Assessment of Household Flood Vulnerability in Panaytayon, RTR Using Multi-Criteria Decision Making and Geographic Information Systems (GIS) Techniques

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Assessment of Household Flood Vulnerability in Panaytayon, RTR Using Multi-Criteria Decision Making and Geographic Information Systems (GIS) Techniques

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Abstract: *In December 2021, Panaytayon, RTR was struck by Typhoon Odette, exposing households to increased flood risk. Before the typhoon, a river re-channeling was conducted in the area, which residents believed aggravated the impact of the typhoon. The risk of intensified floods in the area has increased, but the vulnerabilities of individual households remain unknown. This study sought to evaluate the flood vulnerability level of each household in Panaytayon using Multi-Criteria and GIS techniques, considering three domains: sensitivity, exposure, and adaptive capacity. The Analytic Hierarchy Process (AHP) was used to assign weights to each indicator based on the geospatial and socio-economic conditions. GIS methods were used for spatial analysis and vulnerability maps. Results showed a varied vulnerability level among the households, emphasizing that 31% are highly vulnerable and 45% moderately vulnerable. Based on the results, there is a need for targeted interventions to support those with higher exposure and vulnerability levels.*

Keywords: Vulnerability Assessment, MCDM, AHP, GIS

1. INTRODUCTION

Flooding, often caused by heavy rainfall and typhoons, is a major natural disaster in the Philippines. It affects a significant portion of the population, causing extensive property damage, financial loss, and untimely death [1].

Due to the severity and frequency of floods in terms of risk and casualties, it is becoming a concern to many regions worldwide, particularly in Asia. Countries such as Bangladesh, Cambodia, India, Thailand, Vietnam, Laos, and the Philippines are notably affected. Bangladesh is the most flood-prone country due to many factors, including river inundations, inadequate drainage systems, and unpredictable monsoon precipitation [2]. In terms of flood damage, India ranks as the most vulnerable country in Asia, with an annual economic loss of 56.49 billion USD and 1,654 human lives lost due to floods between 1953 and 2018 [3].

The Philippines is highly vulnerable to many natural disasters, affecting 74% of its population. These hazards include landslides, typhoons, and the most prominent is floods [4]. Agusan del Norte in Caraga Region, is a province in the Philippines that suffers from significant flooding annually and frequently, causing potential flood-related casualties and damages to properties. This vulnerability arises from its geographic features, characterized by low-lying areas and a network of rivers. One of the affected flooding areas in Agusan del Norte is the Remedios T. Romualdez (RTR). Flooding occurs in Panaytayon when there is excessive rain and tropical storms, which cause the overflow of the surrounding river.

The consequences of floods extend across various domains, profoundly affecting human well-being, food stability, economic productivity, physical infrastructure, ecological resources, and the overall environment. The aftermath of floods frequently leaves regions without electricity and access to clean drinking water, setting the stage for waterborne diseases to emerge. Even after the floodwaters recede, the aftermath lingers, causing significant challenges. The impact on households' vulnerability to flooding is shaped by socio-economic factors defining people's capacity to manage adversity and adapt to changes. These vulnerability factors include income level, occupation, health, housing structure, disabilities, and many more [5].

In the face of increasing flood damages and casualties, it is imperative to manage disaster risk mitigation techniques and vulnerability assessment effectively. This necessitates investment in innovation and advancement. One such avenue is the utilization of Geographic Information Systems (GIS) to enhance flood vulnerability assessment management. GIS applications, a powerful tool for visualizing, analyzing, retrieving, and interpreting spatial and non-spatial data, can potentially improve our understanding of relationships, patterns, and trends [6].

The process of flood vulnerability assessment for households involves evaluating the susceptibility of people and their homes to the impacts of flooding, by leveraging GIS techniques. This approach provides a comprehensive understanding of vulnerability, aiding in prioritizing at-risk households and formulating targeted mitigation strategies. GIS also facilitates the visualization of spatial relationships, enhancing decision-making for disaster preparedness, response, and recovery efforts [7]. This study uses AHP which is a pairwise comparison method to determine the weights of criterion that will then be the basis to produce maps [8].

The main concern of this study is to comprehensively assess the flood vulnerability level of each household in Barangay Panaytayon, RTR, during Typhoon Odette, specifically to:

- Identify and analyze the key factors used in assessing the vulnerability of each household within the study area.
- Integrate geospatial data and socioeconomic variables in assessing the flood vulnerability of households

- Generate maps that reveal the varying degrees of flood vulnerability among households in the study area, providing a comprehensive understanding of spatial patterns.

The area is adjacent to the river which is naturally fertile [9] making it a good choice of location for some small-scale farmers. However, this also makes them vulnerable thus, the result of this study can be used as the basis for local government units and other agencies to enhance flood mitigation and risk management in the area.

