SOCIO-ECONOMIC IMPACT ASSESSMENT OF FLOOD DISASTERS USING HYDROLOGICAL MODELING IN THE PANAY RIVER BASIN, PHILIPPINES

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ABSTRACT

Floods pose a significant threat to communities, particularly to those residing in river basins. Such incidents have devastating and debilitating effects with immense socio-economic consequences. This study examines the socio-economic impact of floods on communities living along the Panay River Basin in the Philippines and explores the consequences of recurrent flooding events, identifies the exposure of affected communities, and highlights potential preventive and mitigation strategies to counter the impacts of floods. Further. This study draws upon a comprehensive analysis using both scientific and ground-based approaches to provide a deeper understanding of the recurrent problem of flooding in these localities. The findings revealed the multifaceted nature of flood impacts that revolve around economic, social, and environmental aspects. This study concludes with recommendations for enhancing flood resilience and promoting sustainable development in flood-prone areas.

Keywords: *Flood Disasters, Flood Risks, Flood Hazards, Exposure, Flood Loss and Damages Flood Countermeasures*

INTRODUCTION

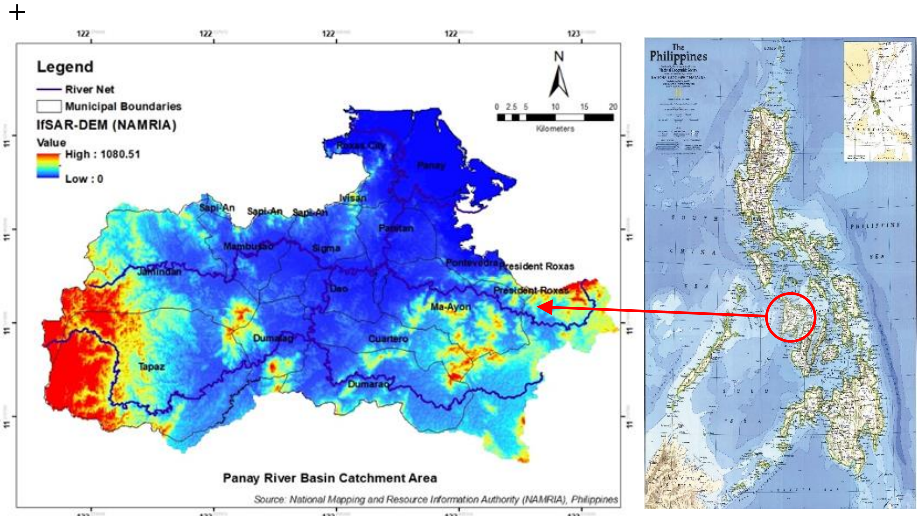

Figure 1 (a). Topographic Map of the Panay River Basin Catchment, (b) Philippine Topographic Map

The Panay River Basin is one of the 18 major river basins in the Philippines. It drains 16 municipalities and one city. The catchment area of the Panay River basin is approximately 2,046.03 km^2. The main river of the Panay River basin is 168.56 km long with three major tributaries.

The Panay River Basin encompasses a diverse range of socio-economic activities, including agricultural, businesses, and residential areas. The basin is regularly subjected to devastating flood events owing to its hydro-geographical features, including steep slopes, heavy rainfall, and inadequate water management systems. The basin has experienced significant losses in terms of life, infrastructure, and economic productivity. This study focuses on the socio-economic impact assessment of flood disasters to highlight the impacts of flood

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disasters on livelihoods and influence appropriate legislations and key disaster management directions. Furthermore, the lack of scientific and evidence-based assessment processes provides inaccurate loss and damage projections resulting in prioritization issues in disaster management, as well as fiscal management focus of local Disaster Risk Reduction Management (DRRM) funds. Scientific flood damage estimates were generated using the Rainfall Runoff Inundation (RRI) simulation results and GIS-processed flood maps, then compared with ground reports for validation. Tool development and adaptation were performed to enhance the accuracy of loss and damage reports.

