Assessment Of The Existing And Proposed Dike System Along The Cabulig River In Lower Jasaan, Misamis Oriental, Philippines

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Abstract

The issue of flooding in the town of Jasaan in Misamis Oriental province poses a threat to 42% of the population. This is more worrisome during the rainy season, especially in the months of October and December were typhoons are at their strongest and passes in proximity to Mindanao island. Residents have reported significant damage to their properties due to flooding, and typhoons like Super Typhoon Odette in December 2021 have worsened the situation when it brought rain while the dike system was dilapedated. The dike systems in the area have been damaged by these natural disasters, and the lack of repair has made the situation worse. Flood hazard mitigation measures have since been implemented. With the frequent occurrence of flooding in the Cabulig River, a validated model is needed to investigate the behavior of the river during strong and significant rainfall events while taking into consideration the current state of the existing dike systems by coupling the modelling systems HEC-HMS and HEC-RAS. Data from the USGS, DOST-PAGASA, DPWH, and Landsat 8 have been used in this study. The results of the Flood Inundation Analysis showed that most of the flooded areas in Barangay Lower Jasaan and Bobontugan are urban areas which exacerbates during heavy rain events. The results of the simulations of the researchers' proposed dike structures shows that it should be extended towards the upstream direction and a minimum dike height of 2.5m is needed with no discontinuities. A 2.5m high dike on the Bobontugan side should also be placed.

1. Introduction

1.1 The Problem and its Setting

Flood is a disastrous phenomenon that endangers the livelihood, infrastructures, and properties of vulnerable communities. One cause of flooding is river overflow which can be attributed to extreme rainfall. Rainfall over an extended period on an extended area can cause major rivers to overflow their banks. It is also known to have the potential damage to downstream areas which result in death, displacement of people, and damage to properties (Klippe, 2020). According to Rentshler and Salhab (2020) the Philippines is one of the top ten countries with a high absolute population exposure to flood risk. An average of twenty tropical cyclones enter the Philippine Area of Responsibility where about eight to nine of them cross the Philippines and leave severe damages and deaths.

Jasaan, Misamis Oriental is a location exposed to flood hazard constituting 42% of their population. Numerous residents claim that flooding is very common particularly during rainy seasons in the months October and December. A section in Mindanao Daily Newspaper authored by Cris Diaz and Ruel Pelone (2014) reports flooding in Jasaan in the month of October due to heavy rainfall associated with the Intertropical Convergence Zone (ITCZ). This event flooded the towns of Jasaan and caused multiple damaged house properties in the area. In addition to heavy rainfall, several typhoon events have also contributed to the flooding of Jasaan. One of the recent typhoons that hit Jasaan was Super Typhoon Odette dated in December 2021. The Super Typhoon affected 7,518 residents and caused Php 101,482,000 cost of damages to houses and infrastructure (NDRRMC, 2022). Moreover, according to the situational report from the Municipality Disaster Risk Reduction and Management Office of Jasaan (MDRRMO), the barangay Lower Jasaan and Bobontugan has the highest number of families affected, estimated to a number of 478 and 446 families, respectively.