2. MATERIALS AND METHODOLOGY

2.1 Study Area

The research focuses on Barangay Panaytayon, situated in the landlocked municipality of Remedios T. Romualdez (RTR) in the coastal province of Agusan del Norte, Philippines. Panaytayon is one of eight barangays in RTR, located approximately at 9.0376^{O} N latitude and 125.5725^{O} longitude on Mindanao Island. Panaytayon is situated on low-lying terrain and surrounded by networks of rivers [10]. Historically, this barangay suffered from flooding whenever there was heavy rainfall and typhoon due to the surrounding river. In December 2021, a Super Typhoon Odette struck the Philippines, bringing strong winds, heavy rains, floods, and storm surges to the Visayas and Mindanao Islands. This typhoon triggered mass evacuations and caused extensive damage to homes, infrastructure, and livelihoods [11]. In Agusan del Norte, the impact was significant affecting 18,910 families, and 19 barangays experienced flooding, including Barangay Panaytayon [11].

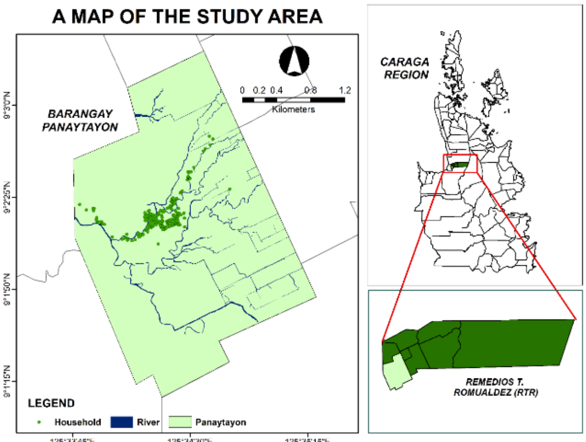

Fig. 1. Map of Barangay Panaytayon, RTR.

2.2 Data Collection

This study utilized geospatial datasets such as household shapefiles, Digital Elevation Models (DEMs), road and river networks, and flood risk map to assess the vulnerability of households in the study area. Socio-economic data with key vulnerability indicators were also used to evaluate each household's susceptibility to flooding and their coping mechanisms. The mentioned datasets were obtained from PDRRMO, CCGeo, and MPDC.

2.3 Selection of Experts and Indicators

This study employed the Analytic Hierarchy Process (AHP), with nine experts selected through snowball sampling, which started with a few initial experts and expanded based on recommendations from those already involved. The experts include academe, Department of Environment and Natural Resources (DENR) Caraga and Provincial Environment and Natural Resources Office (PENRO), Municipal Disaster Risk Reduction and Management Office (MDRRMO), Municipal Planning and Development Coordinator (MPDC), National Economic and Development Authority (NEDA), Office of Civil Defense (OCD), Provincial Disaster Risk Reduction and Management Office (PDRRMO), and Provincial Planning and Development Office (PPDO). These experts assessed the flood vulnerability indicators through pairwise comparison. The appropriate vulnerability indicators were selected and tailored to the study area's characteristics through expert consultation, community input, literature review, and existing indicators utilized by DENR-Caraga. These indicators were assigned into their respective domains: sensitivity, exposure, and adaptive capacity.

2.4 Geospatial Data Processing

This study involves geospatial data processing in the collection of data for exposure domain, where it considered the physical properties of the area that contribute to flooding. These include indicators such as flood depth, elevation, slope, TWI, proximity to the river, and evacuation center. The indicators are reclassified into five scale which corresponds to very low, low, moderate, high, and very high in order to conform to the flood vulnerability level. These physical indicators were used to create a flood exposure map of Barangay Panaytayon.

2.4.1 Flood Depth Map

A flood depth map of 10 years Rainfall Return Period (RRP) was utilized to identify the flood depth and the extent of the flooding within the area. Barangay Panaytayon is situated within the Rainfall Intensity Duration Frequency (RIDF) station of Butuan City. Additionally, the Rainfall Return Period (RRP) was based on the accumulative rainfall of Butuan City during Typhoon Odette which is equivalent to 207.6 mm [12]. RIDF table was used to identify the corresponding RRP during Typhoon Odette given the accumulative rainfall.

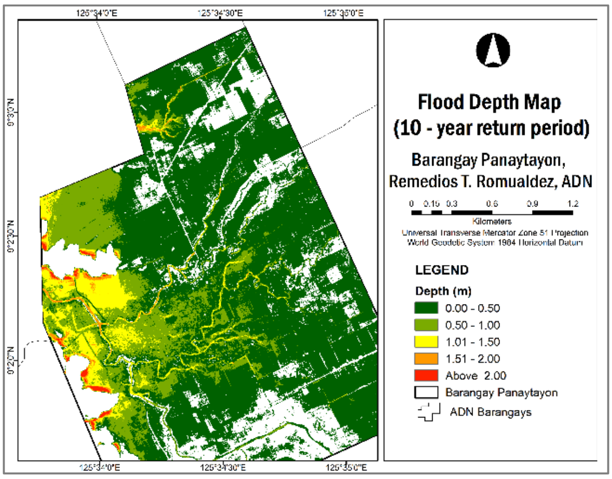

Fig. 2. Flood Depth Map (10-Year Rainfall Return Period).

