Integrated Flood Risk Analysis for Riverine Community in Chico River Basin, Mountain Province, Philippines

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ABSTRACT

The upper Chico River, located in mountainous region, frequently overflows during heavy rainfall events, causing rapid flows that threaten the lives of inhabitants, agricultural areas, and essential infrastructure. This study aimed to enhance community resilience to flood risk by investigating the channel capacity, flow pattern, and morphological changes in river using integrated hydrological and hydraulic analysis. A rainfall-runoff inundation model was used to evaluate the discharge from the basin using processed rainfall data (GsMap). The model was calibrated with daily rainfall data, achieving good accuracy (NSCE = 0.94, RMSE = 74.88), and was validated with hourly data. The resultant hydrographs were used as boundary conditions to evaluate the morphological changes in the Chico River using a 2D-depth average model.

The September 2018 Typhoon Ompong was one of the most damaging events for the Chico River, causing severe riverbank erosion and community flooding. This disaster resulted in 6 deaths, 4 injuries, damage to 593 houses, and agricultural and infrastructure losses totaling $14 million (Provincial Disaster Reduction Management Office, Mountain Province). The Chico River was also evaluated for 25-, 50-, 100-, and 400-year return periods.

This study provides key insights, including channel capacity, erosion-prone areas, and which communities, Ab-abtana-Samoki (A), Fagkay-Samoki (B), Eyeb-Pakkil (C), and Lanao-Cheppay (D), will be most affected by extreme events, with Ab-abtana-Samoki (A) at greatest risk. These findings are crucial for proactive flood management to protect lives, property, and infrastructure. This study is a valuable resource for policymakers, planners, and designers to safeguard communities near the Chico River in Bontoc, Mountain Province.

Keywords: Flood risk, Channel Capacity, River erosion, Bed deformation, Flow depth, Flow Velocity

INTRODUCTION

The Philippines, known for its demographic and archipelagic conditions, experiences an average of 20 typhoons per year. Mountain Province, with its rugged terrain and steep valleys, is highly susceptible to landslides and flooding, posing a risk to local communities near the river, particularly in the Municipality of Bontoc. The climate is tropical monsoon with 249 mm of annual rainfall. The dry and wet seasons are from November to April and May to October, respectively. A notable typhoon event

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occurred in September 2018 (Typhoon Ompong), posing significant challenges to Bontoc, where the riverbank eroded, inundating communities settling along the river, and aggravating the damage caused by the previous typhoon in 2016. Typhoon Ompong resulted 6 deaths and 4 injuries, damaging houses (575 partially damaged & 18 completely damaged), agricultural (US$ 6.4 million), and infrastructure (US$ 7.6 million; Provincial Disaster Reduction Management Office, Mountain Province). The province is highly vulnerable to water-related disasters such as typhoons, landslides, and flash floods. Among these, typhoons and flash floods have the most severe impact on the lives, livelihoods, and economies of the province.

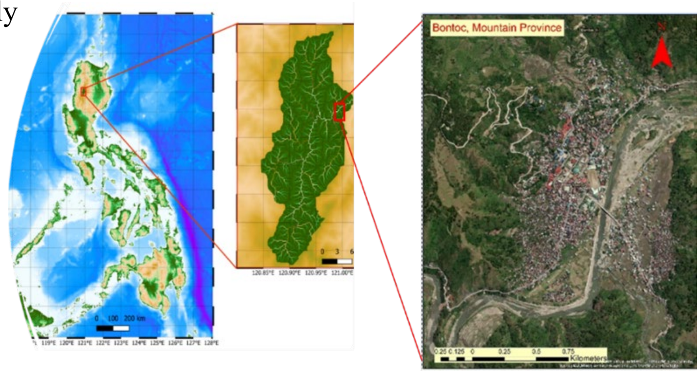

Figure 1. Chico River Basin and Study Area

The Upper Chico River Basin covers approximately 1,064 km^2, with Bontoc, the study area, as the center of government, commerce, and education, home to 24,104 people. In 2018, a typhoon caused the Chico River to swell, resulting in fatalities and damage to homes, agriculture, and infrastructure, particularly in Bontoc. This event led to the construction of flood control structures such as concrete retaining walls by local and national governments. This study aimed to assess the flood risks from extreme events, evaluate the effectiveness of these structures, identify erosion-prone areas, and determine the channel capacity to develop effective protection strategies for the community.

