Development Of Proposed Non-Structural Flood Mitigation Plan in City of San Fernado, Pampanga

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***Abstract*: Flooding continues to be one of the major concerns in the City of San Fernando, Pampanga, particularly during extreme weather events. This study aims to develop a comprehensive non-structural flood mitigation plan to reduce flood risks and enhance community resilience in seven selected barangays. To assess hydrologic and hydraulic behavior, simulations were conducted using HEC-HMS and HEC-RAS simulation, considering a 100-year return period. The discharge for the entire watershed used in HEC-HMS modeling was 97.7 m3/s. These simulations allowed the study for a more accurate understanding of flood depths and extents within each barangay. A mixed-method approach was applied for the flood risk assessment, which included both quantitative scoring and qualitative data collection. Risk scoring was based on four key categories: flood depth risk, infrastructure analysis, community awareness, and inventory resources, which were designed to reflect the overall vulnerability of each barangay. Barangays Del Pilar, Juliana, San Nicholas, and San Pedro were identified as moderate risk, while San Felipe, San Jose, and Santa Lucia were classified as low risk. Additionally, qualitative interviews with local officials provided valuable insights for drafting the proposed non-structural flood mitigation plan. Overall, the study demonstrates that non-structural measures, when grounded in technical analysis and community input, can offer effective, sustainable solutions for urban flood management.**

***Keywords*: Flood Mitigation Plan, Urban Flooding, Flood Risk Assessment, Non-Structural Measures, Hydrologic Modeling, Hydraulic Analysis.**

1. Introduction

Flooding has been a dilemma faced by urban and rural areas around the world. It has had a significant societal and economic impact causing substantial damage especially to infrastructures and citizens. Urban areas, in particular, contain many commercial establishments that contribute significantly to economic progress. Mallakpour and Villarini (2015) stated that frequency of flood events has remained high over for the past decades. In addition, risks due to flooding have affected a large number of people globally [1]. This vulnerability is particularly pronounced in City of San Fernando, Pampanga, which is widely recognized as the province's economic powerhouse and a community at risk of flooding [2]. The persistent threat of flooding in City of San Fernando, Pampanga, necessitates the implementation of comprehensive and sustainable mitigation strategies. This study aims to develop a comprehensive plan that addresses the root causes of flooding, enhances community resilience, and promotes long-term sustainability. The United Nations recognizes the importance of flood mitigation strategies and includes it as a key component of the Sustainable Development Goals (SDGs), specifically SDG 11: Sustainable Cities and Communities, specifically targets 11.5 and 11.B which address the urgent need for flood disaster resilience and climate change adaptation.

2. Review Of Related Literatures

A. Flooding and Mitigation Managements

The Philippines is an archipelago consists of more than 7,000 islands located in Southeast Asia in the western Pacific Ocean – planet's biggest ocean [3]. The location of the archipelago lies along the "Ring of Fire" where most of the natural disasters develops. In addition, the country stands at the boundary of the earth's major tectonic plates and a huge part of it straddles the typhoon belt – massive region in the west Pacific Ocean which at 165 million square kilometers.

Fig.1. Destruction of Typhoon Yolanda in Tacloban City, Philippines [5]

This belt can fit all the continents of the planet and one-third of the tropical cyclones of the world form on this [4].

Figure 1 illustrates the strongest typhoon recorded in the Philippines was the typhoon "Yolanda." This was reportedly to be the deadliest typhoon to visit the Philippines. On November 8, 2013, the typhoon has left a total number of 8,000 people dead, over 14 million people loss their houses, including 5.9 million workers affected.

Flooding is still a major issue since many countries around the world are hit by tropical storms and these places receive a lot of rainfall. Pampanga, one of the provinces in the Philippines, is included to the most at-risk provinces from climate damage [6].

However, flood control in the Philippines is regarded as a multifaceted challenge that encompasses both structural and non-structural measures, as outlined by Qi et al. (2021). Structural mitigation strategies, such as landscape reconstruction, aim to diminish the impact of flooding, while non- structural approaches focus on minimizing risk by relocating people and assets away from hazardous areas. However, the effectiveness of structural solutions has diminished over time due to the deterioration of aging dams and locks. The interplay of these factors underscores the urgent need for innovative flood management strategies that can adapt to the evolving climate landscape [7].

B. Hydrologic and Hydraulic Assessment

The US Army Corps of Engineers created the comprehensive Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), which is frequently used to analyze dendritic watershed systems. In the City of San Fernando, Pampanga, HEC-HMS plays a pivotal role in flood mitigation planning. Its ability to simulate intricate hydrologic processes and generate comprehensive flood inundation maps empowers researchers to develop data-driven and highly effective flood management strategies. Because it can accurately simulate runoff for both short-term and long-term events, HEC-HMS is very popular. It is accessible to a wide range of users due to its intuitive interface and reliance on standard modeling techniques [8].

A potent software program called Hydrologic Engineering Center's River Analysis System (HEC-RAS) was created to simulate the hydraulic behavior of water flow in natural rivers and channels. For intricate networks of channels, floodplains, and overbank areas, it is capable of performing hydraulic calculations in both one and two dimensions. Engineers can determine water levels, locate areas at risk of flooding, and carry out flood studies by using HEC-RAS to simulate water flow [9].

HEC-RAS serves as an indispensable tool for researchers engaged in flood mitigation planning within the City of San Fernando, Pampanga. This tool enables a comprehensive understanding of flood dynamics, and aids in the identification of high-risk and vulnerable areas requiring priority intervention.

C. Flood Risk and Management

Flood risk is the sum of the likelihood or chance that an event will occur and the impact or consequences if it does. Flood risk depends on the presence of a flood source, like a river, a pathway for floodwaters to follow, and a receptor, like a housing estate, that is impacted by the flood [10].

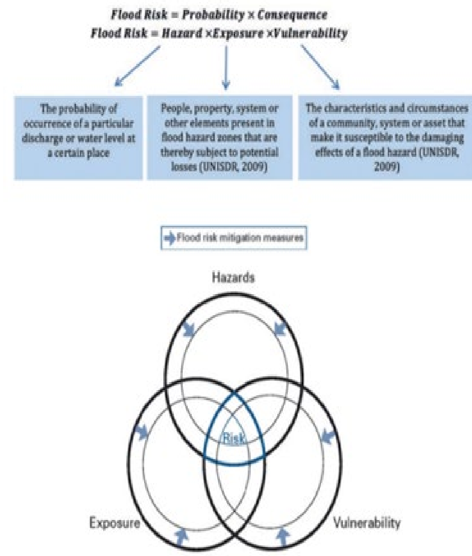

Fig.2. Concept of Flood Risk and Reduction [11]

Meyer et al. (2011) identified two key components of flood risk management: (1) flood risk assessment, which encompasses damage analysis, and (2) the evaluation of risk mitigation measures. Both components hinge on the accurate quantification of flood risk, making flood damage estimation a critical element of the process [12]. Furthermore, analyzing the spatial distribution of flood damage can serve as a valuable tool in crafting effective flood disaster mitigation policies.