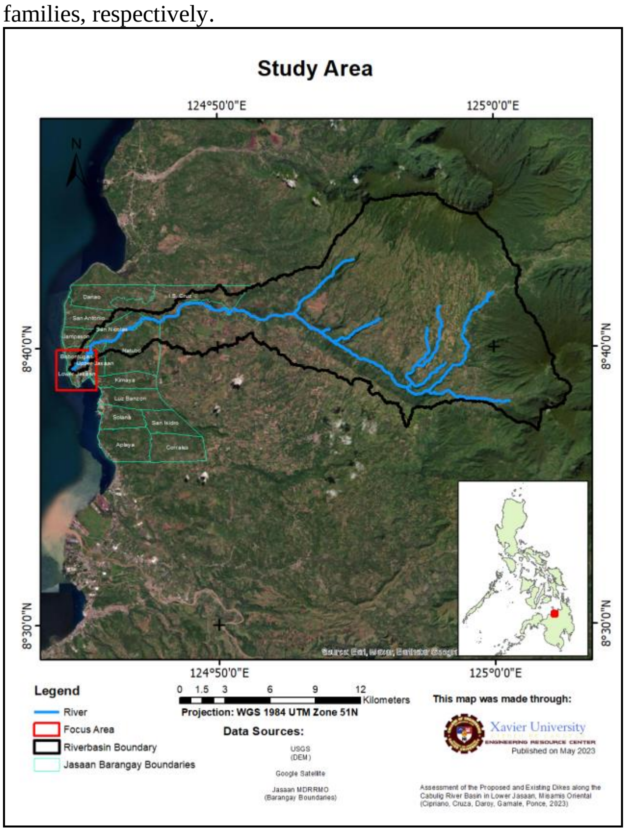

Figure 1: Study Area Map

Another typhoon was Typhoon Agaton that stranded 40 people in the Barangay San Nicolas of Jasaan in January 2014. According to Gallardo (2014), the attempt of the Army soldiers to rescue the San Nicolas residents failed due to the raging waters of Cabulig River. This flooding can be attributed to the overflowing of Cabulig River which is a river basin situated west of Bobontugan River, and northwest of Solana River. It has a total area of 23,370 hectares and has a catchment area of approximately 233.70 sq. kilometers. It is bounded by Balingasag and Claveria in the north; Gingoog and Claveria in the east; Claveria and Villanueva in the south; and Jasaan in the west. The river drains towards the western direction into Macajalar Bay (Paringit, E., & Puno, G., 2017).

According to CDO Dev (2021), Cabulig River is closely monitored by the LGU of Jasaan particularly during heavy rainfall due to its rise of water level. During rainfall events, their LGU personnel immediately alerts the residents in low lying areas beside the river such as the barangay of San Nicolas, Lower Jasaan, and Bobontugan for the possible rise of water level and if there is a need of evacuation in the area. The MDRRMO of Jasaan addresses the flooding problems through nonstructural mitigation measures such as incorporating immediate flood warning to the residents, evacuation planning, and emergency preparedness response. The LGU of Jasaan also intends to focus on structural mitigating measures through improving the dike systems along Cabulig River.

A dike system was built along the Cabulig River to protect the residents against flooding from the river during heavy rainfalls. However, these dike systems have been damaged due to the previous flooding and were left unrepaired. A disconnected part of the dike can also be observed near the SEVAGA Village allowing the river to flow freely inside the dike. Flood protection structures such as dikes are designed to protect river-bank areas, including urban and agricultural communities, homes, and other economically valuable areas, and the people located within them. These structures are used to divert flows of water, by redirecting rivers, slowing natural changes in embankments and coastlines, or preventing inundation of vulnerable coastlines or floodplains (Climatelinks, 2012). These dike structures, if properly maintained and monitored, werefurther reduce flood risks in vulnerable areas in Jasaan, Misamis Oriental.

There is a growing flooding problem in the surrounding areas of the Cabulig River in Lower Jasaan, Misamis Oriental. Residents have experienced flooding that reaches up to the second floor of their houses during heavy rainfall events which usually happens in the month of December as mentioned by the municipal mayor. There are a few factors that affect the occurrence of floods along the river basin of Cabulig river including the excessive precipitation along the upstream or the downstream of a river, the absence and/or damaged flood mitigation structures, lack of engineering interventions, and/or silting.

The study aims to shed light on the issues of flooding on the study area by investigating the behavior of the river during strong and significant rainfall event while considering the present state of the dike systems and the proposed dike system by the national government.

2. Methodology

2.1 Research Design

To derive a flood inundation map of the Cabulig River watershed and investigate the adequacy of the existing dike systems and the proposed dike system by the national government, the study is composed of seven (7) major phases namely: study area determination and data acquisition, land use classification, basin model development, model sensitivity analysis, model validation, floodplain modeling of different dike scenarios, and flood inundation analysis.

The first phase involves the determination of the study area and delineating the river basin and identifying its drainage networks. These served as a valuable input for both hydrologic and hydraulic models. The following data were needed to serve as inputs to create the model: physical data such as Digital Elevation Model (DEM) from United States Geological Survey (USGS), Rainfall Data from DOST - Philippine Atmospheric Geophysical and Astronomical Services Administration (DOST-PAGASA) – Mindanao PAGASA Regional Services Division, Soil Type Map from Bureau of Soils and Water Management (BSWM), and Land Cover Map from DENR’s attached agency – the National Mapping and Resource Information Authority (NAMRIA), while the dike geometric specifications, and baseflow measurements were collected through field obsesrvations. In the second phase, a land use classification consisting of five unique classifications were generated for spectral analysis, which is necessary for the flood models. The third phase involves developing a hydrological and hydraulic base model.