THEORY AND METHODOLOGY

Observation and analysis of satellite imagery: Over the past 90 years (1933–2023) the study area experienced significant changes, particularly in population growth. The topography of rivers and population growth have caused people to encroach on the river's natural area and building structures have gradually reduced the width of rivers in some areas. Figure 2 shows the 1933 photo and satellite imagery from Google Earth of the study area, showing a notable increase in houses constructed within the riverbank, creating riverine communities.

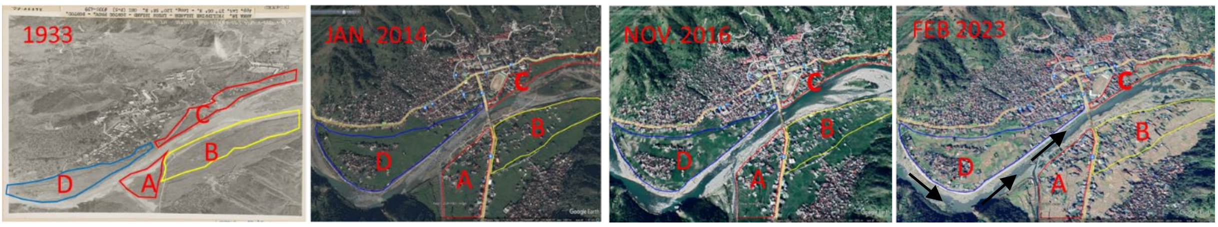

Figure 2: 1933 photo and satellite imagery from of the study area showing the population expansion for the span of 90 years. (A = Ab-abtana-Samoki, B = Fagkhay-Samoki, C= Eyeb-Pakkil, D = Lanao-Cheppay). Flow direction is from left to right.

Hydrological Modeling: Hydrological modeling uses the rainfall-runoff-inundation (RRI) model, which is a 2D tool that can simulate rainfall-runoff and flood inundation simultaneously (Sayama et al., 2012). This model treats slopes and river channels separately. In grid cells containing a river channel, the model assumes that the slope and the river channel exist within the same cell. The channel is represented as a single line along the center of the slope grid cell. The flow over the slopes was calculated using a 2D diffusive wave model, whereas the flow in the channels was calculated using a 1D diffusive wave model.

Hydraulic Modeling: The 2D-depth-average model in the iRIC software was used to simulate water flow and sediment movement in rivers and other water bodies. This simplifies the complexity of the 3D flow equations by averaging the flow properties over depth, making the computations easier to understand, while still accurately representing water dynamics. In the simulation, we employed a 2D depth-average governing equation. Mass and momentum conservation equations for water flow, mass conservation for bed load equations. The Egashira equation (Mechanics of Sediment Transportation and Channel Changes – For water-related risk management Course – 2009-Present) was utilized for the bed load computation.

The computational domain of the Nays2DH solver of the iRIC was developed to understand the topography of the study area. Below is a table of calculation conditions.

Bed Load Formula	Egashira Equation
Grid Size	7 m × 12 m
Calculation Time Step	0.1 s
Upstream Discharge	Unsteady Flow
Downstream Discharge	Uniform Flow
Sediment Type	Non-uniform
N-value	0.04
Tributary is considered	

Methodology: This study used hydrology and hydraulic models, along with an analysis of past photographs and satellite imagery, to examine community expansion towards the river and related flood risks. The RRI model, a 2D tool, simulates rainfall runoff and flood inundation, producing a hydrograph for upstream hydraulic simulations. Owing to a lack of local data, GsMap Rainfall data were used for the RRI model. The model was calibrated using discharge data from a typhoon in September 2018 and validated using hourly rainfall data, showing acceptable results. Frequency analysis of GsMap data-simulated hydrographs was conducted for 25-, 50-, 100-, and 400-year return periods.