D. Gap Analysis

A community vulnerable to flooding due to its geographical location and rapid urbanization can benefit significantly from implementing non-structural flood mitigation measures. These measures enhance community resilience, improve land use planning, preserve ecosystems, and provide cost-effective solutions. Integrating hydrologic modeling tools like HEC-RAS and HEC-HMS with non-structural flood management strategies and flood risk assessments offers a comprehensive approach to mitigating flood risks in urban areas.

E. Background of the Study

The City of San Fernando, located at the central of Pampanga province, stands as a key hub in the Central Luzon region. It has a major strategic advantage over other major urban centers in the region due to its central location within both Pampanga and the larger Central Luzon plain [13-14]. The 35 barangays that covers the City of San Fernando are all categorized as urban.

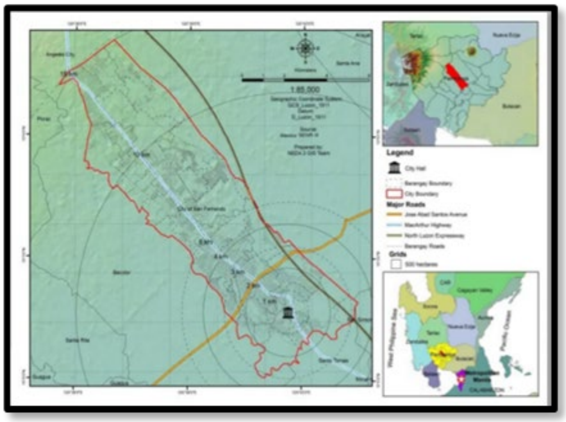

Fig.3. The Study Area [15]

Based on the Comprehensive Land Use Planning for 2012-2021, as depicted in Figure 3, the City of San Fernando shares borders with Bacolor to the west, Santo Tomas to the south, Mexico to the east, and Angeles City to the north. Notably, the northernmost boundary of the city, specifically the Angeles City to City of San Fernando, has an elevation difference of 98 meters and 24 meters above sea level [14]. While this topography may indicate a relatively flat area, it actually facilitates surface water flow from these two tributary neighborhoods to the City of San Fernando.

The city's principal and largest drainage channel, the San Fernando River, serves as the main conduit for floodwaters and surface runoff, playing a critical role in the city's flood management system. Due to its geographical location and topography, San Fernando lies at one of the lowest elevation points in the surrounding area. [16].

Fig.4. Flow system of San Fernando River [17]

About 20% of the barangays in the City of San Fernando (7 out of 35) are completely situated within areas that are extremely vulnerable to flooding, as per the Mines and Geosciences Bureau's (MGB) flooding map. Furthermore, areas of a number of other barangays are susceptible to floods to varying degrees, ranging from high to moderate [18-19].

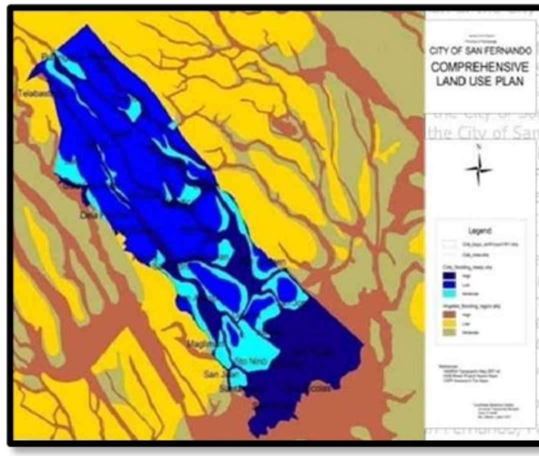

Fig.5. Flooding Map for READY Project [20]

The results of a recent study carried out by the Department of Environment and Natural Resources' (DENR) Mines and Geoscience Bureau (MGB) as part of the READY Project in Figure 1.8. The 100-year return period flooding map establish three different levels of vulnerability are used by the study to identify areas in the City of San Fernando that are vulnerable to flooding [20]. The southern part of the city is particularly vulnerable to flooding, especially in areas near natural drainage systems such as streams and creeks.

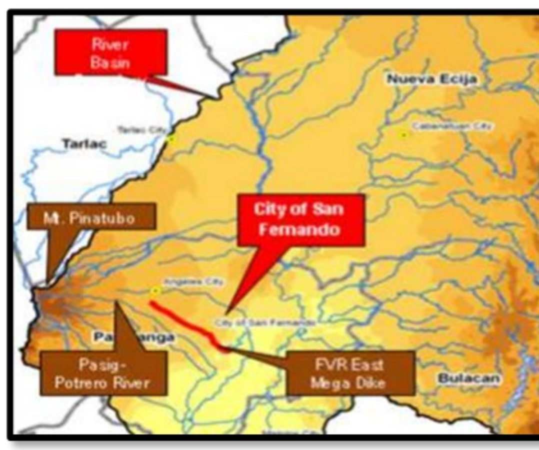

Fig.6. The FVR East Mega Dike map [20]

The City of San Fernando has implemented several flood control measures to lessen the effects of flooding. To increase the capacity of rivers, creeks, and drainage systems throughout Central Luzon, including the San Fernando River, a significant project known as the Pinatubo Hazard Urgent Mitigation Project, Phase II (PHUMP 3B) started at 2008 and fully implemented in 2015 was put into place. By lowering water levels and reducing the length of floods in the City of San Fernando and the nearby towns of Mexico and Santo Tomas, PHUMP 3B is specifically intended to lessen property damage brought on by frequent flooding throughout the Central Luzon and the highlight for renovation of southwest mega-dike as a protection to the residents of the City of San Fernando [21]. However, flooding and inundation are still common problems in the city, despite the past ten years of efforts to improve storm drainage systems and put flood control measures into place. To address this underlying issue, the study generally seeks to develop a comprehensive flood mitigation plan for the City of San Fernando, Pampanga.

3. Methodology

A. Research Design

The study adopts a mixed-method approach which involves the collection and analysis of numerical data, integrative process and scientifically rigorous method of data collection and assessment that enables quantification of hydrologic and hydraulic analysis. In accordance with the research design, the following methods are identified to proceed to risk assessment: vulnerability analysis and risk quantification.

B. Methodological Framework

This methodological framework involves analyzing data, evaluating risks, and implementing strategies to develop comprehensive flood management plans.

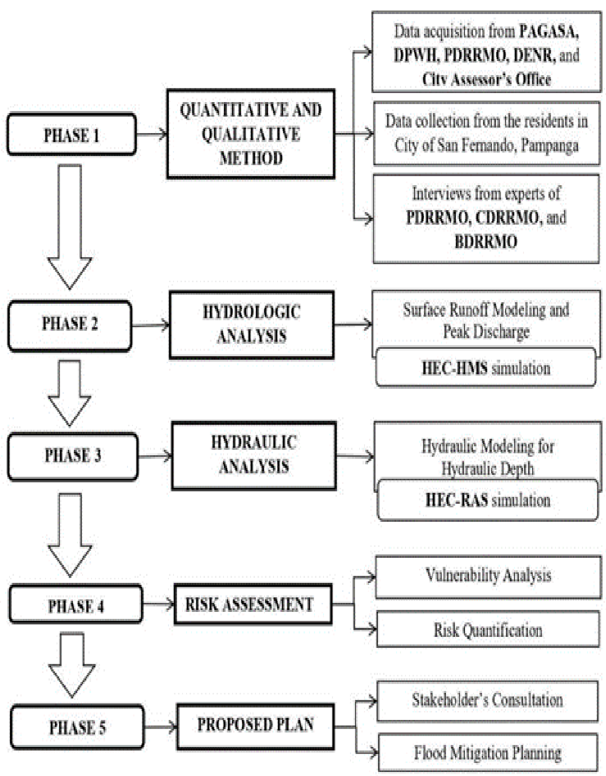

Fig.7. Methodological Framework

C. Primary and Secondary Data

The first phase for the methodology involves all qualitative data particularly, primary and secondary data which are gathered in this study. Primary data includes request letters approved by the school administration were made to collect relevant data, which were given to the following government agencies: The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), Department of Public Works and Highways (DPWH), Provincial Disaster Risk Reduction and Management Office (PDRRMO), and Department of Environment and Natural Resources (DENR), and City Assessor's Office of the Municipality of San Fernando, while secondary data includes historical flood data, rainfall patterns, river flow rates, and land use changes, are gathered which are important in assessing flood risk.