2.4.2 Elevation

The methodology involves acquiring elevation data through Digital Elevation Models (DEMs). The process of mapping the elevation was done ArcGIS software, reclassifying into five (5) classes which corresponds to the flood vulnerability map.

2.4.3 Slope
The approach involved acquiring slope data from DEMs using the slope tool in ArcGIS. Slope was used as an indicator to determine the slope conditions of the area, highlighting those areas with low and flat terrain which are more exposure to flooding.

2.4.4 Topographic Wetness Index (TWI)
The Digital Elevation Model (DEM) data was utilized to extract the area's Topographic Wetness Index (TWI) using ArcGIS software. The Topographic Wetness Index (TWI) serves as an effective tool for predicting water accumulation in regions characterized by varying elevations. It is determined by factors such as slope and the contributing area upstream, and its calculation involves a specific formula.

$$TWI = ln\ ln\ \left(\frac{a}{tan\ (b)}\right) \qquad \text{Equation 1}$$

where α is the upstream contributing area and is the ground slope. TWI will be used to delineate areas that are prone to waterlogging and flooding [13].

2.4.5 Proximity to River
The proximity of households to the river channel is considered a primary criterion for assessing flood exposure. The proximity to the river was determined using the Euclidean distance in ArcGIS, with the river as the input features. This highlights the importance of recognizing that areas situated near river channels and characterized by lower elevations are inherently more exposed or prone to the impacts of flooding.

2.4.6 Generated Flood Exposure Map
The flood exposure map was created using a weighted overlay for the five exposure indicators: flood depth, elevation, slope, proximity to river, and TWI. Relative weights were assigned to each indicator based on their level of importance in terms of flood exposure, ensuring weights were summed up to 1. With the prepared data and assigned weights, a weighted overlay tool in ArcGIS was employed to generate a flood exposure map. The generated map was used to extract values of the exposure level of each household in Panaytayon.

2.5 Data Normalization
Data normalization in the study involved converting values into a standardized scale of 0-1. Numerical data were normalized using the min-max method, while non-numerical and scaled data were assigned values ranging from 0 to 1 based on their relevance to the vulnerability domains. The data normalization was carried out using the formula:

$$X_i = \frac{X_I - X_{min}}{X_{max} - X_{min}} \qquad \text{Equation 2}$$

$$X_i = \frac{X_{max} - X_i}{X_{max} - X_{min}} \qquad \text{Equation 3}$$

Where, X_I is the normalized value of the indicators, the X_{min} corresponds to the minimum value of the indicators, and X_{max} is the maximum value of the indicators. Equation 2 synchronized the variables when the indicator had a positive relationship with its corresponding domain. Equation 3 was used when the indicator had a negative relationship with its corresponding domain [14].

2.6 Generation of Relative Weights
This study assigned relative weights using the Analytic Hierarchy Process (AHP) through pairwise comparison to establish priorities and allocate weights to the selected vulnerability indicators and domains. Experts from various agencies were selected to provide their evaluations and ratings relevant to flood vulnerability assessment. The experts assigned relative importance using Saaty's scale among indicators through an AHP form [15].

2.7 Consistency Ratio
Calculation of the Consistency Ratio requires the value of the Random Index (RI), which is identified based on the number of indicators. The RI value for sensitivity, exposure, and adaptive capacity are 1.35, 1.11, and 1.49, respectively. The Consistency Index (CI) is also required in the calculation of the consistency ratio, which was determined by the equation:

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad \text{Equation 4}$$

The λ_{max} is the maximum eigenvalue of the comparison matrix, and n is the number of evaluated indicators. Furthermore, the consistency ratio should be less than 0.1. Otherwise, it is necessary to revise the comparison matrix and re-calculate the weights [f]. The equation gives the calculation of CR:

$$CR = \frac{CI}{RI} \qquad \text{Equation 5}$$

2.8 Geospatial Analysis
Geospatial datasets were integrated with socio-economic data in GIS software, utilizing the join tool in ArcGIS for comprehensive analysis. AHP-derived weights were incorporated into household data in ArcMap, assigning specific weights to indicators. This allowed the calculation of household vulnerability using equation 6.

$$Vulnerability = Sensitivity + Exposure - Adaptive\ Capacity \qquad \text{Equation 6}$$

2.9 Household Flood Vulnerability Map
This study generated sensitivity, exposure, and adaptive capacity maps using the field calculator in ArcGIS and a weighted mean equation for precise calculations. Vulnerability assessments for individual households were conducted using Equation 6, which categorized vulnerability into five classes: very low, low, moderate, high, and very high. Subsequently, a vulnerability map illustrating the vulnerability level of each household was generated and served as the end output.

3. RESULTS AND DISCUSSIONS

3.1 Panaytayon, RTR Flood Exposure Map
The flood exposure map for Barangay Panaytayon in Remedios T. Romualdez, Agusan del Norte, highlights varying levels of flood risk within the area. The map uses a gradient of colors to depict flood exposure, ranging from areas not flooded to those with very high flood exposure. The flood exposure map provides critical insights into the flood risk profile of the area, which have several implications for risk mitigation and preparedness. Also, the map can be used for informed decision making as well as planning and development strategies that can enhance the areas resilience to flooding events.