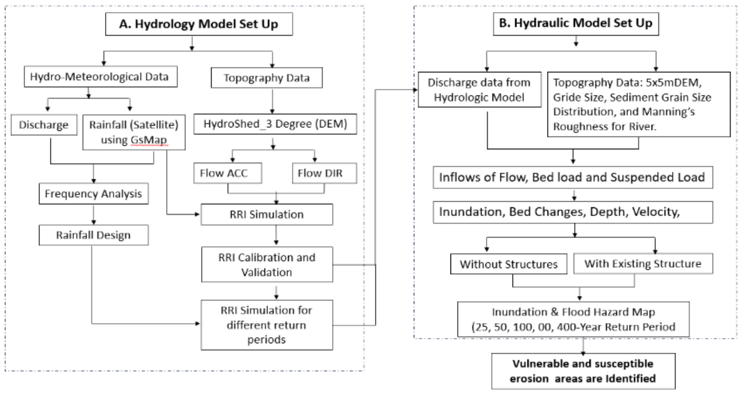

Figure 3: Methodology framework

The hydraulic model was set up using the 2D depth-averaged model in the iRIC software with simulated hydrograph results from the hydrologic model as upstream boundaries. The software supports various solvers, including Nays2DH by Professors Yasuyuki Shimizu and Hiroshi Takebayashi, who assessed the flow dynamics, bed deformation, and sediment transport in the study area. Calibration was confirmed by comparing satellite imagery with simulated results, and the velocity obtained from Manning's formula matched the observed data. The simulated water depths were aligned with the observed depths. Once the calibration was verified, extreme events were simulated to determine the flow depth and extent of flooding in the study area as well as the erosion-prone areas.

DATA

Hydrologic Model: This study used HydroSHEDS topography data derived from SRTM elevation data at 3 arc-second resolutions, to model the Chico River Basin. Hydrologic data were obtained from the

GsMap Satellite Rainfall data, as the nearest rainfall data were 140 km away, and local rain gauges were not operational. A simulation of the September 2018 typhoon Ompong produced a hydrograph for flood risk assessment. Hourly satellite data validated the results and ensured accuracy.

Hydraulic Model: Topographic data from a 2013 IFSAR DTM DEM at 5 m × 5 m resolution, provided by NAMRIA, were used. These high-resolution data helped generate elevation models and analyze terrain features such as slopes, drainage patterns, and landforms, which are essential for understanding hydrological processes. Although ground survey data are preferred, the 2013 IFSAR DTM DEM is a valuable alternative. The RRI model hydrograph model was used as the upstream boundary for the simulations.

RESULTS AND DISCUSSION

Hydrology Model: The RRI parameter calibration using Typhoon Ompong on September 15–16, 2018 the following produced results: calibration (daily rainfall-GsMap) – NSCE = 0.94, RMSE = 74.88. Owing to the unavailability of discharge data of previous typhoon events in the study area, this study conducted its validation using hourly rainfall data of the same typhoon events. We cannot directly compare the NSCE values; however, by carefully examining the hydrograph patterns, we can assume that the calibration is valid, as shown in Figures 5 and 6, which display the similarity of calibration and validation results, respectively. The total maximum peak discharge of the hourly data was 1,858 m^3/s, which was almost double that of the daily data. The hourly flood peak is shown to be significant, particularly for flood risk assessments, decision-making, planning, and designing integrated flood risk management.

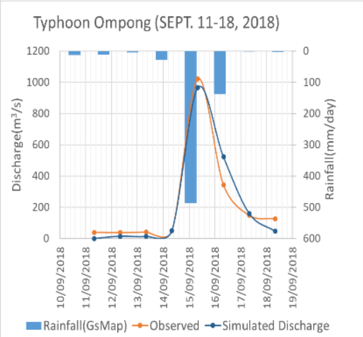

Figure 5: RRI calibration using daily rainfall

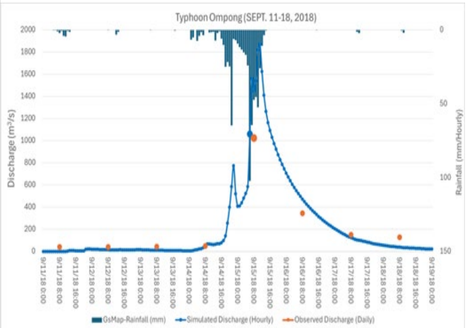

Figure 6: RRI validation using hourly rainfall

Hydraulic Model: In the simulation, we employed a 2D depth-average governing equation. We also applied mass and momentum conservation equations for water flow, mass conservation for bed sediment, and bed load equations. Specifically, the Egashira equation was utilized for bed load computation. The Nays2DH solver of the iRIC was developed to understand the topography of the study area; Figures 7 shows the resultant hydrograph generated from the RRI as a valuable input at the upstream boundary.