D. Research Locale

This study is conducted in the selected barangays in the City of San Fernando, Pampanga. This city is subdivided to thirty-five (35) barangays and they are all classified as urban areas. For the coverage of the study, only limits on identifying respondents in seven (7) high-risk flooding barangays in city of San Fernando. The target population for this study is comprised of 69,117 residents from these high-risk barangays, representing a specific demographic that is most vulnerable to the issues under investigation [22].

Purposive sampling method is utilized in this study to identify the number of respondents as a sample size of the city's population. Purposive sampling is a non- probability sampling approach in which researchers select respondents depending on characteristics relevant to the research investigation. [23].

E. Sample Size Calculator

The Raosoft Sample Size Calculator is a tool for estimating the appropriate number of samples for a survey or research study. From the Research Locale, the population of City of San Fernando is 69,117. At a 95% confidence level, the figure showed that 383 samples were drawn from a population of 69,117. The range that the true population parameter is likely to fall within is indicated by the reported margin of error, which is 5% [24].

F. Quantitative and Qualitative Instrument

A self-formulated questionnaire, validated by a statistician, grammarian, psychometrician, and a disaster management expert from PDRRMO, is used to collect data and generate responses from residents of the City of San Fernando, Pampanga. The data gathered through this questionnaire serve as a valuable foundation for shaping effective flood mitigation strategies, guiding evidence-based decision-making, and strengthening the city's overall resilience to flood-related risks and climate-induced challenges.

This qualitative method aims to gather informations from experts of Pampanga Provincial Disaster Risk Reduction and Management Office (PDRRMO), City Disaster Risk Reduction and Management Office (CDRRMO) in City of San Fernando, and Barangay Disaster Risk Reduction and Management Office (BDRRMO) from the 7 selected barangays.

This approach not only highlights the nuances in expert perspectives but also facilitates the identification of underlying factors or trends that might inform practice, policy, or future research [25].

G. Hydrologic Analysis

The hydrologic analysis in this study is conducted using HEC-HMS software, a model widely used for runoff estimation based on rainfall distribution. The software is mostly used for studies which require hydrologic analysis for data collection and analysis. The software is utilized to develop hydrographs of a certain area for the determination of peak flow and discharge of runoff. [26].

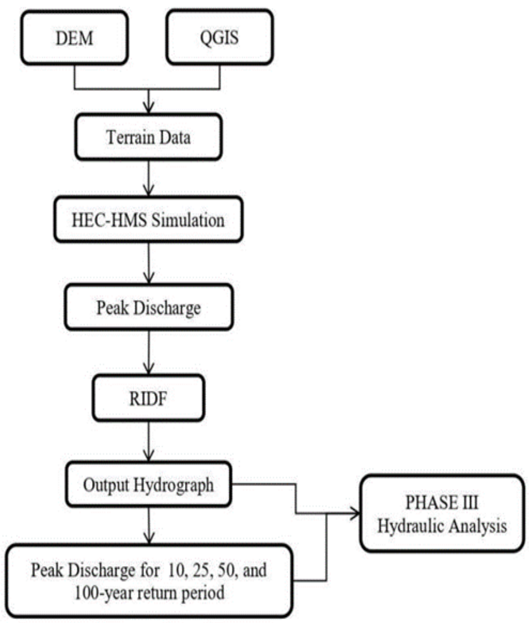

Fig.9. HEC-HMS Simulation Flowchart

H. Hydraulic Analysis

Critical parameters such as water levels and flow velocities can be accurately computed using HEC-RAS, thanks to its robust capability to create both one-dimensional and two-dimensional hydraulic models. The software offers exceptional flexibility in simulating a wide range of hydraulic scenarios, including both steady-state and unsteady flow conditions, allowing for detailed and dynamic analysis. As a result, HEC-RAS is widely utilized in environmental impact studies, river and watershed management, infrastructure design, and flood risk assessments. Its integration with GIS platforms further enhances spatial analysis [27]. HEC RAS has three main components: - (a) the geometry data which consists of a description of the size, shape, and connectivity of stream cross-sections; (b) the Flow data which contains discharge rates; and (c) the Plan data which contains information pertinent to the run specifications of the model, such as a description of the flow regime.

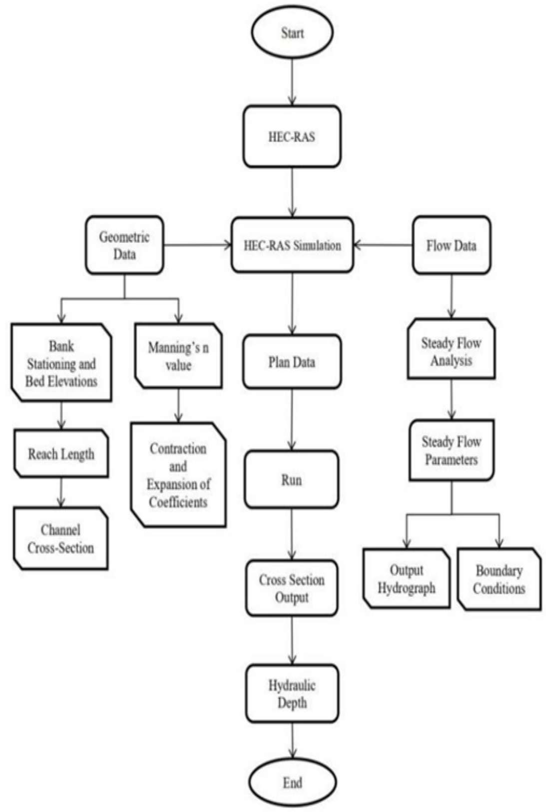

Fig.10. HEC-RAS Simulation Flowchart

I. Vulnerability Analysis and Risk Quantification

This phase utilizes flood mitigation scoring system consisting of four (4) criterias as an instrument validated by PDRRMO. These criteria, presented as a checklist, are based on data gathered from officials.