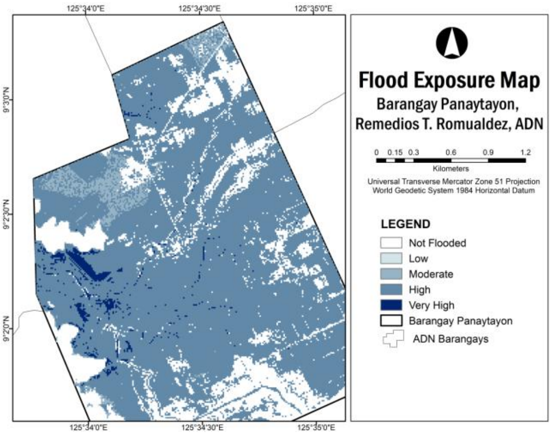

Fig. 3. Generated Flood Exposure Map of Barangay Panaytayon.

Not flooded areas, shown in white, cover a minor part of Barangay Panaytayon, indicating zones not susceptible to flooding. Light blue areas, indicating low flood risk, are scattered throughout, but only cover small portion of the area. Mid-blue areas represent moderate flood exposure and cover a few portions of the barangay. Blue areas indicate high flood exposure, prevalent in most parts, while the dark blue areas signify very high flood exposure, concentrated in specific zones most vulnerable to severe flooding. Based on the map, the households are mostly located in areas with high exposure to flooding, indicating a higher susceptibility to flooding due to various indicators.

3.2 Analytic Hierachy Process (AHP) Weighting

Table 1. Indicator Weights

Domain	Indicators	Weight
S	House Construction Type	0.129077
	House Storey	0.154943
	Household Population	0.122191
	Elderly Population	0.171577
	Young Population	0.130821
	Number of Person with Disability	0.152049
	Nutritional Status (0-5 years old)	0.139342
E	Elevation	0.370817
	Slope	0.175712
	Flood Depth	0.193819
	Proximity to River	0.139084
	Topographic Wetness Index	0.120568
AC	Access to Electricity	0.092948
	Access to Safe Water Supply	0.153505
	Access to Telecommunications	0.091835
	Access to Drills and Simulations	0.054109
	Access to Health and Medical Facilities	0.090967
	Access to Financial Assistance	0.047805
	Highest Educational Attainment	0.130474
	Household Total Income	0.091484
	Number of Employed Member	0.128995
	Proximity to Evacuation Center	0.117777

Table 1 presents the criteria weights for each indicator within the exposure, sensitivity, and adaptive capacity domains. Regarding flood sensitivity, house storey was deemed to have the least impact, while elderly population was identified as the most influential indicator. Similarly, TWI had the lowest contribution within the exposure domain, whereas elevation was considered the most critical factor. In the adaptive capacity domain, the highest educational attainment received the lowest weight, whereas access to water supply received the highest weight, highlighting its critical importance for flood resilience.

3.3 Consistency Check

Table 2. Consistency Check

Vulnerability Domain	Consistency Check
Sensitivity Domain	λmax = 7.2117 CI=0.0352 RI= 1.35 **CR= 0.0261**
Exposure Domain	λmax = 5.1538 CI= 0.3846 RI= 1.11 **CR= 0.0346**
Adaptive Capacity Domain	λmax = 10.1521 CI= 0.0169 RI= 1.49 **CR= 0.0113**

Table 2 shows the λmax, consistency index, random index, and consistency ratio of the three respective domains. The sensitivity domain displayed a consistency ratio of 0.0261, the exposure domain had a consistency ratio of 0.0346, and the adaptive capacity domain had a consistency ratio of 0.0113. Notably, the adaptive capacity domain displayed the lowest consistency ratio, indicating a more consistent response from the various experts. All consistency ratio values across the domains were below 0.1, signifying a high level of consistency among the experts' ratings.

3.4 Vulnerability Assessment

The vulnerability assessment's results and discussions include a comprehensive assessment of sensitivity, exposure, and adaptive capacity, providing insights on the susceptibility and resilience of the households. The assessment highlights the households with various levels of vulnerabilities. It primarily helps in the analysis of the intricate relationship between the three domains and how their distinct levels affect the vulnerability of households. This integrated approach facilitates informed decision-making and targeted interventions to enhance resilience and reduce vulnerability in the area.

3.4.1 Households Flood Sensitivity

The map shown in Figure 4 is the generated flood sensitivity map for households in Barangay Panaytayon, based on their socio-economic data, which include household size, elderly population, young population, house structure and storey, and number of PWD within a household. The sensitivity level of each household is represented by point features where red indicates very high sensitivity, orange indicates high sensitivity, yellow represents moderate sensitivity, light green presents low sensitivity, and green suggests very low sensitivity. White points indicate households that are not vulnerable to flooding or are unaffected by floods. Based on the results shown on the map, most points fall under the categories of low sensitivity to flooding. This result suggests that most households in the study area have a significant socio-economic resilience to flooding.

