Assessing the Efficacy of Newly-Constructed Drainage Canals in Butuan City Proper, Philippines through Field Survey and Hydrologic Modelling Approach

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Abstract: *Urban drainage systems play a crucial role in flood management by handling rainfall accumulation. However, the capacity of existing drainage canals to cope with water varies due to urbanization and changes in land cover, affecting runoff and infiltration rates. Researchers aimed to evaluate the maximum water volume and rainfall that newly constructed drainage canals could handle. We conducted watershed delineation to achieve this, dividing the basin into subbasins with drainage areas where rain collects and flows into outlets. Land cover and hydrologic soil groups were considered to estimate runoff and infiltration rates. Using HEC-HMS, two simulations were performed with an 18-hour rainfall to assess the capacity of the new canals. The study found that these canals could only manage approximately 667,920 cubic meters of water generated from a 43.77-mm rainfall over 18 hours. Feedback and evidence were gathered from residents to validate this finding.*

Keywords: Urban Flooding, Newly Constructed Canals, Butuan City, Hydrologic Modeling

1. INTRODUCTION

The urban environment is continually evolving, influenced by population growth, land development, and changes in land cover. One significant consequence of this evolution is altering natural hydrological processes, particularly concerning rainfall runoff and drainage patterns. Urbanization often leads to increased impervious surfaces, such as roads, buildings, and pavements, which can significantly alter how water moves through the landscape [1]. As urban areas expand, the demand for effective flood management strategies becomes increasingly critical. Urban flooding poses significant risks to infrastructure, public safety, and the environment, highlighting the urgent need for stronger drainage systems capable of handling rainfall accumulation. However, the capacity of existing drainage infrastructure to cope with changing urban landscapes is not always well understood [2].

In the Philippines, Butuan City is one of the highly urbanized cities facing a recurring flooding problem. Due to its geographical location with lower elevation compared to neighboring areas, Butuan City faces a heightened susceptibility to flooding [3]. Over time, the city has confronted severe inundations resulting in substantial property damage, displacement of residents, and disruptions to livelihoods. Notably, in 2023, a low-pressure system compelled the evacuation of over 1,000 individuals residing in various Barangays, including Libertad, Pangabugan, Maon, Villa Kananga, Imadejas, Ambago, San Vicente, and Bonbon [4]. Moreover, this February, 11,980 individuals living along riversides and low-lying communities were displaced due to floods despite the fair weather. This scenario asks, “Do officials in Butuan City, Philippines, take action on this?”

Butuan City has always had drainage system projects. One thing to consider in this scenario is that the existing drainage system in Butuan City was designed and implemented years ago based on prevailing knowledge and engineering practices. It was suggested in the study of Casinginan et al. (2015) that these drainage canals should be widened [5]. As an indirect response, city authorities have invested in developing and implementing new flood mitigation measures and an improved drainage system. In 2023, new canals were constructed based on data provided by the city government of Butuan City and the DPWH-Caraga, aiming to address the persistent urban flooding issue. Now, the focus shifts to assessing whether these newly constructed canals can effectively manage varying amounts of rainfall, taking into account urbanization and changes in land cover that have influenced runoff and infiltration rates. Thus, this knowledge gap highlights the necessity for a thorough investigation into the performance of these canals as time progresses, and various factors must be considered.

With this, to assess the efficacy of the newly constructed canals in Butuan City Proper, two of the most sought-after applications in hydrologic modeling, such as HEC-GeoHMS (an extension in ArcMap and HEC-HMS are considered. HEC GEO-HMS facilitates the accurate delineation of watershed boundaries, providing essential insights into the hydrological context within which the drainage system operates. At the same time, HEC HMS enables hydrological simulation and modeling, assessing the drainage system's capacity to manage excess water during flood events and, through computation, determining the maximum amount of rainfall these drainage canals can manage.

While existing literature has examined drainage canals in Butuan City, there remains an ongoing discussion regarding assessing newly constructed canals and considering changes in land cover and drainage systems. Thus, identifying a research gap is crucial to determining the capacity of these newly built canals to handle maximum rainfall. This study seeks to address whether the newly constructed drainage canals can accommodate varying levels of rainfall or if specific limits constrain them. Specifically, this study aims to delineate the specific geographic boundaries of the watershed in Butuan City Proper, as defined by existing canals, newly constructed drainage canals, and river networks, analyze key hydrological characteristics, and determine how these characteristics influence the parameterization of the hydrologic model, particularly concerning factors such as surface runoff and infiltration rates, determine the maximum volume of water that the newly-constructed canals can accommodate and to identify the corresponding amount of rainfall required to reach this capacity.