J. Flood Scoring System

The Flood Scoring System offers an innovative approach to identifying and understanding flood risks in such urban environments [28]. The scoring method, which incorporates critical factors derived from the HEC-RAS simulation of maximum hydraulic depth in overbank areas, is essential for accurately evaluating disaster risk and assessing the potential severity of damages in cyclone-prone regions. By integrating hydraulic data with risk indicators, this method provides a data-driven foundation for prioritizing resource allocation, enhancing early warning systems, and supporting evidence-based decision-making in disaster risk management. Additionally, quantifying flood depth and flow characteristics, this approach enables more precise identification of vulnerable zones, informs targeted mitigation strategies, and supports effective disaster preparedness and response planning tailored to the unique challenges posed by cyclonic events. It enhances the overall resilience and adaptive capacity of affected communities.

Table.1. Flood Depth Scoring System [28]

Flooding Depth (m)	Rating	Category
>3.05	5	Very High Risk
0.91-3.05	4	High Risk
0.3-0.91	3	Moderate Risk
<0.3	2	Low Risk
No Flooding	1	No Risk

K. Infrastructure Analysis

The type of materials used in the construction of houses plays a significant role in determining the vulnerability of residences to flood damage. The structural integrity and resilience of buildings during flood events are heavily influenced by the materials used for construction [29]. In this section, data on the types of materials used for infrastructure in various barangays are collected from the Municipality of San Fernando - City Engineer's Office and the Local Barangay Halls from each selected barangays, providing a comprehensive overview of building practices across the area. This section currently contains three sections: Building Structure Type, Residential Construction Materials for Outer Walls, and Residential Construction Materials for Roofing. The average score that obtained from the three is the rating score for the specified barangay.

L. Building Structure Type

The table below presents the criteria employed to evaluate and determine the level of flood risk associated with different types of building structures. Each structure type is assigned a specific weight or percentage, representing its relative vulnerability and significance in the overall flood risk assessment of the barangay. This approach ensures a more accurate and data-driven evaluation, supporting targeted mitigation efforts and informed planning decisions.

Table.2. Criteria for Type of Building Structure [29]

Type of Building Structure	Score Rating
Commercial/Industrial/Agricultural Building or Houses	5
Single House	4
Duplex	3
Multi-unit residential	2
Other Housing Unit	1

M. Construction Materials for Outer Walls

This section assesses the influence of construction materials used for the outer walls on the overall flood risk of residential buildings. This evaluation offers critical insights into the potential structural vulnerabilities of residential buildings. The findings help identify which materials are more susceptible to water damage, erosion, or structural failure.

Table.3. Criteria for Construction Materials for Outer Walls [30]

Construction Materials for Outer Wall	Score Rating
Wood	5
Makeshift/Salvaged/Improvised Materials, Tarapal, Bamboo/Sawali/Cogon/Nipa, Asbestos, Glass, and Others	4
Half Concrete/Brick/Stone and Half Wood	3
Concrete/Brick/Stone	2
Galvanized Iron/Aluminum	
No Walls	1

N. Construction Materials for Roofing

This section presents a table of roofing materials that contribute to the flood risk in the area. When heavy rains or floods impact these different materials, they contribute differently to the extent of damage or risk, affecting the overall infrastructure resilience. Therefore, it is crucial to consider the type of roofing material as a key factor in assessing the flood risk for urban planning.

Table.4. Criteria for Construction Materials for Roofing [31]

Construction Materials for Roofing	Score Rating
Tarapal and Makeshift/Salvaged/Improvised Materials	5
Bamboo/Sawali/Cogon/Nipa, Asbestos, and Others	4
Half Galvanized Iron and Half Concrete	3
Galvanized Iron/Aluminum	2
Tile/Concrete/Clay Tile	1

O. Community Awareness Analysis

Community resiliency is a key for the effectiveness and successful implementation of any flood mitigation program. [32]. This section focuses on the collection of data from survey questionnaires completed by a selected sample size of respondents across each barangay. A total of 383 respondents are required for data analysis, with the responses being evaluated based on a rating scale designed to assess flood risk.

Table.5. Likert's Interval Scale [33]

Likert – Scale	Interval	Description
1	1.00 – 1.79	Strongly Disagree
2	1.80 – 2.59	Disagree
3	2.60 – 3.39	Neutral
4	3.40 – 4.19	Agree
5	4.20 – 5.00	Strongly Agree

This table outlines the Likert's scale that serves as the foundation for evaluating community awareness. The scale ranges from Strongly Agree to Strongly Disagree, offering participants a clear spectrum to express their opinions. To apply the statistical computation for the flood mitigation scoring instrument that is utilized in this study, convert the raw Likert scale ratings into a uniform, standardized score using the following formula:

Final Rating Factor = 6 − Likert's Rating Factor

The Likert's Rating Factor ranges from 1 to 5. By subtracting the Likert score from 6, the study reverses the scale so that a higher score reflects better preparedness and awareness. The Final Rating Factor is then be integrated into the Community Awareness Category of the flood mitigation scoring instrument, which serves as a tool for analyzing and comparing the resilience and preparedness of different barangay.

P. Inventory Resources Analysis

This section features a detailed checklist that evaluates the emergency response resources available in each selected barangay. Data for this assessment is gathered through consultations with the Provincial Disaster Risk Reduction and Management Office (PDRRMO) for standard flood rescue equipments and local barangay councils for the actual data.

Table.6. Description for Inventory Equipment Standards [34]

Equipment	Standard Quantity
Flashlight	1 per rescuer
Battery-powered or hand-crank radio	1 per family
Extra batteries	Sufficient for 72 hours of operation
First aid kit	1 per family
Life jacket	1 per person
Rescue Helmet	1 per rescuer
Rescue Boot	1 pair per rescuer
Rescue Gloves	1 pair per rescuer
Traction Rope	1 per team (length depending on operation scope)
Rope Throwing Bag	1 per team
Knives and Cutting Tools	1 per team (multipurpose, safety tools)
Signaling Devices	1 per team (whistle, flare, mirror, or other)
Rescue Rafts	1 per team (or per number of rescuers depending on conditions)
Wading poles	1 per team, or as needed depending on depth of water
Floating Objects	2-3 per family
Whistle	1 per rescuer
Inflatable Rescue Boats	1 per team for 1 family (or more for larger teams)

In alignment with these standards, the study employs a weighted average method to comprehensively assess whether each barangay zone maintains a sufficient and strategically distributed stockpile of materials necessary for an effective and timely response to potential risk events. This approach systematically accounts for resource variations to evaluate each zone's emergency preparedness and response capacity.

Table.7. Instrument for Flood Operation Equipment

1	2	3	4	5
CHECKLIST				
Complete resources (100 %)	**Mostly complete resources (75%)**	**Partially complete resources (50%)**	**Incomplete resources (25%)**	**No resources (0%)**
☐	☐	☐	☐	☐
☐	☐	☐	☐	☐
☐	☐	☐	☐	☐
☐	☐	☐	☐	☐
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Q. Flood Mitigation Program Scoring System

This section provides a comprehensive summary of all the scores derived from the four analyses, offering a detailed categorization of each barangay based on their vulnerability to various flood risks. This utilizes a scoring instrument validated by the experts from PDRRMO.