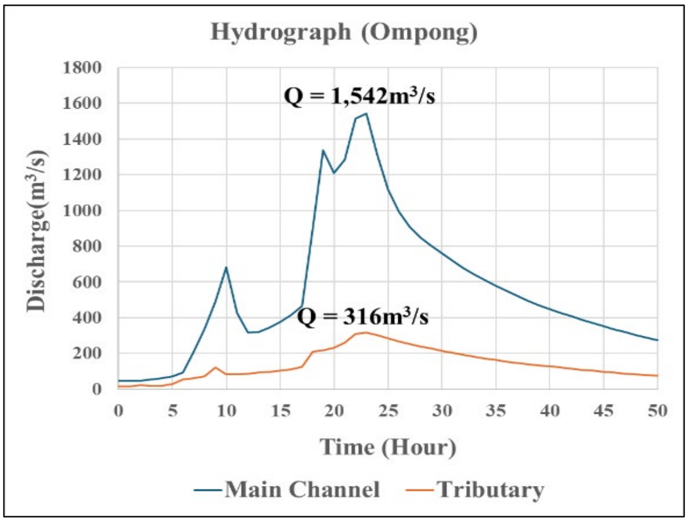

Figure 7: Typhoon Ompong (Hourly)

Channel Capacity: Figure 8 shows the maximum channel capacity of the river, which was 1,180 m^3/s. The three lines indicate the location at which the initiation of inundation or overtopping occurs when the flow discharge exceeds the channel capacity.

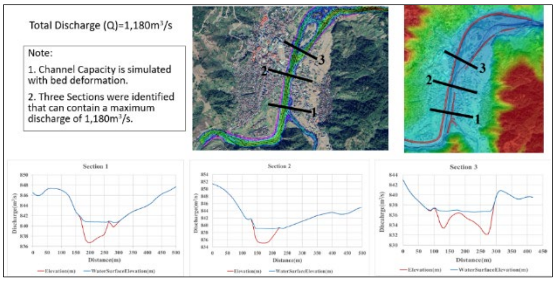

Figure 8. Channel Capacity

Extreme Events: Figures 9 and 10 provide a comprehensive understanding of the extent of flooding that may occur in the study area, particularly for the riverine communities of Ab-abtana-Samoki (A), Fagkay-Samoki (B), Eyeb-Pakkil (C), and Lanao-Cheppay (D), which are most affected by extreme events, with Ab-abtana-Samoki (A) at the greatest risk. The river structure magnified its effectiveness by protecting Eyeb-Pakkil (C) and Lanao-Cheppay (D); however, if damage or collapse occurred, inundation would occur. Another factor that contributes to the inundation in Ab-abtana-Samoki(A) is the flow coming from the tributary.

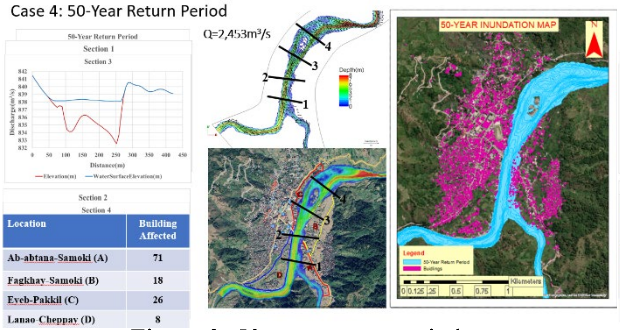

Figure 9: 50-year return period

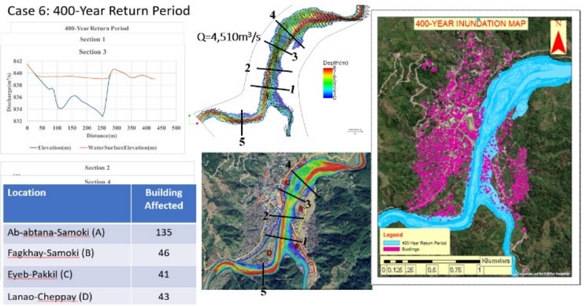

Figure 10: 400-year return period

Deposition and Erosion: Figure 11 shows the locations of deposition and erosion within the channel. However, the results show that the locations of deposition and erosion for different flow events are consistent at the same location.