2. METHODOLOGY

2.1 Study Area

Butuan City, situated in the Caraga Region of the Philippines, is a highly urbanized city known for significant urban development with an area of 816.62 sq. km. The city experiences a tropical climate, classified as Type II. Annually, the city accumulates 1941 mm of rainfall. This study focuses on the city proper of Butuan City, comprising 28 barangays.

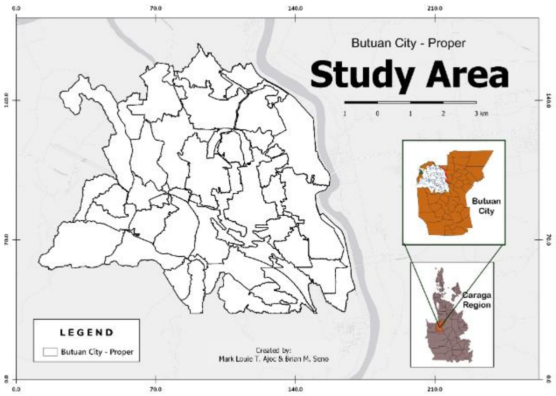

Fig. 1. Butuan City Proper as the Area of Interest of the Study

2.2 Hydrologic Modeling

Hydrological modeling emerges as a critical procedure in water resource utilization [6], simulating the movement, flow, or variation in water storage over time within the diverse components of the natural hydrological cycle [7]. Hydrologic modeling requires the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) software to simulate precipitation-runoff dynamics within dendritic watershed systems [8]. This software allowed researchers to explore the potential outcomes of different management strategies and environmental changes. Hydrologic modeling required specific tasks, including watershed delineation, land cover classification, creating watershed parameters, parameterization and characterization, field survey, gathering rainfall data, and the simulation itself.

2.2.1 Watershed Delineation

Watershed delineation involves establishing a boundary delineating the contributing area for a specific control point or water outlet within a study area, facilitating characterization and analysis. The drainage networks of Butuan City were sourced from the City Engineering's Office. In ArcMap, the river networks within the study area were digitally mapped and merged with the acquired drainage networks. This merged shapefile and the Digital Terrain Model (DTM) were crucial for delineating the watershed. Additionally, HEC-GeoHMS identified the upstream subbasin and all connecting rivers draining into the project location. These parameters were utilized to simulate the hydrologic model.

2.2.2 Land Cover Mapping

Land cover refers to the natural or human-made features covering the earth's surface [9]. Alterations in land use within the catchment area of drainage canals can affect their effectiveness in mitigating floods. The development of urban regions, involving the construction of buildings, roads, and paved surfaces, can lead to heightened surface runoff and reduced infiltration rates [10]. The Landsat image of Butuan City – Proper was downloaded from USGS Earth [11]. The land cover classification was done in Envi 4.3 through Maximum Likelihood Classification using supervised classifications by training pixels where each band is normally distributed and calculating the probability that a given pixel belongs to a specific class. This includes different classes such as built-ups, barren water bodies, grasslands, forests, and rice fields.

2.2.3 Creating Watershed Parameters

Parameters can be estimated as subbasin average and grid-based values using the soil and land cover map. The soil type data acquired from the Bureau of Soil and Water Management (BSWM) was clipped to the boundary of the study area. The Hydrologic Soil Group (HSG) was used as a basis for the reclassification of the soil type data. The NRCS-developed rainfall and runoff potential measurements were used to categorize the HSG according to their respective soil textures [12].

In creating the Curve Number (CN) and Initial Abstraction Grid necessary for the parameterization of the flood model, a hydrologic soil cover complex was established. A hydrologic soil cover complex combines land cover derived from image classification and soil type data reclassified to hydrologic soil group using the GIS technique. By integrating these essential components, the researchers have constructed a detailed representation of the terrain's hydrological characteristics, enabling more precise simulations and predictions of flood behavior.

2.2.4 Field Survey

Gathering the initial discharge from the field was necessary as it was one of the variables needed to compute for the initial discharge, which is one of the parameters of the recession. Using an Acoustic Doppler Current Profiler (ADCP), the initial discharge from the field was gathered at Barangay Pequeño, Butuan City, where the identified outlet for the delineated watershed is located. In hydrology, ADCP is an instrument used to measure how fast water is moving across an entire water column [13].