Hydrologic base model was designed to simulate rainfall-runoff processes of the identified river basin. Hydraulic base model, on the other hand, was generated through simulating an unsteady flow condition to identify the flood extent, flow distribution, flow direction, water depth in the focus area. In the fourth phase, sensitivity analysis was conducted simultaneously for both models, hydrologic and hydraulic model. This phase presents how sensitive a trial model can be with regards to the value of the parameters when compared to the base model. By conducting sensitivity analysis, the appropriate values for each parameter were determined to generate an improved model. Fifth phase involves validation of the hydraulic model with existing dikes by establishing validation points in the focus area of Jasaan, Misamis Oriental, particularly in Barangay Bobontugan, Lower Jasaan, and Upper Jasaan for Super Typhoon Odette 2021. Sixth phase was modeling the floodplain considering different scenarios in the study area, this includes the modeling of the current situation of the focus area with the existing dikes to identify as to which areas are at risk of flooding disaster, as well as the assessment of the proposed dike structures of the national government, and the proposed dike system to check the flood inundation of the area accordingly. The final step was to perform a flood inundation analysis to assess the effectiveness of the constructed dike system. This involves identifying important areas, flood-prone zones, and portions of the dike system that may experience overflow during a flood event. This evaluation builds upon the models developed in the previous phases.

2.2 Defining Focus Area

As shown in Figure 1, the main attention of the study is focused within the boundary of Lower Jasaan where the dike system has already existed and proposed to be constructed along areas in the Cabulig River.

2.3 Land Use Mapping

The generation of Land Use classification utilizes the satellite imagery from the Landsat 8 with 30x30m multi-spectral spatial resolution and eight (8) spectral bands. The least cloud-covered

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images were taken on July 26, 2019, due to the El Nino Phenomenon.

The ArcMap software was used to establish 550 Regions of Interest (ROI) for the five (5) unique classification signatures: Water, Built-up, Light Vegetation, Heavy Vegetation, and Open Spoil. Each classification had an allocation of 110 ROIs. These ROIs were subsequently processed to produce the final land use classification maps with a multi-spectral spatial resolution of 30x30. Image enhancement and band merging was performed to improve the image visually for better interpretation. Band merging is useful for image interpretation and information on land cover.

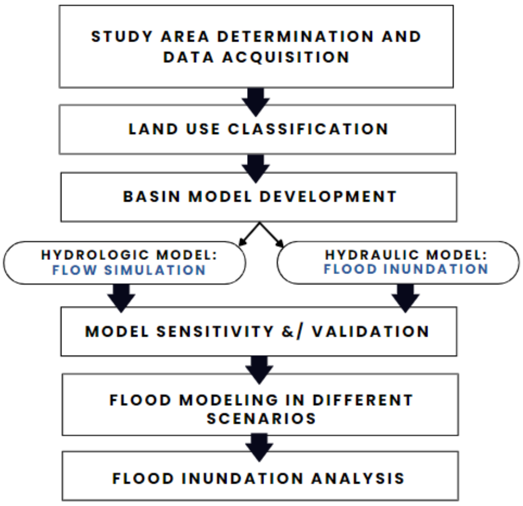

Fig 2. Research Design

The five (5) band combinations used were B543, B764, B432, B564, B753 for analysis. After the image enhancement and band merging, the signature information of each class was extracted. Plots of land were classified in the training sample manager and saved as a reference shapefile for the classification process. Then, the image was trained with the Interactive Supervised Classification (ISC) algorithm. This satellite imagery was then utilized in the validation through setting five random ROIs. Accuracy assessment is used to quantify the effectiveness of the pixels being classified at their correct land cover. Validation points of 100, 150, 200, and 250 were then used to validate the accuracy of the sampled maps.

Land Use Classification	*Manning's n Values*
Open Soil	*0.02*
Heavy Vegetation	*0.1*
Light Vegetation	*0.035*
Urban	*0.015*
Water	*0.03*

Table 1. Manning's n Values

2.4 Hydrologic Modeling

In this study, the hydrologic model of the watershed was generated using HEC-HMS while the GIS pre/post processing using ArcMap v.10.1 extension HEC-GeoHMS. The public domain software, HEC-GeoHMS, was used to simulate event-based and continuous rainfall-runoff of dendritic watersheds. The hydrologic modeling process was adapted from recent works on HEC-GeoHMS

2.4.1 River basin delineation

For river basin delineation, terrain processing were conducted to delineate the Cabulig River basin's drainage or stream network, and its subbasins. This is used to define the study area that were used to develop the input files for an HEC-HMS project. The DEM were processed to create required layers to delineate the river basin to extract hydrological products, which includes flow direction, filled sinks, stream definition, flow accumulation, catchment grid delineation, catchment polygon processing, and stream segmentation, as well as drainage line processing, adjoint catchment processing, drainage point processing and batchwatershed delineation adapted from the work of Ersahin B. (2020). A Lidar survey from DOST-Phil Lidar project was used for the digital elevation which then processed to produce stream networks, a delinated watershed, and other hydrologic elements i.e. subbasins, junctions, and reaches.