Table.8. Flood Mitigation Scoring Instrument

Barangay	Criteria	Score
	Flood Scoring System	
	Infrastructure Type	
	Community Awareness	
	Emergency Action Response	
Total Average Score:		

Table.9. Rating Scale Remarks for Flood Risk Scoring System

Rating Scale Remarks	
1.000 - 1.800	No Risk
1.801 - 2.600	Low Risk
2.601 - 3.400	Moderate Risk
3.401 - 4.200	High Risk
4.201 - 5.000	Very High Risk

R. Flood Mitigation and Management Planning

The most important objective of the process is to carefully examine the data that was gathered from the residents and interviews from experts of City of San Fernando, Pampanga. The process starts by compiling the outcome of the surveys carried out and then progressing to statistical disposition of the obtained figures. The findings of this study inform the development of effective and appropriate interventions, based on specific characteristics.

S. The Flood Mitigation Plan

The flood mitigation plan for San Fernando, Pampanga focuses on non-structural measures to manage flood risks and reduce community vulnerability. The plan prioritizes improving early warning systems and actively involving communities in flood prevention efforts.

T. Ethical Consideration

The study adheres to a strict set of ethical considerations to safeguard the confidentiality and privacy of all relevant documents and respondents' personal data. This ensures transparency and accountability throughout the research process, ensuring full compliance with the Data Privacy Act of 2012 to protect participant information. The research obtains all necessary permits and approvals from relevant authorities to ensure that the study was conducted in accordance with ethical guidelines.

4. Results And Discussion

A. Flood Mitigation Assessment

This section presents a comprehensive analysis of the hydrological and hydraulic conditions of Sto. Niño Creek, Del Carmen Creek, Calulut Creek, and the San Fernando River, utilizing advanced modeling tools such as HEC-HMS and HEC-RAS. The hydrologic simulations generated by HEC-HMS provide critical insights into rainfall-runoff relationships, while the hydraulic depth and flow dynamics produced by the HEC-RAS model offer detailed information on water surface elevations, flow velocities, and flood extents. These outputs are essential for accurately identifying flood-prone barangays and form the foundation for developing targeted, data-driven flood mitigation strategies.

B. Hydrologic Assessment

Hydrologic Analysis is essential for determining the discharge of a watershed for different return periods. The HEC-HMS was utilized in this study for its reliability and credibility on multiple studies relating to water resources and management [26]. Running simulations for different return periods in this study helped the researchers identify probable severity of damage and effect of a particular hydrologic event based on its intensity for the construction. The 100-year return period was highlighted due to its immense intensity, as it poses a significant risk that necessitates immediate action to mitigate its potential consequences.

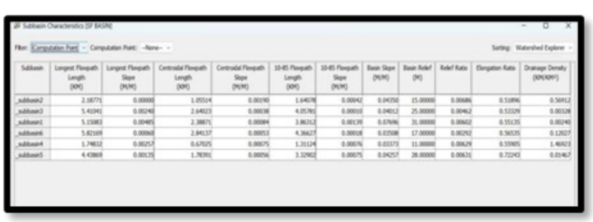

Fig.11. Subbasins Characteristics

The characteristics of each subbasins were generated by the simulations as shown in Figure 3.1. These subbasins characteristics are Longest Flowpath Length, Longest Flowpath Sope, Centroidal Flowpath Length, Centroidal Flowpath Slope, 10-85 Flowpath Length, 10-85 Flowpath Slope, Basin Relief, Basin Slope, Relief Ratio, Elongation Ratio, and Drainage Density.

Table.10. Catchment Area and Lag Time of Subbasins

Subbasin	Area (km^2)	Lag Time (min)
Subbasin 1	6.3344	2.61
Subbasin 2	1.0124	1.89
Subbasin 3	6.5385	4.04
Subbasin 4	0.7503	1.41
Subbasin 5	8.0759	2.50
Subbasin 6	8.5081	3.87
Cumulative Area	31.2196	

Table 10 shows the area in square kilometers and lag times of individual sub-basins within the watershed considered in this study. Within the watershed, a delineation process has identified a total of six subbasins. This provided a important information about the distribution of water sources of the rivers and creeks hydrology. It presents computed lag times of each subbasin within the watershed. These indicate the amount of run-off present in a certain area for a certain amount of time due to the delay of the discharge. These lag times provide fundamental grasps in determining the hydrologic response of individual subbasins.

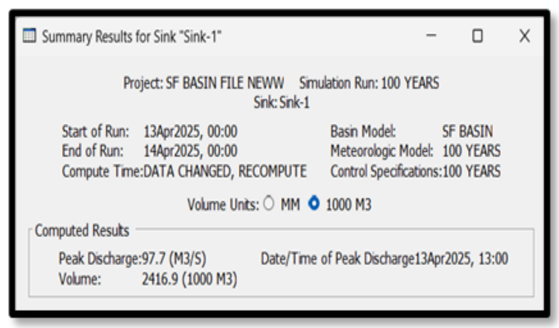

Fig.12. Flood Hydrograph and Summary of Results for 100-year Return Period

Figure 12 shows the hydrograph and the summary results of Sink 1 for a 100-year return period. Sink one represents the outlet of all the flow within the catchment area. Considering a 100-year return period for simulation, sink 1 have a peak discharge of 97.7 m3/s meaning, this will occur once in very 100 years or have a 1% of probability [35]. Relating to this study, the peak discharge of the catchment for a 100-year return period served as a crucial basis for the development of the non-structural flood mitigation program to mitigate areas in the City of San Fernando raising community awareness and resiliency and reducing risks brought about by flooding.

C. Hydraulic Assessment

Hydraulic analysis served as an essential assessment for river and creeks behavior. The HEC-RAS was the modeling adopted because it is freely available and accessible [9]. Aligned with the objectives of this study, hydraulic analysis was performed using HEC-RAS model to determine mainly the flood depth of each barangay for a 100-year return period event.

The Manning's n value holds essential importance in hydraulic modeling by regulating flow resistance and water surface elevation changes. Furthermore, the typical surface roughness ranges values for different channel types were referenced from the DPWH Design Guidelines, Criteria, and Standards Volume 3 for Water Engineering Projects, as well as Chow (1959). During the model simulations for the Sto. Niño Creek, Del Carmen Creek, Calulut Creek, and San Fernando River various Manning's n values within the accepted range were tested to determine the most suitable roughness coefficients for the main channels and overbank areas. Following a thorough process of calibration and analysis, a Manning's n value of 0.03 was found to be the most appropriate for all sections—applicable to both the main channels and the left and right overbanks of the identified waterways.

The maximum channel depth and hydraulic depth provide crucial information for flood-carrying capacity analysis of waterways under 100-year return period extreme events. Model data processed from HEC-RAS served as inputs at Station 10 for Sto. Niño Creek, Calulut Creek, Del Carmen Creek, and the San Fernando River. The analysis reveals distinct flood responses across waterways, providing a foundation for strategic flood control approaches tailored to each creek's unique features and risk exposure during heavy rainfall events. The accompanying figure illustrates the cross-sectional data collected from each creek under the 100-year return period, serving as a visual verification of the research findings. he analysis reveals distinct flood responses across waterways, providing a foundation for strategic flood control approaches tailored to each creek's unique features.