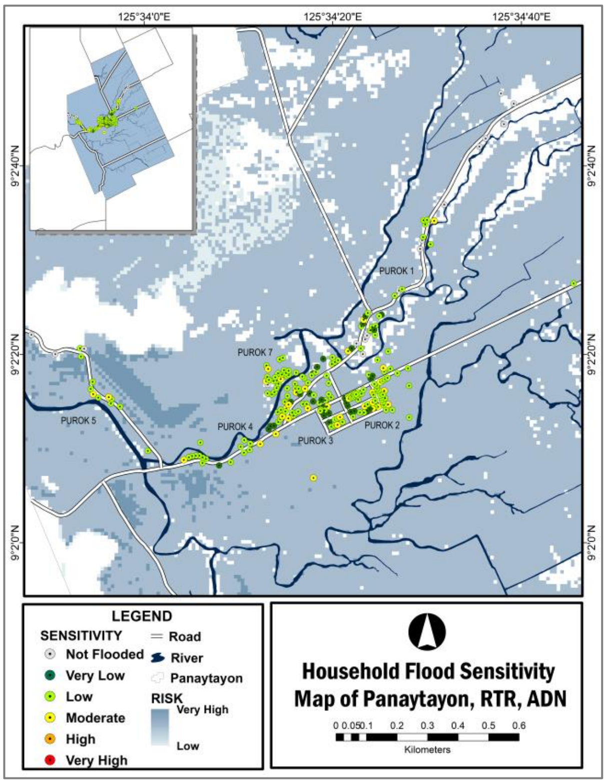

Fig. 4. Barangay Panaytayon, RTR Household Flood Sensitivity Map.

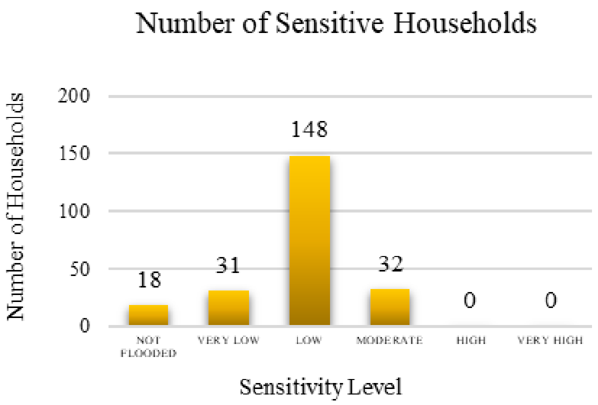

Fig. 5. Number of Sensitive Households.

Among the 229 households in Barangay Panaytayon, 32 (or 14%) are categorized under moderate sensitivity, 148 (or 65%) have low sensitivity, 31 (or 14%) display very low sensitivity, and 18 (or 8%) households were not affected by flooding, as shown in Figure 5.

3.4.2 Households Flood Exposure

A flood exposure map was generated in this study to depict the varying degrees of likelihood that households will be affected by flooding under various physical factors, such as elevation, slope, previous flood depth, proximity to river, and Topographic Wetness Index (TWI). Based on the map above, most households fall into the High to Very High Exposure to flooding, represented by the colors orange and red, respectively. This indicates that most households are highly susceptible to flooding due to the minimal variation of factors assessed. This uniformity of the data on environmental characteristics suggests that large community sections are equally exposed to flood risk due to their low elevation, flat terrain, and households are mainly situated near the river network.

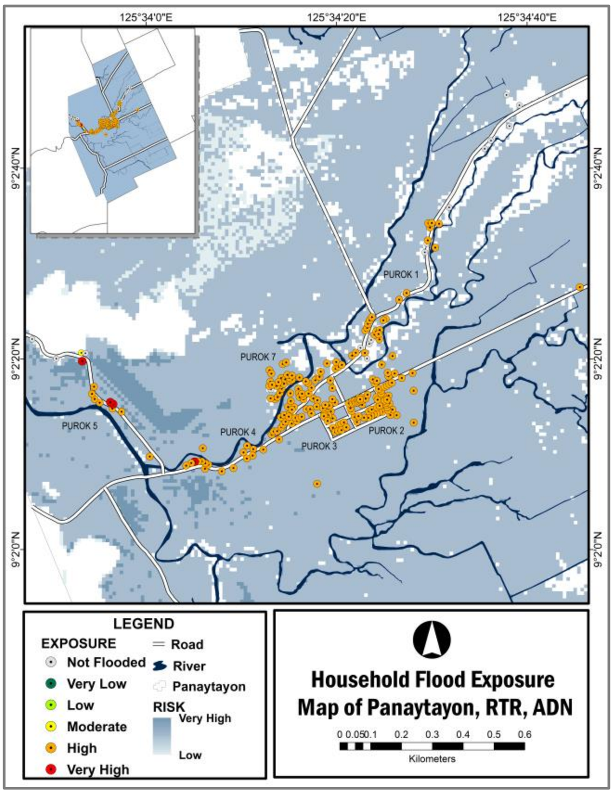

Fig. 6. Barangay Panaytayon, RTR Household Flood Exposure Map.