2.4.2 Characterization and Parametrization of the Delineated River Basin

HEC-GeoHMS computes several topographic characteristics of streams and subbasins that can be used for estimating hydrologic parameters (Ersahin, 2020) including River Length (length of the river segments reaches from end to end), River Slope (upstream and downstream elevation of a river, and a surface of which one end or side is at higher level than another). To add to this Ersahin (2020) also mentioned other parameters such as Basin Slope, Longest Flowpath, Basin Centroid, Centroid Elevation, and Centroidal Longest Flowpath are used for extracting topographic characteristics of rivers and subbasins.

After the characterization of the delineated river basin, parameters of the model was estimated as subbasin average and grid-based values using the soil and land cover map. The HMS Process parameters for the subbasins and reaches were be selected. Different methods were used for the calculation of each hydrologic element. These methods are shown in Table 1.

Hydrologic Element	Calculation Type	Method
Subbasin	Loss Rate	SCS Curve Number
	Transform	Clark Unit Hydrograph
	Baseflow	Recession
Reach	Routing	Muskingum-Cunge

Table 2. Methods used for the Calcualtion for each Hydrologic Element (HEC-HMS User's Manual)

The soil type, land cover, and the Hydrologic Soul Group were used as basis for the computation of the hydrologic elements namely I_a as initial abstraction, Curve Number as CN, imperviousness as % impervious, and the Manning's coefficient as *n*, all are computed for each subbasin.

After calculating values for the CN field for each subbasin, the Initial Abstraction, Imperviousness (%), Time of Concentration, Storage Coefficient, Base Flow were calculated using the following formulas:

Initial Abstraction (I_a), a parameter that accounts for all losses prior to runoff which consists of interception, infiltration, evaporation, and surface depression storage.

$$I_a = 0.2\,S \qquad [1]$$

$$S = \frac{25400}{CN} - 254 \qquad [2]$$

Percent Imperviousness are solid surface that prevent infiltration, and water penetration. For all built-up areas, the value assigned for Imperviousness should be 100, and 0 to all non-built-up areas based on the land cover map.

The lag time and baseflow of the subbasin were calculated from the terrain of the watershed. Time of Concentration (T_c), is the time required for runoff to travel from the hydraulically most distant point in the basin to the outlet. It can be calculated by using the formula:

$$T_c = \frac{BasinLag}{0.6} \qquad [3]$$

By running River Auto Name and Basin Auto Name, the model were assigned with names to the identified river segments and sub-basin for HMS. The Subbasin Parameters were converted to Raster to create grid layers. These parameters include CN grid, I_a grid, and Percent Imperviousness grid.

For Basin Model Export Preparation, convert HMS units to SI units, this converts the physical characteristics of reaches and subbasins to SI unit system. Run Map to HMS units for HEC-HMS Basin model preparations. Then check data to verify all the input datasets correctly. This checks if there are errors and problems in exporting the data.

2.5 Hydrological Data

2.5.1 Rainfall

The rainfall data were acquired from the PAGASA rainfall database specifically at San Luis Malit-bog Station as it is the closest one available to the river basin. The data acquired was dated on December 16, 2021, during the Super Typhoon Odette and had a 10-minute interval in a day. This data was used in HEC-HMS during the simulation of actual and hypothetical rain events.

2.5.2 Gauge Height - Discharge

The gauge height and discharge data stationed at Nahalinan, Jasaan, Misamis Oriental was obtained from the Quality Assurance and Hydrology Division of the Department of Public Works and Highways - Regional Office X. The collected data was then manually tabulated in excel format and used for further analysis through generating a rating curve. The rating curve established the gauge height – discharge relationship in which the discharge, *Q*, can be used to represent as a function of the depths which in this case the gauge height, *h* readings which is then to be used in the calibration of the HEC-HMS Model.

2.6 Sensitivity Analysis

Sensitivity Analysis was performed in this study in order to analyze the interaction between the different parameters and their spatial variability. This analysis was useful in making the development of the hydrologic model and hydraulic model more accurate.