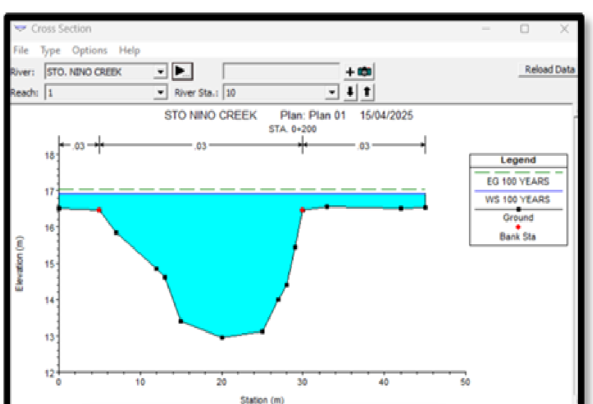

Fig.13. Sto. Niño Creek Cross Section Output for 100-year return period at Station 10

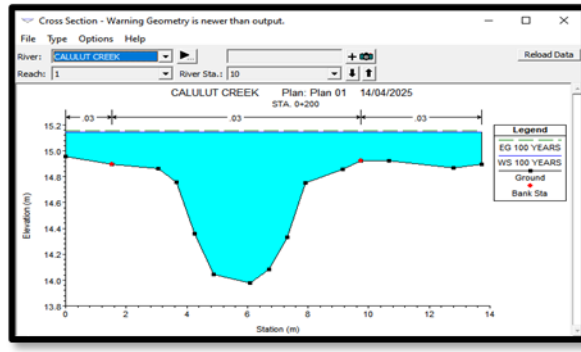

Fig.14. Calulut Creek Cross Section Output for 100-year return period at Station 10

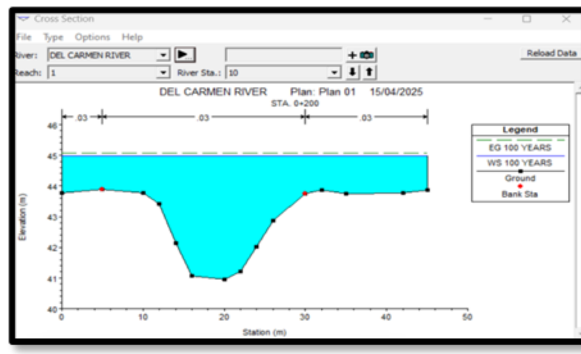

Fig.15. Del Carmen Creek Cross Section Output for 100-year return period at Station 10

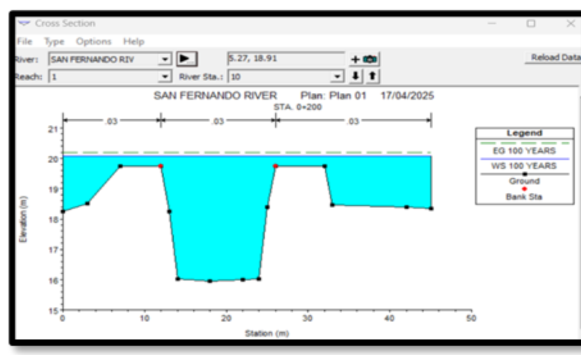

Fig.16. San Fernando River Cross Section Output for 100-year return period at Station 10

D. Flood Mitigation Scoring Criteria

This section employs four (4) key scoring criteria that are critical in formulating an effective flood mitigation action plan. Each criterion plays a pivotal role in identifying the levels of flood risk across the selected barangays in the City of San Fernando, Pampanga, allowing for a risk assessment.

E. Flood Scoring System Assessment

The depth of flooding experienced by the respondents is considered as one of the critical factors influencing their vulnerability to flood events. [76]. This section incorporates the results of flood depth data from each barangays, which were derived through hydraulic analysis.

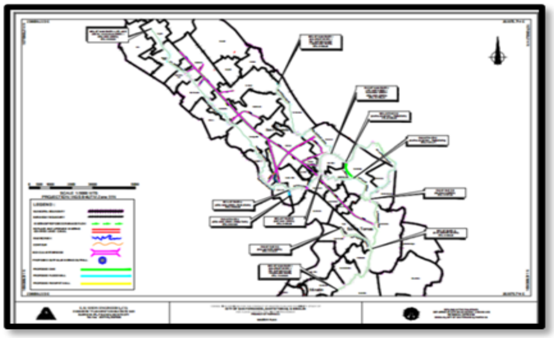

Fig.17. DPWH Master Plan for City of San Fernando [77]

Table.11. Flood Depth per Barangay

Rivers and Creeks	Maximum Flood Depth	Barangay Associated
Sto. Niño Creek	0.44 m	Santa Lucia
Del Carmen Creek	1.19 m	Del Pilar Juliana San Jose
Calulut Creek	0.25 m	San Felipe
San Fernando River	1.20 m	San Nicholas San Pedro

Table 11. presents the simulated flood depths at various monitoring stations along the creeks for the maximum 100 year-return periods within the City of San Fernando, generated using the HEC-RAS modeling software. Complementing this, Figure 17. illustrates the topographic map of the City of San Fernando, sourced from the San Fernando Master Plan prepared by DPWH. The map outlines the barangay boundaries and their spatial relationship to specific creek systems, thereby enabling a geospatial correlation between flood-prone areas and administrative divisions.

Table.12. Summary of Results based on Flood Scoring System

Part I. Flood Scoring System		
Barangay	**Rating Scale**	**Risk Classification**
Del Pilar	4	High Risk
Juliana	4	High Risk
San Felipe	2	Low Risk
San Jose	4	High Risk
Santa Lucia	3	Moderate Risk
San Nicholas	4	High Risk
San Pedro	4	High Risk

The summary results of the flood risk ratings—based on the maximum simulated flood depths as presented in Table 12—provide a clear overview of the flood vulnerability levels across selected barangays in the City of San Fernando. These risk ratings focuses on the worst-case flood scenarios to ensure a conservative and safety-oriented approach in risk assessment. These risk rating values play a critical role in understanding the spatial distribution of flood vulnerability across the barangay. Beyond identifying areas of heightened risk, they serve as a vital tool for guiding and prioritizing the city's flood mitigation efforts.

F. Infrastructure Assessment

Table.13. Summary of Results based on Infrastructure Analysis

Part II. Infrastructure Analysis		
Barangay	**Rating Scale**	**Risk Classification**
Del Pilar	2.666	Low to Moderate Risk
Juliana	2.647	
San Felipe	2.697	
San Jose	2.681	
Santa Lucia	2.658	
San Nicholas	2.709	
San Pedro	2.774	

Table 13. presents the risk scoring for each barangay in the City of San Fernando based on infrastructure analysis. The scores indicate that the average risk rating for all barangays falls within the range of 2.6 to 2.7, classifying them as low to moderate risk areas in regards to their infrastructure. Furthermore, the analysis reveals that the predominant building structure in these barangays consists of single-storey houses, with outer walls typically made of concrete, brick, or stone, and roofing predominantly using galvanized iron or aluminum. These construction characteristics play a significant role in the overall risk assessment, which is mainly used as one of the criteria for flood mitigation scoring. The assessment underscores the importance of continuously monitoring and upgrading infrastructure to mitigate risks.