THEORY AND METHODOLOGY

A. Flood Inundation Analysis

The Rainfall Runoff Inundation (RRI) model, a hydrological modeling tool developed by the Public Works Research Institute (PWRI) and the International Centre for Water Hazard and Risk Management (ICHARM) was used to simulate and predict flood characteristics in rivers and floodplains for a specific rainfall event. An Interferometric Synthetic Aperture Radar-Digital Elevation Model Interferometric Synthetic Aperture Radar – Digital Elevation Model (IFSAR-DEM), obtained from the National Mapping and Resource Information Authority (NAMRIA) was used in this study. The flood event of June 2008 (Frank) was used for calibration- using rainfall data combined from six different gauging stations of the PAGASA, DOST-ASTI, NIA and other local government units, as well as the observed discharge obtained from Capiz Environmental and Natural Resources Office (CENRO). Flood Events of April 2022 (Agaton) and October 2022 (Paeng) were also simulated to validate the calibrated parameters, which were necessary to stabilize the model efficiency by comparing them with the observed discharge from the said flood events. The Nash-Sutcliffe efficiency (NSE) criterion and Coefficient of Determination (r^2) were employed to verify the performance of the RRI model. Frequency analysis using Gumbel and generalized extreme values (GEV) probabilities was conducted to design rainfall patterns for flood events with different return periods (2-year, 5-year, 10-year, 25-year, 50-year and 100-year floods). Geo-hazard maps obtained from the Mines and Geo-Sciences Bureau (MGB), along with local flood data from the Local Disaster Risk Reduction Management Offices (LDRRMO) in the Province of Capiz, were used as validation tools for the generated Flood and Hazard Risk Maps.

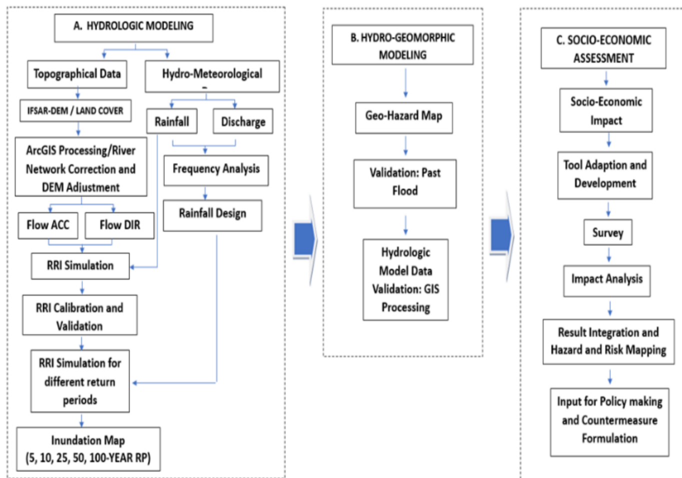

Figure 2. Overview of methodology

B. Socio-Economic Assessment

(1) Population Exposure was assessed using population data of the smallest administrative unit, obtained from the Philippine Statistics Authority (PSA). Processed using GIS, population density per barangay was mapped out. Combined with the generated flood extent, the geo-spatial data were analyzed using geoprocessing tools and calculations to arrive at a scientific-based estimate. **(2)** Agricultural Exposure was assessed using land cover data obtained from NAMRIA. It was classified to reflect cropland cover using GIS, and processed with the generated flood extent map to extract the agricultural exposed areas, specifically flood depth and duration. Furthermore, the extracted data were used to calculate and quantify yield losses in terms of rice production cost using the flood damage curves developed by Shrestha et al., 2016, who analyzed flood-damaged crops based on (a) Flood Depth, (b) Flood Duration, and (c) Plant Growth. The templates and the local planting and harvest calendar were obtained from the Department of