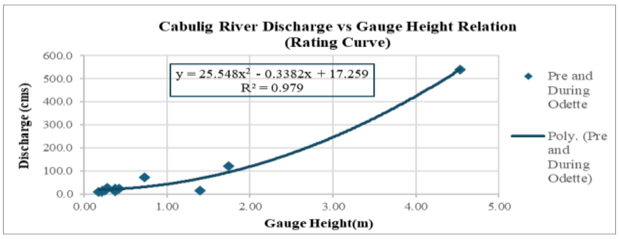

Figure 3. Cabulig River Rating Curve (Pre and During Odette)

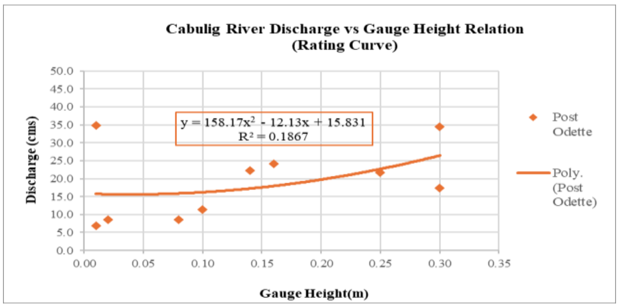

Figure 4. Cabulig River Rating Curve (Post Odette)

The different parameters were adjusted in different scenarios to develop models and determine the most sensitive parameter. This analysis is important for this study to establish the parameters that have the most effect on the peak flow of the water. Thus, the effect of each parameter: curve number, initial abstraction, % imperviousness, time of concentration, storage coefficient, baseflow, manning's n, and river width were determined separately by keeping other model parameters constant. The sensitivity of the parameters was observed based on the percentage match of each trial wherein the base model peak flow at outflow point was compared to the peak discharge obtained by increasing the values of each parameter by +-10%, +-20%, and +-30%, while keeping all other parameters fixed at their intial values.

The sensitivity was compared to the base model in terms of the peak flow value at outflow point using the formula:

$$Percent\ Difference\ (\%) = \frac{|Q_{s(peak)} - Q_{b(peak)}|}{\frac{Q_{s(peak)} + Q_{b(peak)}}{2}} \times 100$$

Where: $Q_{s(peak)}$ = simulated model peak flow at outflow point

$Q_{b(peak)}$ = base model peak flow at outflow point

2.7 Hydraulic Modeling

A hydraulic base model was utilized as basis for comparison of the resulting models from the sensitivity analysis. Its parameters were referenced to the conducted base flow survey and assumed parameters such as the normal depth. The model was also based on the Digital Elevation Model (DEM) that was further refined though terrain modification to coincide with the present river path. The modification was done through HEC-RAS with the use of Google Satellite to trace the present path of the river.
A two-dimensional hydraulic model was then generated through simulating an unsteady flow condition in HEC-RAS. The model developed presents the extent of flood, flow distribution, water

depth, water velocity, and flow direction data that was processed from the geometric data and boundary conditions set on the model.

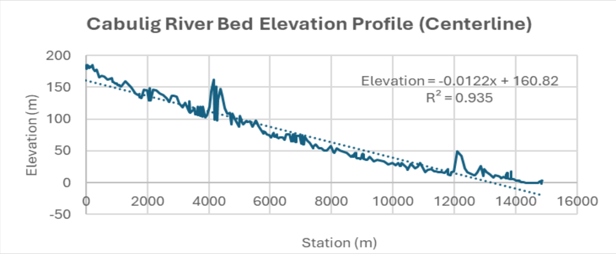

Figure 5. Elevation Profile at Centerline of Cabulig River Bed

2.8 Hydraulic Modeling

The Resulting models from the sensitivity analysis were compared to the base model and were utilized to evaluate which parameter requires improvement to obtain a more accurate representation of the hydraulic model.

Sensitivity of a parameter is identified with the use of percent match of each trial compared to the base model. The formula used:

$$\%\,match\ (P) = 100 - \left| \frac{A_b - A_p}{\frac{A_b + A_p}{2}} \times 100 \right|$$

The value of P ranges from 0% to 100%, a lower value indicates how far the results are compared with the base model results which in turn identifies a parameter to be sensitive. The value A_b is the inundated area of the hydraulic base model while A_p is the inundated area of each trial in each parameter.
Below are the list of parameters and values for each trial made during the sensitivity analysis.

2.9 Discharge and Manning’s n

The discharge utilized for simulation was taken from the conducted base flow survey and the flow hydrograph produced from the simulation of the Super Typhoon Odette rainfall data in HEC-HMS with different parameters adjusted.