G. Community Awareness Assessment

Table.14. Finalized Summary of Results based on Community Awareness

Part III. Community Awareness Analysis		
Barangay	**Rating Scale**	**Risk Classification**
Del Pilar	1.975	No to Low Risk
Juliana	2.244	Low Risk
San Felipe	2.578	Low to Moderate Risk
San Jose	1.764	No to Low Risk
Santa Lucia	2.496	Low to Moderate Risk
San Nicholas	2.756	Low to Moderate Risk
San Pedro	1.800	No to Low Risk

Table 14 presents among the barangays listed, San Jose indicate a lowest rating scale of 1.764, corresponding to a "No to Low risk" classification. These converted statistical values are used for the evaluation of final flood mitigation scoring. The results presented in Table 14 provide a clear, data-driven overview of the flood risk classifications across various barangays. By converting Likert scale ratings into standardized Final Rating Factors (FRFs), this assessment enables a more precise and objective evaluation of each barangay's level of community awareness and preparedness for flooding. This conversion process ensures consistency in interpreting qualitative survey responses, allowing for meaningful comparisons across barangays regardless of population size or subjective biases. The resulting FRFs serve as critical inputs in the overall flood mitigation scoring framework, helping to identify areas with the greatest need for intervention. These values directly inform the prioritization of non-structural mitigation strategies, guiding local authorities in allocating resources, designing targeted education campaigns, and implementing tailored preparedness initiatives. Ultimately, this data-driven approach strengthens the city's capacity to reduce flood vulnerability and enhance long-term community resilience across all identified barangays.

H. *Inventory Resources Assessment*

Table.15. Summary of Results based on Inventory Resources Analysis

Part IV. Inventory Resources Analysis		
Barangay	**Rating Score**	**Risk Classification**
Del Pilar	2.556	Low to Moderate Risk
Juliana	3.056	Moderate Risk
San Felipe	1.5	No to Low Risk
San Jose	1.944	Low Risk
Santa Lucia	1.5	No to Low Risk
San Nicholas	3.278	Moderate Risk
San Pedro	3.772	Moderate to High Risk

The summary results of the Inventory Resources Analysis for selected barangays in the City of San Fernando, Pampanga are presented in Table 15. This table provides a comparative overview of the availability and readiness of flood rescue equipment across different barangays, serving as a critical input in evaluating local flood preparedness and response capacity. These risk ratings are essential components of the overall flood mitigation program scoring system, offering a quantifiable and evidence-based foundation for identifying vulnerabilities and prioritizing the allocation of resources. In addition to supporting strategic planning and decision-making.

I. *Flood Mitigation Program Scoring System*

Table.16. Summary of Result for Flood Risk Classification of each Barangay

Barangay	**Rating Scale**	**Risk Classification**
Del Pilar	2.799	Moderate Risk
Juliana	2.986	Moderate Risk
San Felipe	2.194	Low Risk
San Jose	2.597	Low Risk
Santa Lucia	2.414	Low Risk
San Nicholas	3.186	Moderate Risk
San Pedro	3.087	Moderate Risk

This assessment aligns with the second objective of the study, which is to determine the high and low risks of the selected barangays in City of San Fernando. These classifications, as detailed in Table 16, are based on a multi-criteria assessment framework that considers simulated flood depth, infrastructure vulnerability, community awareness, and flood rescue equipment availability. The variation in scores highlights the differing capacities and geographic conditions of each barangay, and emphasizes the importance of localized flood risk management.

J. *Survey Results*

Across seven barangays, the flood scoring system generally showed strong alignment with simulated flood depths, confirming the reliability and consistency of both data sources in most cases. In Barangay Juliana, a higher flood depth of 4 to 8 feet (1.2 to 2.4 meters) was recorded in the survey, which aligned with a simulated depth of 1.19 meters, reflecting consistency despite the broader range. In Barangay Del Pilar, Santa. Lucia, San Nicholas, and San Pedro reported flood depths ranged from 1 to 3 feet (0.3 to 1 meter), closely matching simulated depths of 1.19 to 1.20 meters, indicating high consistency. However, a notable discrepancy was observed in Barangay San Jose. The flood scoring system reported no flooding, while the simulation indicated a depth of 1.19 meters, suggesting a lack of accuracy or a mismatch between observed and modeled data in that specific instance. In terms of Infrastructure, across all assessments in the seven barangays, a consistent observation emerged: the majority of homes are constructed primarily from concrete or steel, indicating a preference for durable building materials. This finding is further supported by the observation that exterior walls are predominantly made of concrete, stone, or brick. Regarding flood equipment, the survey responses across the barangays reveal varying levels of awareness regarding local resource inventories, which align closely with the corresponding Inventory Resource Analysis assessments.

K. *Qualitative Analysis*

The thematic analysis identified four critical areas that require focused attention to enhance non-structural flood mitigation efforts in the City of San Fernando. These include the urgent need for innovative strategies such as consistent implementation of clean and green programs and community education seminars to raise flood awareness and preparedness. There is also a strong push to improve service facilities by relocating evacuation centers to higher ground and promoting effective waste management practices like public compost pits to prevent drainage blockages. Ensuring dependable resource storage and securing adequate, sustainable funding for emergency supplies and preparedness programs emerged as key concerns among local officials. Despite ongoing efforts, the study highlights the need for more comprehensive planning, inter-agency collaboration, and long-term financial support to build a truly responsive and community-based non-structural flood mitigation framework tailored to the vulnerabilities of each barangay.

L. *Flood Mitigation Action Plan*

The City of San Fernando, a rapidly urbanizing central hub in the province of Pampanga, is increasingly vulnerable to flooding, particularly in its low-lying and densely populated barangays. Recent comprehensive assessments, utilizing a multi-factor flood scoring system that evaluated flood depth, infrastructure vulnerability, community awareness, and the availability of critical flood equipment resources, have uncovered urgent vulnerabilities demanding strategic intervention. To address these challenges, researchers from Don Honorio Ventura State University aims to propose the MASFKUP Plan, which stands for "Mitigating Areas in San Fernando as Key Urban Preparedness." This holistic initiative centers on non-structural flood mitigation strategies. The MASFKUP plan aims to mitigate the impact of flooding without relying solely on physical infrastructure. It is a comprehensive non-structural flood mitigation program designed to address flood risks.

M. Plan Title

MASFKUP

Mitigating Areas in San Fernando as Key Urban Preparedness

A Proposed Non-Structural Flood Mitigation Program

N. Non-Structural Flood Mitigation Plan

This section outlines a comprehensive non-structural flood mitigation plan designed to address the specific needs of barangays based on their varying flood risk levels. The plan emphasizes community engagement, capacity building, and proactive measures to minimize vulnerabilities and strengthen local disaster preparedness. For moderate-risk barangays—Del Pilar, Juliana, San Nicolas, and San Pedro—the primary focus is on resource augmentation, enhancing early warning systems, and correcting community risk perceptions. These areas face a higher likelihood of flood impact, necessitating more robust and targeted interventions. Key strategies include Establishment of Barangay Emergency Operations Centers (EOCs), Improvement and Maintenance of Barangay-Level Inventories, Risk Communication and Public Education, Community forums and seminars will be conducted to engage households and address misconceptions about flood threats. Expansion of Community-Based Early Warning Systems (CBEWS) and Capacity-Building Workshops.