Agriculture (DA) and used to enhance the accuracy of local crop damage assessment. **(3) -** Infrastructure Exposure (Road Access) was assessed using GIS data on roads and bridges obtained from an open-source website on the Internet (igismap.com). These data were processed using GIS along with the generated flood maps to extract the exposure data. **(4) -** Housing Unit Exposure was assessed using Microsoft Building Footprints (MBF), processed through GIS and used to represent housing units. A threshold of above 10 square meters and below 300 square meters on the MBF polygons was set and assumed to represent housing units; below or above the said threshold were disregarded in the calculations. The generated flood maps were then used to extract the estimated exposed housing units corresponding to their spatially distributed household members. **(5) –** Local Businesses Exposure was assessed using surveyed data from local businesses in the Municipality of Mambusao, Capiz. GIS processing were also used to extract exposure level and losses due to flood events.

RESULTS AND DISCUSSION

A. Calibration and Validation

The RRI parameter calibration yielded the following results: Calibration – (Frank) NSE: - 0.64, and R^2: - 0.66; validation – (Agaton) NSE: - 0.63, R^2: - 0.75; and (Paeng) NSE: - 0.77, R^2: - 0.80, all of which yielded acceptable range. Google Earth Engine (GEE) generated flood inundation and exposure data were also used to validate the Agaton 2022 flood events. However, the 2008 flood event yielded no records as GEE did not cover such a year/period.

The frequency analysis results were as follows – Generalized Extreme Value (GEV) – NSE: - 0.88 and Root Square Mean Error (RSME): - 19.87; and Gumbel – NSE: -0.8 and RSME: - 25.3, which indicates good fit for GEV.

B. Inundation Map

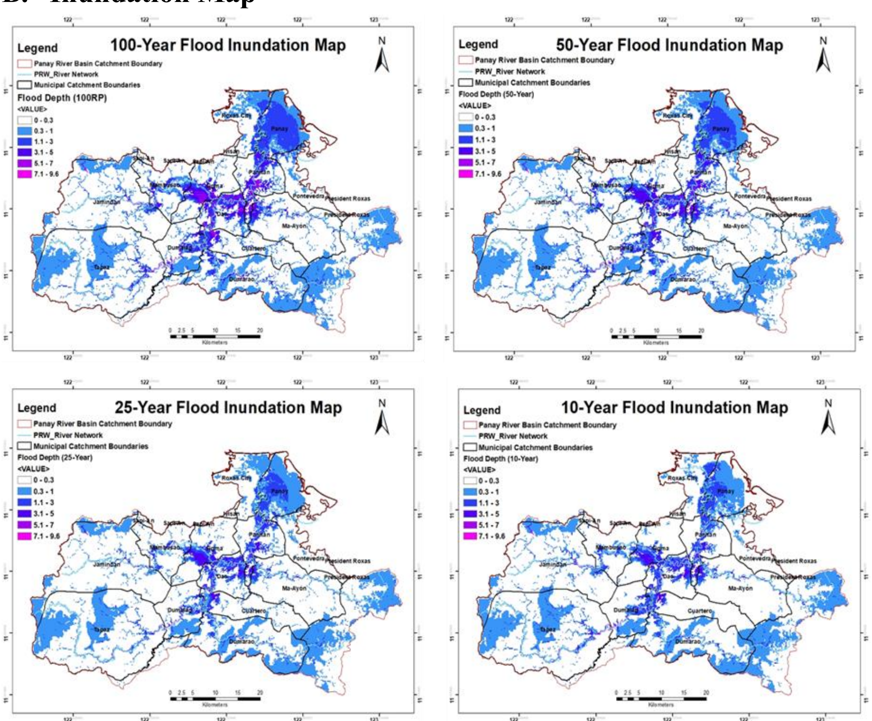

Figure 3. Inundation Maps (5-year, 10-year, 25- year, 50- year, 100-year Return Periods)

Using the rainfall design (5-year = 223.17 mm, 10-year= 274.1 mm, 25-year = 351.41 mm, 50-year = 422 mm, 100-year = 505.55 mm) generated through rainfall frequency analysis using 2-day maximum rainfall of the flood event of June 2008 (Frank), inundation maps for different return periods were generated using the RRI Model.