Trial	Discharge Description
Base	December 16, 2021 Rain Event (ST Odette) Peak Discharge: 876.7 cu.m
1	December 16, 2021 Rain Event (ST Odette) Peak Discharge: 889.8 cu.m
2	December 16, 2021 Rain Event (ST Odette) Peak Discharge: 1024.1 cu.m
3	December 16, 2021 Rain Event (ST Odette) Peak Discharge: 875.8 cu.m
4	December 16, 2021 Rain Event (ST Odette) Peak Discharge: 882.1 cu.m
5	December 16, 2021 Rain Event (ST Odette) Peak Discharge: 984.2 cu.m

Table 3. Sensitivity Analysis on Discharge: Trial Descriptions

Manning's n values were obtained through the land use layer which represents the resistance to flow in channels and floodplains. These values were changed and varied with different assumptions for the floodplain that is associated with the land use classification layer.

2.10 RAS Validation

The hydraulic models underwent validation to produce a more accurate representation of the flood models. Validation points were pointed out which indicated either a flooded area or an unflooded area during the flooding event that was caused by Super typhoon Odette.

2.10.1 Adjustments

Adjustments were made using the sensitive parameters that were identified during the sensitivity analysis of the base model in HEC-RAS and trials were done to identify and produce the model which produced the highest %match of the validation points. Restrictions due to the limitations within the parameters (e.g. bridges, spillways, dams, debris, and updated river profile, were not considered) prevented the production of precise simulation and modelling of the flooding event.

2.10.2 Final Modeling

The final phase of hydraulic modeling is to produce an accurate model of the flooding event after the validation and adjustment phase. The model which produced the highest %match value was then selected and made as the final model entitled “Final Model with Existing Dike”.

2.10.3 Final Modeling Considering the Proposed Dike System

The floodplain was delineated and modelled to determine and investigate the route of the river water. Two further scenarios were to be modelled and considered in this study. The first scenario that is considered in this study were investigated in this phase. The first scenario includes the modeling of the floodplain with the proposed dike systems of the national government. This helped determine the effects of the proposed dike systems. The result is now entitled “Final Model with Proposed Dike”.

The second scenario that is considered in this study was investigated in this phase. This includes identifying the location and dike height that is best suited in preventing the flooding issues on the mainland. The standard flood protection structure height from the DPWH was considered and used as a basis in determining the height of the proposed dike. The result is now entitled “Final Model with Proposed Dike”.

The Cabulig River basin model was developed using ArcMap version 10.1. ArcMap in creating localized flooding scenarios and visualize the effects of flooding on public infrastructure, critical infrastructure, and vulnerable populations (ESRI, 2023). This method allowed the researchers to visualize the impact of river flooding in the local community. The findings can be used by the local government through its Municipal Disaster Risk Reduction and Management Office (MDRRMO) in planning for disaster response for the road and bridges closures and prioritize evacuation in flood-prone zones. This can be used as well by the its Municipal Planning and Development Office (MPDO) in land use planning to devise mitigation strategies such as relocation, zoning, and other strategies. The GIS basin model were used to develop the hydrological model, which were used as input to the river hydraulic model.

The Cabulig River basin model were developed using ESRI's ArcGIS version 10 software. ArcGIS was used to create localized flooding scenarios and visualize the effects of flooding on public infrastructure, critical infrastructure, and vulnerable populations. The solution enables the researchers to understand and visualize the impact of flooding in a community by analyzing the impact of river flooding scenarios using flood depth and elevation data. The analysis' findings can be used to plan road closures, prioritize evacuation zones, and devise mitigation strategies. Furthermore, the HEC-GeoHMS, a special extension of the ArcGIS, was used to import spatial data of the study area and process the hydrologic parameters from spatial layers (Ali, Khan, Aslam, & Khan, 2011). Depending on the available data and the characteristics of the study area, various methods can be chosen. Sub-basin and river reach are typically formed and routed from the most upstream sub-catchments.

The United States Army Corps of Engineers created the Hydrologic Modeling System (HEC-HMS) in 1998 to model hydrological processes in basin systems (USACE, 2018). It was used to develop the hydrological model, which generates flood hydrograph was then used as input to the hydraulic model. Further USACE (2018) describes it as a deterministic, semi-distributed model that incorporates conceptual and empirical techniques for hydrologic process routing and precipitation-runoff simulation. HEC-HMS is a popular hydrological software because it can simulate both short and long-term events (i.e. typhoon flooding) and can be used in any watershed irregardless of its size (Halwatura & Najim, 2013; Verma, Jha, & Mahana, 2010).

The Hydrologic Engineering Center River Analysis System (HEC-RAS) is a software that allows the modelling one-dimensional steady flow, one-dimensional and two-dimensional unsteady flow, sediment transport/mobile bed, and water temperature/quality. It contains several river analysis components and hydraulic design features. It was used in the modelling of the hydraulic models in this study.