Figure 2 shows the pictures of the field survey. A letter of permission and a letter to conduct the survey was sent to the Barangay Hall of Barangay Pequeño for formality. In data acquisition, a succession of three (3) setups was done with a 1-hour interval each before conducting the next setup. With this, the different behaviors of the water flow were considered. With the data collected from the three (3) setups, the mean of the initial discharge from the field was calculated and was used to get the initial discharge.

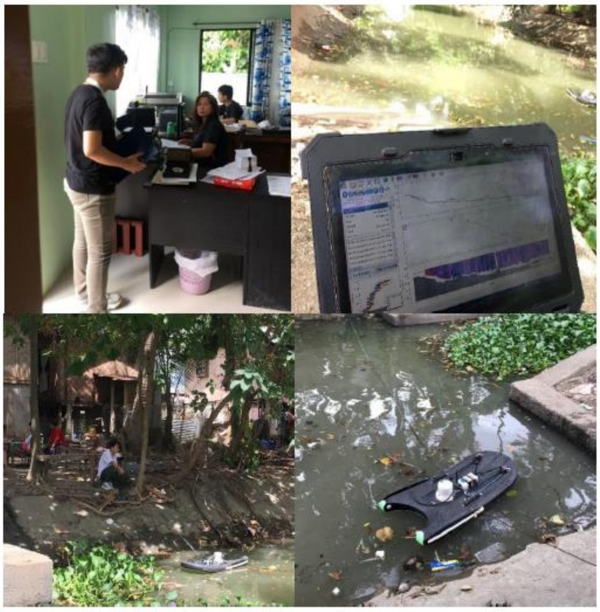

Fig. 2. Gathering the discharge value of the stream at the outlet located in Brgy. Pequeño, Butuan City.

Additionally, rainfall, water level, and discharge measurements were captured to develop the model calibration and validation. These measurements were gathered by deploying a water level logger, velocity meter, and rain gauge in the study area.

2.2.5 Rainfall Data

Rainfall data plays a crucial role in modeling extreme hydrological events like floods and assessing the quantity and quality of surface and subsurface water resources [7]. The data for precipitation used for the HEC-HMS meteorological model was the recorded rainfall values of the rainfall station acquired from Philsensors website [14]. The station closest to the study area is the Caraga State University, Butuan City Station, used for hydrologic modeling. The gathered rainfall data was on May 15, 2022, and May 16, 2022, as they were the latest available rainfall data with enough rain to fill in the volume of the watershed for simulation.

2.2.6 Model Calibration and Performance Evaluation

The model's performance was assessed using three accuracy measures before, during, and after calibration. These metrics are the RMSE-observations standard deviation ratio (RSR), percent bias (PBIAS), and the Nash-Sutcliffe Coefficient of Model Efficiency. Table 1 shows the performance ratings and evaluation statistics.

The dimensionless statistic E quantifies the agreement between observed and simulated data, with values approaching 1 indicating optimal fit. PBIAS assesses the average bias in the simulation, where 0 signifies no systematic deviation from observations. RMSE is normalized by the standard deviation of observed values (RSR) to account for data variability. Model performance was categorized as very good, good, satisfactory, or unsatisfactory. Acceptable performance is characterized by a PBIAS within ±15 to ±25%, an RSR below 0.70, and an E exceeding 0.50. Overall model performance was determined by the most stringent evaluation among these metrics. These evaluation metrics were also used in the study of Salcedo-Albores et al. [15] in developing a hydrologic model for watershed management.

Table 1. HEC-HMS performance ratings are based on three model performance evaluation statistics.

Performance Rating	Statistics		
	Nash-Sutcliffe	*Percent Bias*	*RMSE*
Very Good	0.75 < E ≤ 1.00	PBIAS < ± 10	0.00 < RSR ≤ 0.50
Good	0.65 < E ≤ 0.75	± 10 ≤ PBIAS < ± 15	0.50 < RSR ≤ 0.60
Satisfactory	0.50 < E ≤ 0.65	± 15 ≤ PBIAS < ± 25	0.60 < RSR ≤ 0.70
Unsatisfactory	E ≤ 0.50	PBIAS ≥ ± 25	RSR > 0.70

2.3 HEC-HMS Simulation

HEC-HMS simulation was significant in the study as this generated excess water volume and other data needed to assess the efficacy of the drainage canals. In the HEC-HMS simulation, the basin for the watershed and the precipitation gages were enabled, and the time series data were set out. The rainfall data from May 15, 2022, and May 16, 2022, were inputted for the time-series data for two (2) separate simulations.