As depicted in Figure 3, The 10-year to 100-year flood simulations reflected almost identical extents of flooding but noticeably vary in depth as the rainfall amount increases. However, flooding of 0.3 m is visible in the upstream. Considering these are hilly areas, IFSAR-DEM model must have detected lower elevations, that holds small amount of flood water presented as flood but in truth could only be rainfall runoff.

C. Agricultural Exposure

Figure 4 depicts the land cover map of the Annual Crop areas within the Panay River catchment area. It covers 116,288.1 hectares of cropland. Figure 5 depicts the flood extent areas with flood depth of > 0.3 m during the June 2008 flood (Frank). The total area of exposed cropland was estimated to be 34,471 hectares. The crop loss and damage report obtained from the National Disaster Coordinating Council (NDC) reported total agricultural damage of Php 425.11 million. Using the flood damage curves developed by Shrestha et al.,2016, the amount of agricultural damage was estimated to be at Php 478.18 million, which is slightly over-estimated from the actual ground report. One limitation of the obtained land cover data was the lack of paddy area classification, which may have caused an over estimation.

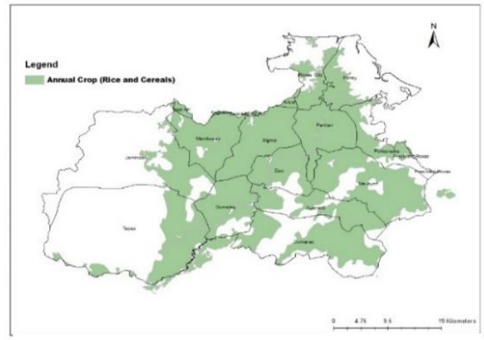

Figure 4. Land Cover Map – Annual Crop

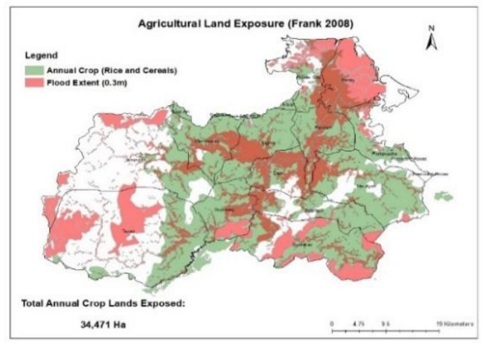

Figure 5. Agricultural Land Exposure

D. Population Exposure

Figure 6 depicts the exposed population in the flood inundation areas during the June 2008 flood (Frank), based on the population density data obtained from Philippine Statistics Authority (PSA). In comparison, the data obtained from the NDCC reported that 320,013 people were exposed to and affected by floods. Using GIS processing and calculations on a flood extent of >0.3 m, the estimated flood-exposed population resulted in 270,530, an underestimated number as opposed to the obtained ground data. This underestimation must have been owing to a lack of distinction regarding the nature of damages. Hence, actual numbers can either collectively indicate typhoons or flood-affected individuals or families. Furthermore, the area of coverage of this study is within the Panay River Basin catchment area, which implies that the catchment area covers only 12 municipalities and one city. Hence, considering the latter, reports from two municipalities outside the catchment area were eliminated resulting in an estimated 281,934 affected individuals. Provided such an analysis, the data generated from the RRI and GIS proved useful as scientific baseline estimates as evidenced by its proximity to the actual estimates on the ground. Such estimates are useful for emergency resource management, emergency response, and the provision of emergency goods and supplies.