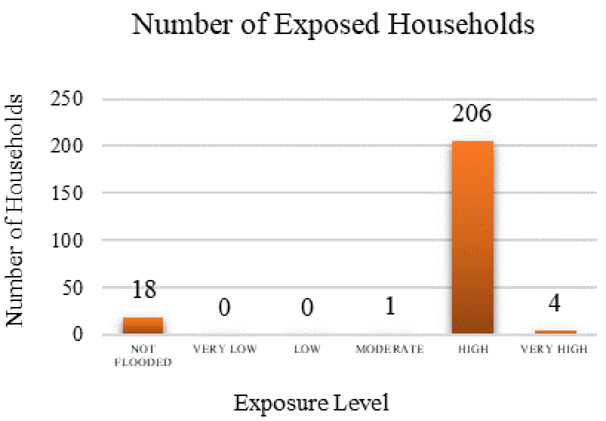

Fig. 7. Number of Exposed Households.

Based on the results shown in Figure 7, 4 households, or 2% of the total number of households in Barangay Panaytayon, are considered to have a very high exposure to flooding. Meanwhile, 206 households, or 90%, are deemed to have high exposure, and one household is moderately exposed. Additionally, 18 households are considered not vulnerable to flooding.

3.4.3 Households Flood Adaptive Capacity

Figure 8 shows the adaptive capacity map of households within Barangay Panaytayon based on their socio-economic status, accessibility to services, and level of knowledge. This map illustrates how these factors contribute to the households' ability to adapt and respond to environmental challenges such as flooding. The distribution shown on the map highlights which households are better equipped to handle adverse conditions and which are more vulnerable. Based on the results, the adaptive capacity of households varies, but the most predominant levels are moderate to high adaptiveness.

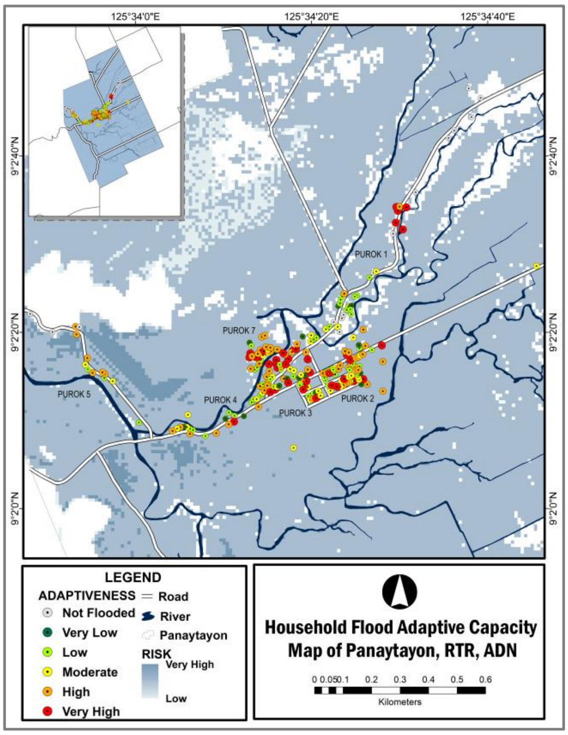

Fig. 8. Barangay Panaytayon, RTR Household Flood Adaptive Capacity Map.

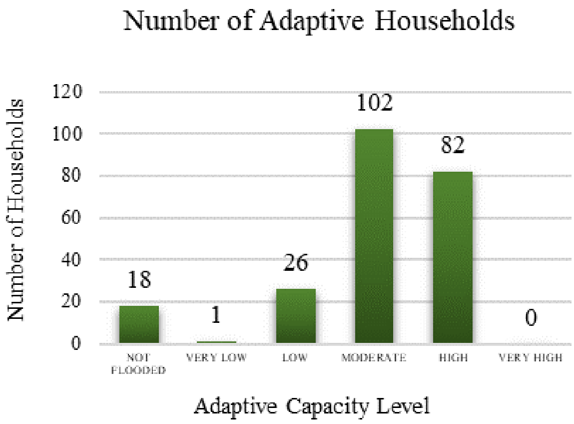

Fig. 9. Number of Adaptive Household.

As depicted in the graph in Figure 9, the results show that out of 229 households in Panaytayon, 102 (or 45%) had moderate adaptive capacity, and 82 (or 36%) had high adaptive capacity. Meanwhile, 26 households (11%) have low adaptive capacity, and 18 (or 9%) are not considered vulnerable. This distribution indicates a generally high level of readiness among households and the ability to cope with the impact of flooding.

3.4.4 Households Flood Vulnerability

In Figure 10, a household flood vulnerability map was generated in this study based on the combined sensitivity, exposure, and adaptive capacity domain. This map depicts the degree of vulnerability of each household in Barangay Panaytayon to flooding events, whose values were divided into different ranges from 0 to 1, corresponding to not vulnerable to very high vulnerability. This study uses an equal division scheme such as 0 (not vulnerable), 0.01 – 0.20 (very low), 0.21 – 0.40 (low), 0.41 – 0.60 (moderate); 0.61 – 0.81 (high), and 1 (very high vulnerability).