The results of every subbasin's excess volume and precipitation volume were determined after running the simulation. The total sum of every subbasin's excess volume and precipitation volume in cubic meters per second as compared to the discharge and volume acquired through actual observation. Comparing these data provides insights into whether the drainage channels can withhold a certain amount of volume and discharge based on the simulation result using HEC-HMS.

2.4 Computation and Comparison

Various calculations and methods were employed to assess the effectiveness of the newly constructed canals in managing excess water volume. The slope-area method determined peak flow rates for maximum canal water capacity. The Chezy formula is generally used in getting the value of the mean velocity of the stream. The Chezy formula is expressed using the equations below:

$$Q = A\left(C\sqrt{RS}\right) \qquad \text{Eq. 1}$$

where:
Q is the discharge of the stream (cu.m/s)
v is the average velocity (m/sec)
A is the mean cross-sectional area in the reach (sq.m)
C is the Kuffer's variable coefficient
R is the Hydraulic mean depth, or hydraulic radius (m)
S is the Longitudinal slope of the water surface (m/m)

Rainfall computation utilized the linear interpolation method to estimate the maximum rainfall that can reach the canal's capacity.

$$y = y_1 + (x - x_1)\left(\frac{y_2 - y_1}{x_2 - x_1}\right) \qquad \text{Eq. 2}$$

where:
x is the maximum volume capacity of the newly constructed drainage canal
x_1 is the excess volume of water for the second simulation.
x_2 is the excess volume of water for the first simulation
y_1 is the amount of rainfall for the second simulation
y_2 is the amount of rainfall for the first simulation
y is the maximum amount of rainfall that can generate maximum volume capacity

Comparison between simulated and observed volumes provided insights into canal performance, aiding in determining their ability to handle specific volumes and discharges.

2.5 Actual Validation

Validation is crucial to validate the outcomes and derive substantial insights. The researchers affirmed the findings via a survey questionnaire (see Fig. 3) and dispersed it among randomly selected residents of Brgy. Libertad, the area where the recently constructed drainage canals are situated. The survey outcomes provide additional data to supplement the evaluation of the simulated versus computed values of the drainage canals' volume, determining if it adequately accommodates the volume of an 18-hour rainfall at a given time.

Fig. 3. Distribution of Survey Questionnaire to the Respondents

3. RESULTS AND DISCUSSION

3.1 Watershed Delineation

Figure 4 shows the delineated subbasins and merged river and drainage canal networks, visually representing the geographical features analyzed through the GIS-based methodology. The 53 subbasins, clearly outlined within the watershed, represent distinct drainage areas contributing to the overall hydrological system. They have a total area of 48.173 square kilometers. Each subbasin delineates the extent of land that drains into a specific water body or watercourse, providing valuable insight into water flow distribution within the watershed. In addition to the subbasins, the merged river and drainage canal networks, represented as 53 reaches with a total length of 74515.94 meters, highlight the interconnected pathways through which water traverses the landscape. This visualization elucidates the network of watercourses, showcasing their connectivity and the direction of flow from upstream to downstream areas. Also shown on the map is the outlet's location in Barangay. Pequeño, where the water flows and goes out. This data was used for further processing, which is hydrological modeling.

3.2 Land Cover Classification

The land cover classification map in Figure 5 shows the different classes that are classified using ENVI 4.3. The classes classified were water bodies, grassland, barren, rice fields, built-up, and forest. As observed, built ups (represented in red) dominate on the map's right side, just beside the Agusan River. While the grassland dominated the bottom-left part, the upper part was a mix of waterbodies and forest. This visualization of land cover depicts the spatial distribution and composition of different land cover types within the area of interest.