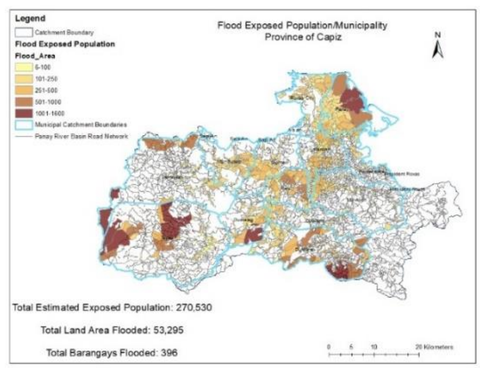

Figure 6. Population Exposure

D. Road Access Exposure

Figure 7 indicates the access road exposure using polyline data obtained from NAMRIA. Ground data obtained from the NDCC reported damage costs amounting to Php 494.930 million in infrastructure (roads and bridges), however, exact locations were not included in the said report. GIS-processed results revealed that 2,231 km local roads and 3,044 km minor roads were exposed to flooding and could have incurred heavy damage to support the NDCC-reported costs. It is essential to identify areas of flooding

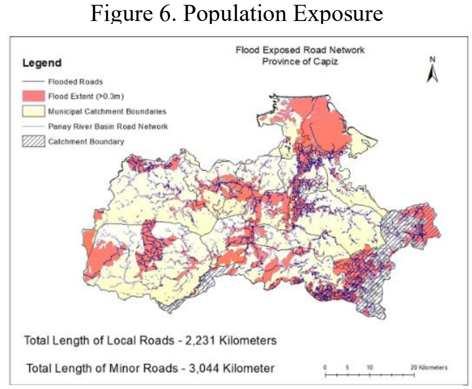

Figure 7. Road Access Exposure

that affect road access. The visualization of areas prone to flooding can aid in the preparedness stage and strategic planning for effective disaster management.

E. Housing Unit Exposure

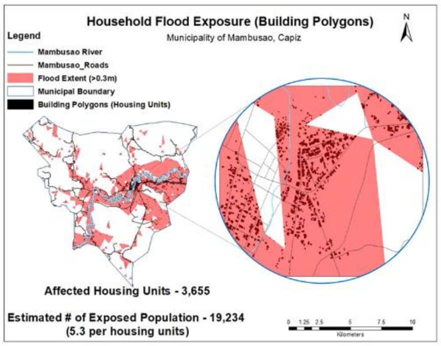

Figure 8. Household/Housing Units Exposure

Figure 8 illustrates Household Flood Exposure using MBF polygons as housing units. As mentioned previously, this part of the study focuses on the Municipality of Mambusao, Capiz. As reported by the LDRRMO of the municipality, 5,075 households were affected, with 22 partially damaged and 200 totally damaged houses. Conversely, the results of the estimates using RRI data and GIS processing tools show an underestimation, with 3,655 housing units/households affected. Based on the assumption of 5.3 household members/housing units, 19,234 individuals were estimated to have been affected. The use of MBF to determine housing and infrastructure units can have limitations and thus requires further processing and manipulation for enhanced accuracy. Satellite cannot capture polygons in dense areas such as forests and rural areas. Hence, it is necessary to validate the data based on field inspections to improve its accuracy.

F. Local Businesses Exposure

Figure 8 depicts the flood extent >0.3m in the Municipality of Mambusao. In terms of the assessment of local businesses, a recent ground survey was conducted in 140 of the existing 408 local business establishments located in the locality's business area, particularly the public market, as part of the ongoing Business Tax Mapping of the municipality. Part of the survey was related to the losses and damage incurred during flood disasters. Based on the surveyed data, Average days of Business Interruption was around 1.5 days, Income Losses due to this interruption amounts to a total of Php 1.7 million (average losses per establishment is at Php 12,139.29/day) and Flood Damage cost amounting to Php 781,200 thousand (in goods and infrastructure damage).

