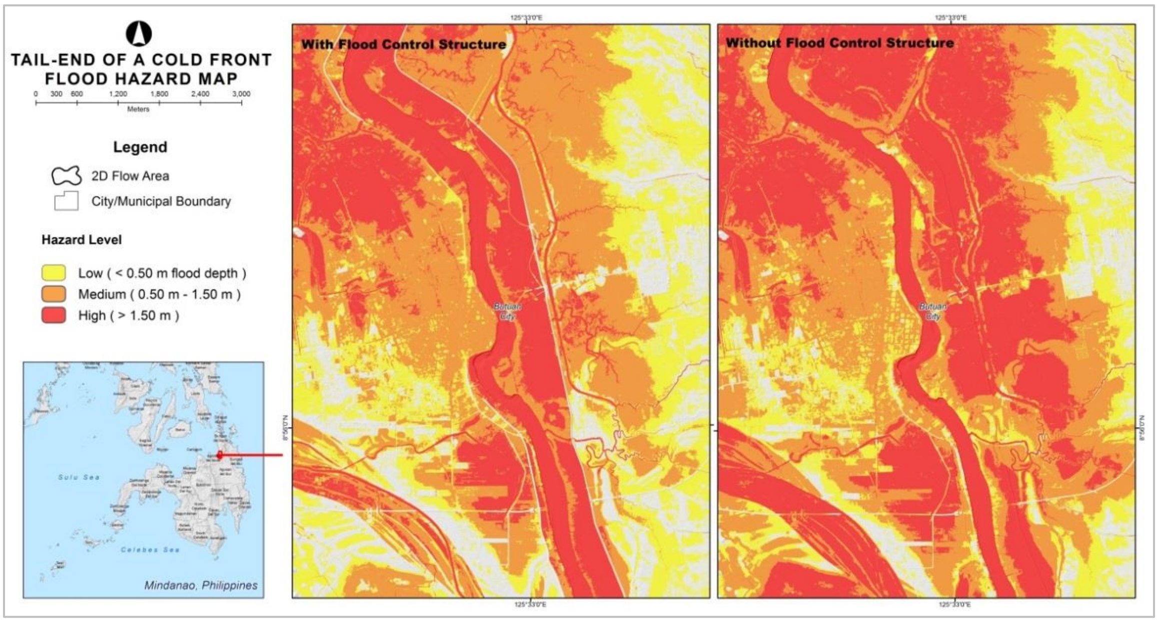

Figure 11. Comparison of the flood hazard maps with and without the presence of FCS

Table 1 Calculated areas of flooding according to Hazard Level during the hit of the Tail-end of a Cold Front

Hazard level	Flooded Area (km2)	
	With FCS	Without FCS
Low (<0.50 m flood depth)	44.65	41.5
Medium (o.5 m - 1.50 m0	73.33	72.57
High (> 1.50 m)	36.74	49.69
Total Area	154.71	163.76

4. CONCLUDING REMARKS

The approach of this study is the comparative analysis of 2D hydraulic simulation results between the models with and without the presence of flood control structures and actual extreme event using geospatial and 2D numerical model simulation. Based on the results, due to extreme and heavy rainfall event the City of Butuan experienced flooding even with or without the presence of FCS. Flood mitigation measure is effective as it decreases an approximate area of 9.05 km^2 of flood extent in the city. However, flooding in the area without FCS have getting worse as it increases the vulnerability of flooding. With this, even if inundation is present, the city has huge advantage as FCS lessens and mitigates the extent of flooding in the community. FCS has its important role in the advent of this phenomena, that is why planning and designing FCS where it will be constructed and placed should be done and is necessary.

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