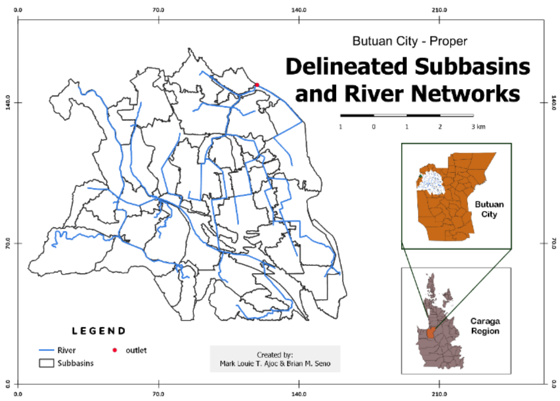

Fig. 4. Delineated Watershed of Butuan City Proper

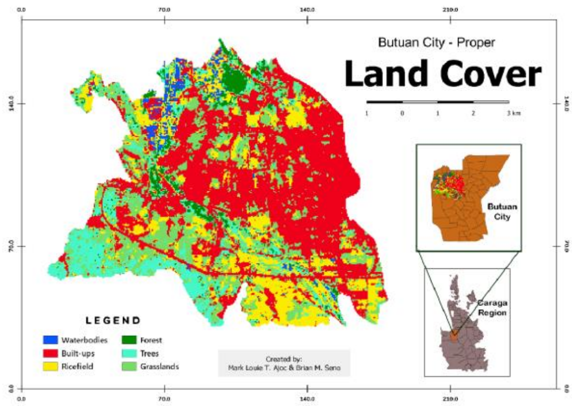

Fig. 5 Land Cover Map of Butuan City Proper

3.3 Characterization and Parameterization

Figure 6 shows the map of the curve number of the delineated watershed of Butuan City – Proper. By connotation, the curve number represents how easily water can infiltrate into the soil in a specific area. The map below shows the highest curve number, "91.1," which mostly represents built-up areas, while the lowest curve number is 0, where the forest classes can be seen, compared with the visualization of the land cover map. However, it does not just depend on the land cover since other classes, such as built-ups in the land cover, lie within the range between 78.6 and 83.2 range. With this, the curve number regards the land cover, the soil type, and the hydrologic condition of the subbasin, which serves as inputs. Moreover, the curve number is dimensionless, typically ranging from 0 to 100, where lower values represent higher infiltration rates and lower runoff potential. In comparison, higher values indicate lower infiltration rates and higher runoff potential. This visualization was used to analyze the distribution of excess water among subbasins.

Figure 7 shows the map of the subbasins of the delineated watershed with their corresponding initial abstraction. Initial abstraction quantifies how much rainwater needs to accumulate before it starts to run off the surface. A higher initial abstraction value means more rain is needed before runoff begins. In this map, the highest value is 29.4, represented in dark green, while the lowest is 0, represented in dark violet. Those subbasins with dark green polygons require enough rainfall to accumulate on the land surface before runoff begins. Compared with the land cover map, these subbasins are usually constituted of forests with high infiltration rates; that's why more water is needed for a runoff to commence. However, land cover classes are not the only things to be considered. Factors such as antecedent moisture conditions, soil infiltration capacity, depression storage, and others play a crucial part. Thus, the map below aids in further analysis of the movement and quantity of water generated in the hydrologic modeling.