G. Flood Hazard Risk Map

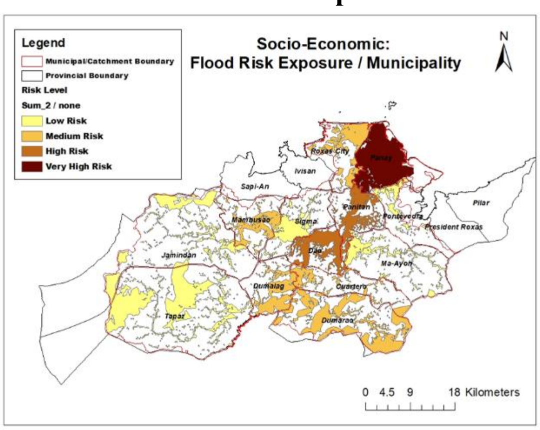

Figure 9. Flood Hazard Risk Map

Figure 9 illustrates the flood risk map, identifying highly exposed municipalities in the Panay River basin. This was achieved by combining the results obtained from the RRI flood simulation, using flood extent >0.3m, and the socio-economic impact assessment based on the flood hazards and flood exposure of three socio-economic factors, namely: Population exposure, cropland exposure and road access exposure.

CONCLUSION & RECOMMENDATIONS

Understanding the socio-economic consequences of floods is crucial for policymakers, disaster management agencies, and local communities to develop effective strategies for risk reduction, preparedness, and response. Integrated approaches that combine hydrological modeling and socio-economic analysis to assess the impacts of floods comprehensively can provide valuable insights into the complex interactions between natural and human systems, enabling informed decision-making and the development of targeted interventions to mitigate the effects of floods. Hence, to further enhance the accuracy of socio-economic impact assessments of flood disasters: (1) Adaption of current and working tool and development tools for assessment and customization for local applicability should be performed.

(2) Establishing a reliable data management system should take precedence. (3) Investment on the Early Warning System, such as, the development of a reliable forecasting system by PAGASA and the use of RRI simulation in local government units can help in the disaster preparedness and mitigation. (4) Conduct of regular excavation and dredging in the heavily silted Panay River basin is imperative to improve water discharge to the bay. (5) Construction of retarding basins in strategic areas, like that of the ODA financed Imus Retarding Basin, a first in the Philippines, should be studied and considered.

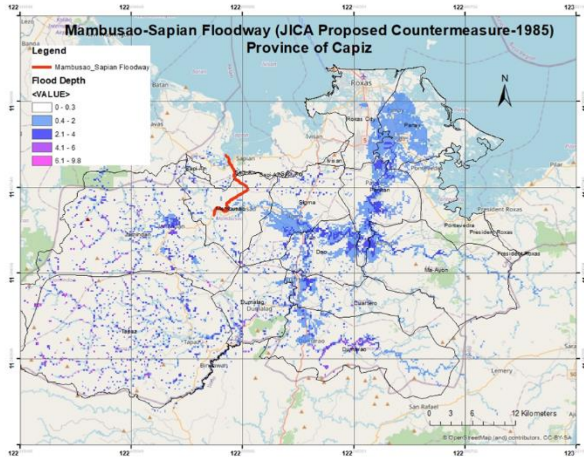

Figure 10. RRI Simulation of Floodway System

JICA's study and proposal on the development of the Panay River Basin (1985), focused on the construction of dams, highline canals, floodway systems and irrigation structure improvements. Using such reference, RRI simulation of the JICA proposed Mambusao - Sapian Floodway was conducted to provide countermeasure options, in addition to the previously mentioned non-structural measures.

Table 1. Flood Impact Comparison Chart

Flood Impact Comparison	w/out Countermeasure	Total Damage Cost (Crops and Assistance)	w/ Countermeasure (Mambusao-Sapian Floodway)	Total Damage Cost (Crops and Assistance)	Cost Difference	% Cost Reduction	Difference in Area (Ha)	% in Area and No. of Population
Cropland Area (Ha)	34,471	₱478,181,712.00	25,029	₱347,202,288.00	₱130,979,424.00	27.4%	9,442	27.4%
Population Exposed (Indv)	281,934	₱4,868,208.00	192,525	₱3,272,925.00	₱1,595,283.00	32.8%	89,409	31.7%

Figure 10 illustrates considerable reduction in flooding, specifically in municipalities along the Mambusao sub-river basin, where 27.4% reduced exposure to flooding for cropland areas and 31.7% reduced exposure to flooding in the exposed population as shown in Table 1.

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