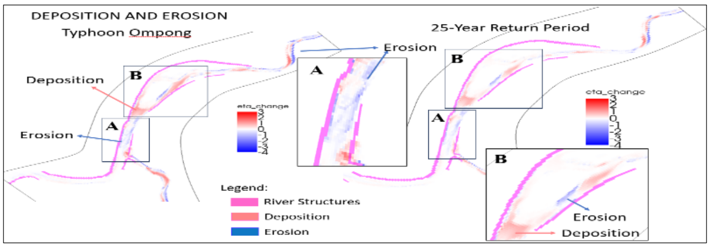

Figure 11: Deposition and erosion

Furthermore, Figure 12 shows the spatial distribution of the bed shear stress near the structure, of both left and right following the flow. We can observe that bed shear stress is higher at location 1 & 2 at the left bank while bed shear stress at right bank varies with 3 & 4 has the larger values. Photos 1 and 3 show the corresponding damage near the location of larger bed shear stress. Additionally, high bed shear stresses-initiate erosion, whereas low bed shear stresses will initiate deposition, which agrees with Figure 11.

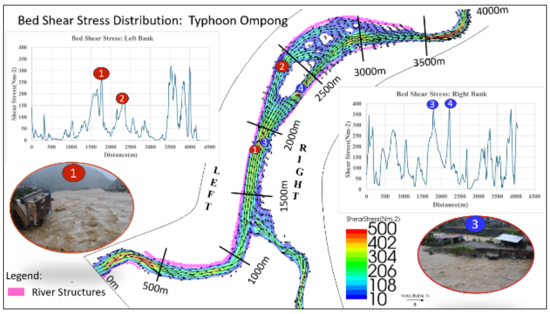

Figure 12: Bed shear tress distribution

Case No	Case Type	Channel Type	Discharge	Time (Hours)	Results
1	Channel Capacity	With Structures	Steady Flow	24-hours	1,180m³/s Maximum Flow
2	Typhoon (Ompong)	With Structures	Hydrograph – Typhoon	50-hours	21 affected buildings
3	25-year RP	With Structures	Hydrograph – 25yr	50-hours	65 affected buildings
4	50-year RP	With Structures	Hydrograph – 50yr	50-hours	123 affected buildings.
5	100-year RP	With Structures	Hydrograph – 100yr	50-hours	163 affected buildings
6	400-year RP	With Structures	Hydrograph – 400yr	50-hours	265 affected buildings
7	100-year – No Tributary	With Structures	Hydrograph – 100yr	10-hours	Tributary contributes significantly to flooding, particularly affecting the community of Ab-abtana–Samoki (A)
8	400-year – No Tributary	With Structures	Hydrograph – 400yr	10-hours	

Table 1: Shows the Summary of Results

Summary of Results: Table 1 represents the results of all conducted cases. It shows that as extreme events progress, the effects worsen, with the tributary notably contributing to flooding, particularly in Ab-abtana-Samoki (A) community, increasing their flood risk.

CONCLUSION AND RECOMMENDATION

Floods in the chico river Basin are not just natural occurrences; human actions like unsustainable land use and poor development planning make them worse. This study analyzed flood risk by looking at extreme events, erosion-prone areas, and changes in the river shape. Using hydrological and hydraulic models, the study confirmed that the river's current conditions match the trends seen in satellite images. The river can handle up to 1,180 m^3/s of flow, and anything beyond that causes flooding. Community A (Ab-abtana-Samoki) is the most vulnerable to flooding, while structures in community C (Eyeb-Pakkil) face risks from foundation erosion. The study also found that tributary contributes to flooding in Community A.

To reduce flood risks, it's important to build and maintain preventive structures in the Chico River Basin. Collecting ground data and educating the community about flood hazard are essential for better flood management. Comprehensive river planning should be conducted for the Chico River Basin. Strict land zoning policies should be enforced to limit the expansion of riverine communities. These findings are valuable for local and national governments in river management and flood risk policymaking. However, re-evaluation with updated data is recommended for a more accurate assessment. Both non-structural and structural measures like infrastructure improvements, are essential for effective flood risk mitigation. Field observation and post-typhoon damage assessment are also crucial.

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