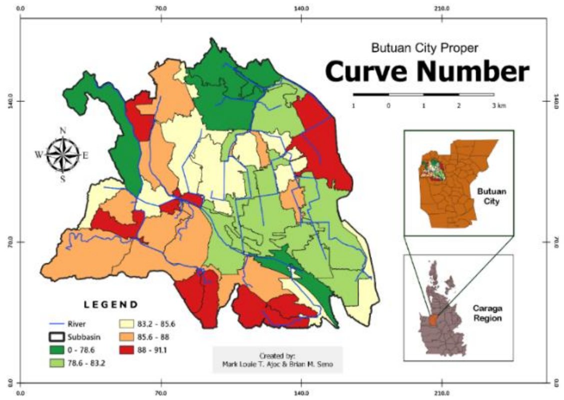

Fig. 6. Curve Number Map of the Delineated Watershed

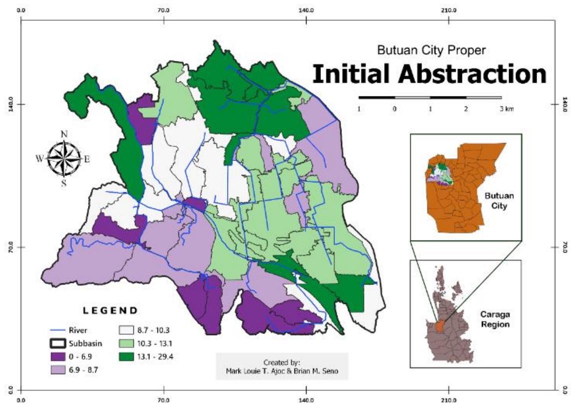

Fig. 7. Initial Abstraction Map of the Delineated Watershed

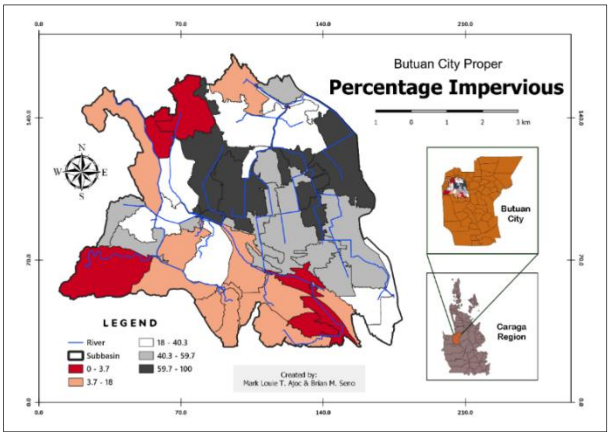

Fig. 8. Percentage Impervious Map of the Delineated Watershed

Figure 8 illustrates the subbasins within the delineated watershed alongside their corresponding percentage impervious values. Percentage impervious signifies the proportion of impermeable surfaces like pavement, concrete, or buildings within a given area. Higher percentages indicate greater coverage by such hard surfaces, hindering water infiltration into the ground. The scale ranges from 0, represented in red, to 100, depicted in dark gray, with darker shades indicating higher percentages of impervious surfaces. Subbasins shaded in dark gray exhibit the highest concentrations of impermeable surfaces, such as buildings and concrete. A higher percentage of impervious corresponds to increased runoff and decreased infiltration rates. Comparing this map with the land classification map reveals that subbasins surrounded by built-up areas tend to have a higher percentage of impervious values. In contrast, those surrounded by water bodies and grasslands typically have lower values. Consequently, this map facilitates further analysis of water movement and quantity generated for hydrological modeling.

3.4 Model Calibration and Performance Evaluation Results

The hydrological model of the study area was calibrated using the available daily rainfall-runoff data from April 8, 2024, to April 12, 2023, and manual calibration techniques were applied to estimate the values of parameters. Based on the statistical results, as shown in Table 2, the Nash-Sutcliff efficiency (ENS) of the calibrated model has been calculated as 0.841, the Standard Deviation of the calibration has been calculated as 0.364, and the Percent Bias (PBIAS) of the calibrated model has been calculated as -11.63%. This shows that the developed hydrological model in the study area performed well for the calibration period.

Table 2. HMS Model Performance Results

Metrics	Value	Rating
Nash-Sutcliffe	0.841	Very Good
Percent Bias	-11.63%	Good
RMSE	0.364	Very Good

3.5 HEC-HMS Simulation Using Calibrated Model

Table 3 compares the excess volume derived from the simulation with the maximum capacity of the canal. These excess volumes were collected from two simulations conducted over an 18-hour, focusing solely on subbasins intersecting or near the newly constructed drainage canals. The maximum capacity of the newly constructed drainage canals was determined using the slope-area method.

By comparing the excess volume with the maximum canal water capacity, it becomes possible to assess whether the canals can accommodate the generated volume under different rainfall scenarios. The first simulation, where the excess volume is 787,700 cubic meters, surpasses the maximum canal water capacity. This indicates that with the recorded rainfall of 50.60 mm, the canals cannot effectively manage the resulting volume.

Conversely, in the second simulation, the excess volume of these subbasins, which is 447,400, falls below the maximum canal water capacity. This implies that within 18 hours, the newly constructed drainage canals can adequately handle the excess volume generated by 31.20 mm of rainfall.

Table 4. Simulation Excess Volume Compared to Maximum Canal Capacity

Amount of Rainfall	Excess Volume from Simulation	Maximum Canal Water Capacity	Can these canals handle excess volume?
50.60	787,700.00	667,920.18	No
31.20	447,400.00		Yes

3.6 Computation and Comparison

Table 4 provides crucial insights into the relationship between rainfall intensity and the maximum volume of water that the newly constructed canal can accommodate. Utilizing linear interpolation, the interpolated value was determined to be 43.77 mm, which signifies the rainfall intensity threshold at which the canal can effectively manage its maximum volume without risk of overflow.