In contrast, low-risk barangays—San Jose, San Felipe, and Santa Lucia—are encouraged to maintain and strengthen routine preparedness activities, recognizing that even areas with lower risk can still be affected by extreme weather events. Key actions for these areas include: Annual Flood Drills and Simulations, Regular Updating of Evacuation Maps and Emergency Contact Lists, Sustained Community Education and Awareness Programs, Integration of Flood Preparedness in School Curriculum, and Incorporation into Barangay Development Plans

Overall, this tailored approach seeks to empower communities at all risk levels, ensuring that both moderate- and low-risk barangays are better equipped to anticipate, respond to, and recover from future flood events. The plan promotes a culture of preparedness and collective responsibility, laying the groundwork for a safer and more resilient community.

O. Key Thematic Strategies

In response to increasing flood risks, a comprehensive non-structural mitigation plan has been developed to enhance community resilience, preparedness, and coordination. Key initiatives include monthly "Flood Awareness and Safety Days," expert-led discussions at barangay assemblies, and the distribution of accessible educational materials in local dialects. To improve resource management, barangay-level inventory checklists will be updated quarterly, and partnerships with local businesses will secure emergency supplies. A Barangay-City Flood Preparedness Council (BC-FPC) will be created to oversee planning and coordination, supported by real-time communication between local and provincial disaster risk offices for synchronized emergency response. The "Know Your Flood Risk" campaign will raise awareness, while regular assessments and feedback mechanisms will ensure continued community engagement and program effectiveness. These integrated efforts aim to build a well-informed, cohesive, and adaptive community capable of effectively managing future flood events and promoting long-term resilience and sustainable development.

P. Timeframe for MASFKUP Implementation

Table.17. Timeframe for MASFKUP Implementation

Phase	Timeframe	Activities
PHASE 1 Groundwork & Assessment	Q1 – Q3 of 2026 (January 2026 to June 2026)	Community profiling and flood risk
		Resource inventory audits
		Stakeholder engagement
		Risk perception baseline surveys
PHASE 2 Initial Implementation & Education	Q4 of 2026 – Q2 of 2027 (July 2026 to June 2027)	- Launch of "Know Your Flood Risk" awareness campaign
		Barangay-level workshops and seminars
		Creation of emergency communication branching
		Procurement and prepositioning of supplies
PHASE 3 Simulation & Preparedness	Q3 of 2027 (October 2026 to December 2026)	Conduct community flood drills
		Activation of early warning systems
		Monitoring of response coordination
		Evaluation of gaps
PHASE 4 Evaluation &	Q4 of 2027 – Q1 of 2028	Post-drill evaluations

Scaling	(October 2027 to March 2028)	Update flood preparedness plans
		Address inconsistencies in perception vs. reality
		Continuous training for barangay officials
PHASE 5 Institutionalization & Sustainability	Q2 – Q3 of 2028 (April 2028 to September 2028)	Integration of flood mitigation modules in barangay programs
		Strengthen city-barangay coordination mechanisms
		Develop long-term public-private partnerships
		Launch flood preparedness digital portal

Q. MASFKUP Implementation Diagram

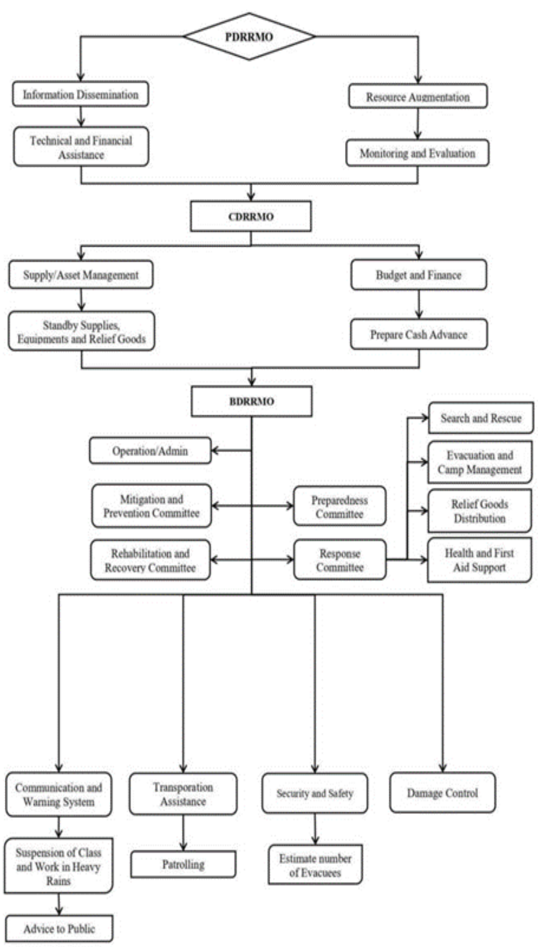

Fig.18. Flowchart for the Implementation of MASFKUP to LGU

To ensure a synchronized and systematic approach across all tiers of local governance (LGU), a detailed flowchart has been developed as a vital operational tool. This comprehensive visual representation meticulously outlines the precise sequence of information flow, beginning with initial alert dissemination and activation of the emergency plan, and progressing through specific operational directives and responsibilities.

5. Conclusions And Recommendations

Based on the study's key findings, it was observed that while several barangays are identified as high-risk areas on the MGB flooding map, they exhibit relatively low to moderate risk levels in other critical areas, such as infrastructure vulnerability and community awareness. This contrast presents a significant opportunity for targeted, non-structural interventions. The MASFKUP Plan, which serves as the foundation for this approach, aims to address these vulnerabilities by focusing on non-structural flood mitigation strategies.

Future researchers seeking to build upon this study have a wide range of potential avenues for further exploration.

- Future researchers should simulate flood scenarios beyond the 100-year return period, such as 200 or 500 years. This will help capture rare but highly damaging flood events for better risk planning.
- Flood models should be calibrated using historical flood data and local flood marks. This ensures the simulations reflect actual flood behavior and improve predictive reliability.
- Researchers should include more rivers and creeks in the City of San Fernando in their simulations. A broader scope provides a more accurate understanding of flood risks citywide.
- Flood models should integrate climate change impacts like increased rainfall and sea-level rise. This allows for better anticipation of future flood risks under changing environmental conditions.
- A comprehensive assessment covering all barangays in San Fernando should be conducted. This ensures flood mitigation strategies address the needs of the entire city.
- Essential infrastructure such as schools and hospitals should be part of the vulnerability analysis. Their inclusion supports emergency response and protects vital community services.
- Researchers must consider how age, disability, gender, and income affect flood risk. This provides a more inclusive understanding of who is most vulnerable during flood events.
- Using geospatial data, researchers can identify populations like the elderly and low-income residents in flood-prone areas. These maps guide targeted interventions and resource allocation.
- The study's findings can be used to develop a flood risk map for the entire city. This map would help raise public awareness and promote preparedness.

- Future research should involve local stakeholders and adopt innovative methods. Expanding the study to more barangay improves community-wide flood resilience.
- Researchers should evaluate the costs and benefits of various mitigation measures. This helps identify the most efficient and economically sound flood protection strategies.
- Maintenance of flood control structures like dams and drainage systems should be regularly evaluated.

These recommendations aim to guide future researchers for further exploration and fostering new insights that will deepen the understanding of this field.

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