3. Results and Discussions

3.1 Land Use

The Cabulig River basin's land cover was analyzed through spectral analysis, which identified five distinct classifications that are crucial for creating accurate rainfall-runoff and flood models. These classifications include water bodies such as rivers, streams, and canals; built-up areas like urban regions, constructed channels, and roads; light vegetation areas such as croplands and grasslands; heavy vegetation areas like dense forests; and open soil areas like windings and barren lands. These specific classifications are crucial for developing a hydraulic model.

Landsat 8 satellite imagery was used to validate by setting five random ROIs to check the accuracy of the classification. The classification yielded a 73.46% average accuracy for the band combination 7-5-3. These classifications conformed to the accuracy range which would be acceptable for the applicable standards. (Karneli, 2010)

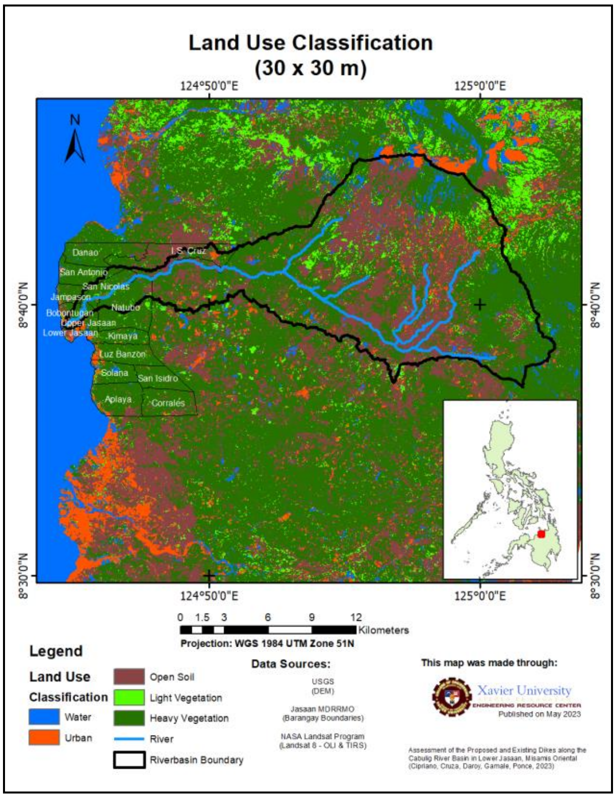

Figure 6: Land Use Classification Map

Based on the map presented, the land use map of the Cabulig river basin shows that the upstream areas are mostly covered by dense vegetation. This is then followed by open soil, light vegetation, water and built-up areas. Meanwhile, the majority of the built-up areas are mostly located in the downstream part of the river basin. From this land use map, the curve number and Manning's n value were derived per sub-basin as identified in the HEC-HMS Model. While the land use shapefiles were used as a parameter in the HEC-RAS model.

3.2 Flood Inundation Analysis

This section provides the total inundation area on the model entitled "Flood Map with Existing Dikes" in each of the identified barangays. As shown in the results of the analysis, most of the flooded areas in Barangay Lower Jasaan and Barangay Bobontugan are urban or built-up areas.

Details regarding the affected areas in each barangay per land use classification are shown in the table below.

Barangay	Flooded Area (Ha.)	Affected Areas per Land Use Classification (%)			
		Urban	Open Soil	Light Vegetation	Heavy Vegetation
Lower Jasaan	36.19	29.46%	34.00%	2.05%	10.74%
Upper Jasaan	1.94	0.00%	7.44%	0.09%	31.45%
Bobontugan	14.21	45.94%	10.73%	0.11%	26.19%

Table 4. Affected Areas per Land Use Classification

In Investigating the effect of the proposed dike systems by the DPWH Region X is essential in determining to what extent were it affected the path of the water and the flood inundation and what structure heights are needed to make these structures effective. It is important to note that the data obtained by the researchers are only limited to the dike’s location since the structural details of the existing dike systems were not available. Thus, assumed dike height values were implemented and adjusted depending on the produced models. The assumed dike height which produced a realistic and effective result was then utilized for the model. Similar parameters were used with this modelling and the modelling of the final model “Flood Map with DPWH Dike”. The dike systems were set to at least have a height of 2.5 m at every section which made it effective in preventing the water from reaching the urban areas.

Numerous models were simulated in order to identify the most appropriate locations of the dike systems which made them effective and prevent the water from reaching the mainland and urban areas. The locations of the DPWH Proposed Dike Systems were also taken into account. The height of such structures was tested in order to identify the minimum height that would make the dike systems effective.