Table 4. Precipitation Threshold for Maximum Canal Capacity

Description	No. of Hours	Volume of Water	Rainfall Amount
First Simulation	18	787,700.00	50.60
Maximum Canal Capacity		667,920.18	**43.77**
Second Simulation		447,400.00	31.20

3.7 Actual Validation Results

Figure 9 shows the distribution of the level of certainty among the respondents' responses. Fifty percent (50%) conveyed high confidence in their responses. Additionally, three participants expressed a slightly lower level of certainty, rating their responses as 4, while two rated 3.

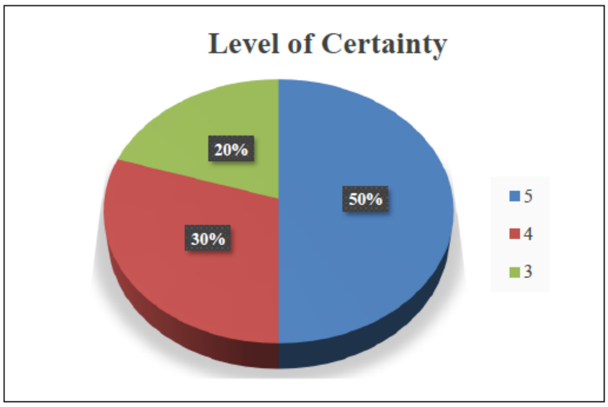

Fig. 9. Level of Certainty of Responses

Table 5 presents data indicating that overflow incidents occurred in the drainage canals of Barangay. Libertad, where recently constructed canals are situated. The table reveals that the average level of certainty expressed by respondents regarding the occurrence of overflow during this timeframe was 4.30. This suggests that respondents generally exhibited high confidence that there is an overflow during an 18-hour rainfall. However, they noted that there will only be overflow if there is a high amount of rainfall, and there will be no overflow if the rainfall is low, indicating drainage challenges during heavy rainfall.

Table 5. Summary of Validation Results

Duration of Normal Rainfall	Overflowed?	Mean Level of Certainty
18 hours	Yes	4.30

Fig. 10. Flooding Incident in Butuan City Proper

Figure 10 illustrates the challenges faced by the newly constructed drainage canals in Butuan City Proper during intense precipitation events. It was captured during heavy rainfall induced by Tropical Storm Kabayan, with around 100 mm of rain on December 18, 2023. Despite their ability to manage rainfall amounts of 43.77 mm and below, they still struggle to accommodate heavy rainfall. This highlights the need for ongoing efforts to improve flood mitigation and drainage systems in Butuan City. By recognizing the limitations of the current infrastructure under extreme weather conditions, decision-makers can prioritize proactive measures to enhance the resilience of the city's drainage infrastructure.

4. CONCLUSIONS AND RECOMMENDATIONS

The researchers assessed the efficacy of the newly-drainage canals in Butuan City Proper using HEC-HMS to simulate the excess volume of the watershed in 2 different scenarios. This amount of volume was influenced by the hydrological and topographic characteristics of each subbasin, considering its curve number, initial abstraction, and percentage impervious. It was determined that the maximum water volume capacity is 667,920.18 cubic meters. In the first simulation, the canals could not handle the simulated volume, but in the second simulation, they could accommodate it. Using linear interpolation, it was found that in 18-hour rainfall, the newly constructed drainage canal can handle up to about 43.77 mm without exceeding capacity. The photographic evidence and survey responses validate that these drainage canals effectively manage light rainfall but demonstrate inadequacy in handling heavy precipitation due to their restricted capacity. From these results, it was concluded that the local government unit of Butuan City needs to extend drainage canals throughout the city.

The study suggests several recommendations aimed at improving its scope and analytical depth. Firstly, expanding the study area to encompass the entirety of Butuan City is proposed. This broader geographical coverage could offer a more holistic understanding of the factors influencing the phenomena under investigation. Additionally, the researchers suggest diversifying the comparison intervals to include various hour increments. By doing so, the study can capture a wider range of temporal variations, potentially yielding more robust conclusions.

Furthermore, integrating HEC-RAS software is recommended to facilitate one-dimensional and two-dimensional hydraulic calculations. Leveraging this advanced tool can enhance the accuracy and sophistication of hydraulic analyses, enriching the study's findings. Lastly, the study encourages consideration of the impact of newly constructed canals installed by Butuan City. Incorporating these recent developments into the analysis framework can provide valuable insights into their implications for the studied phenomena.

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