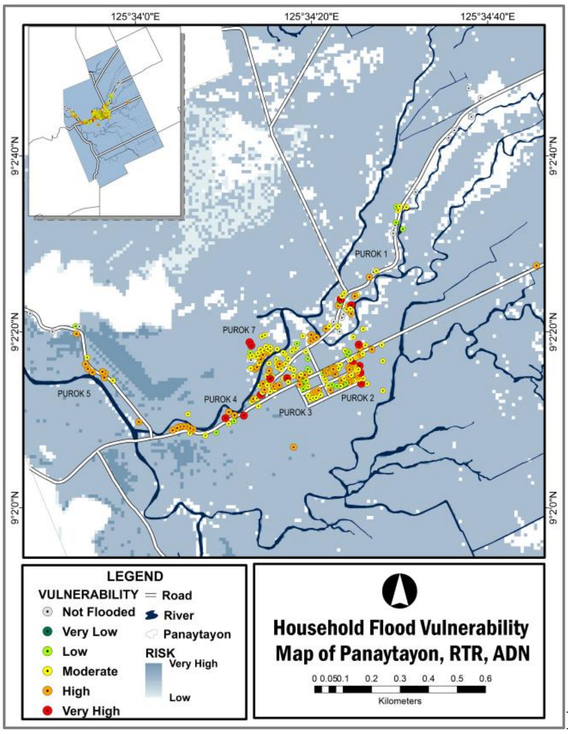

Fig. 10. Barangay Panaytayon, RTR Household Flood Adaptive Vulnerability.

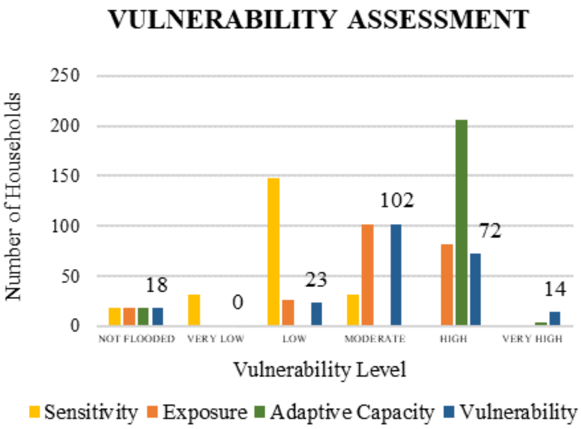

Fig. 11. Household Vulnerability Statistics.

As shown in Figure 11, the household's exposure domain falls mostly into the categories of high to very high exposure, the sensitivity domain ranges from low to moderate, and adaptive capacity varies from moderate to high. This suggests that while most of the household is at significant risk of exposure to flooding, each member's lower sensitivity and higher adaptive capacities may moderate their overall vulnerability.

The vulnerability assessment conducted in this study resulted in identifying households that are most affected by the flood and which are not. The result shows that out of 229 households, 14 (or 6%) were identified with very high vulnerability, 72 (or 31%) with high vulnerability, and 102 (or 45%) as moderately vulnerable, 23 (or 10%) have low vulnerability. Additionally, 18 households (or 8%) were unaffected by flooding. This suggests that the household's vulnerability distribution varies significantly depending on their sensitivity, exposure, and adaptive capacity.

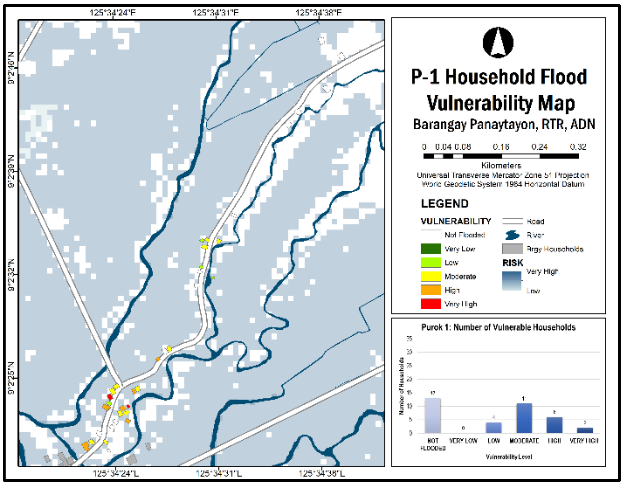

Fig. 12. Flood Vulnerability Map of Purok 1.

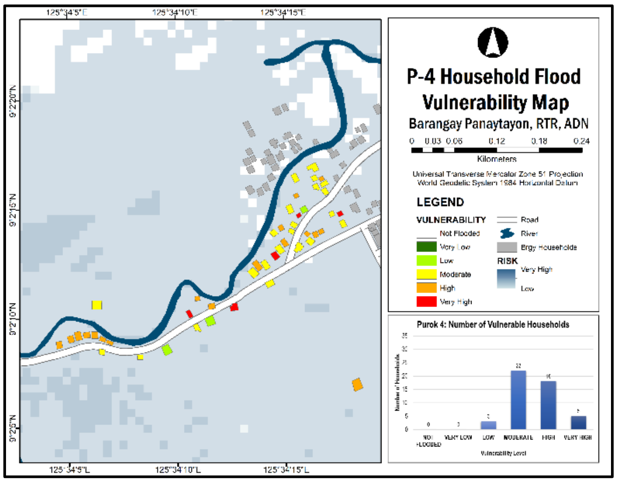

Fig. 15. Flood Vulnerability Map of Purok 4.