After numerous simulations, it was found that a minimum height of 2.5m is needed at every station in order to make the dike systems effective and the locations identified are as shown in the model “Flood Map with Proposed Dike”.

4. Conclusion

The growing flooding problem in the Cabulig River Basin, on the extents surrounding the river, particularly on the low-lying areas of Lower Jasaan and Bobontugan has brought the researchers to investigate the behavior of the river, floodwater path during strong and significant rainfall event to assess the existing flood mitigating structures in the area such as dikes and to produce structural and nonstructural flood mitigating measures recommendations.

With this, the hydrologic and hydraulic model of the basin has been generated to identify the areas prone to flooding. The generated hydraulic model simulates the flood extent of Super Typhoon Odette last December 2021 considering the currently existing dike systems and has generated a percent match of 76.36% based on the validation points.

The results of Flood Inundation Analysis showed that most of the flooded areas in Barangay Lower Jasaan and Barangay Bobontugan are Urban areas which really raises a concern on the locality's inhabitants because they were and will still be the ones who were mostly affected by heavy rain events which causes the overflowing of the river and in turn causes flooding.
It is important to note that during the modelling phase of the study, the researchers have observed that the overflowing water from the river first goes through two points; (1) the end point and (2) the “discontinuity” point or the part of the dike system where the two dikes supposedly connect. This indicates that the discontinuity of the dikes should be addressed and if future dikes are made, discontinuities should be avoided.

The proposed dike system of the researchers emphasizes extending the dike towards upstream direction having a minimum 2.5m height of the dike measured from the mainland elevation. The proposed dike on the Lower Jasaan also has no discontinuities. It also includes having a 2.5m high dike on the Bobontugan side to prevent flooding on the area.

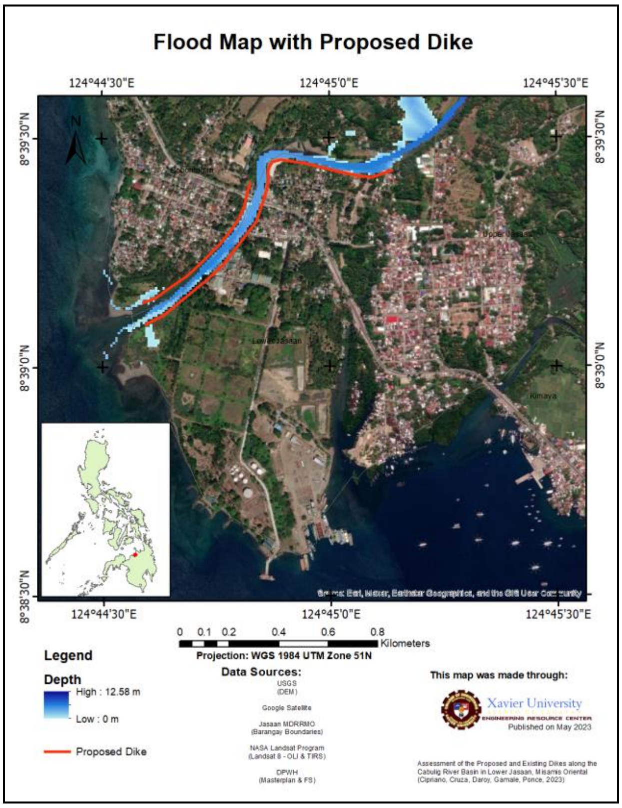

Figure 7: Flood Map result with the proposed dike system

The results of the modelling with consideration of the newly Proposed Dike Systems showed that the proposed dikes can be effective given that dike heights are properly designed. For the produced model, a minimum of height of 2.5 meters for all the dikes was considered which prevented flooding on the urban areas and made it effective. Although this raises a concern in the urban planning of the city because numerous settlements are located on the supposed locations of these proposed dikes.

With the results shown, it is highly recommended that the concerned Local Government Units and organizations involved take careful considerations in planning the necessary engineering specifications and location of the dike systems or other flood protection structures. In addition, the structural integrity of the dike systems and its effect on the water level and flow must be taken into account.

Flooding events provides the opportunity for the people to investigate how man-made structural elements affect or change the outcome of such calamity and invest on these structural elements in order to mitigate such occurrences.
In relation, disaster risk reduction and management is another thing to consider. In order to properly prevent or at least mitigate such calamities, a considerable amount of time is needed to properly plan, study, and design flood mitigation measures such as dikes.

Lastly, it is important to note that limitations of the study may have affected its outcome and therefore it is recommended that other models should also be taken into consideration when using this study’s produced models as references.

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