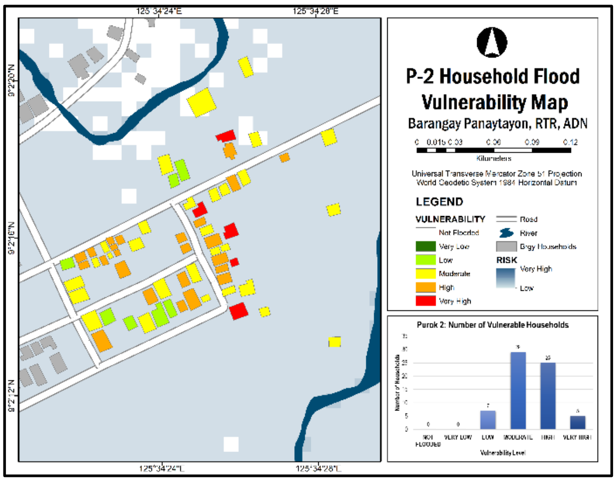

Fig. 13. Flood Vulnerability Map of Purok 2.

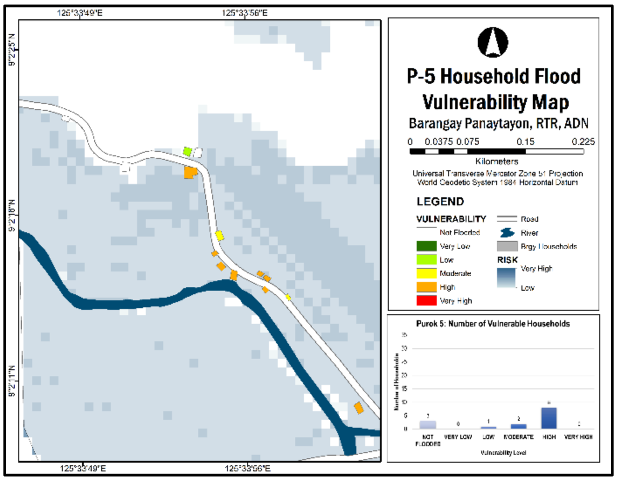

Fig. 16. Flood Vulnerability Map of Purok 5.

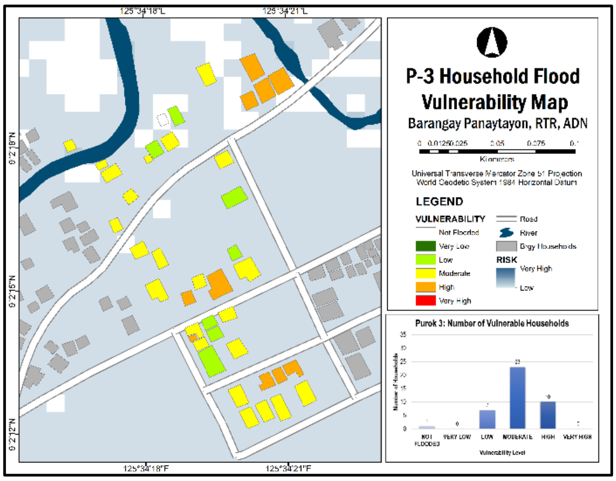

Fig. 14. Flood Vulnerability Map of Purok 3.

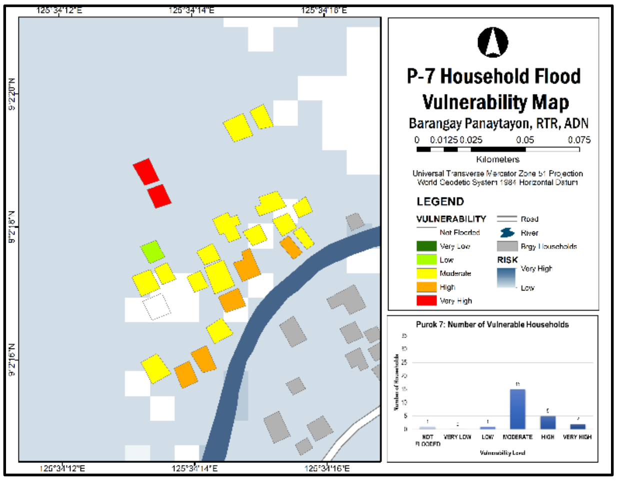

Fig. 17. Flood Vulnerability Map of Purok 7.

The household flood vulnerability maps for each purok, which are based on the combined data factors of sensitivity, exposure, and adaptive capacity, as shown in Figure 12 to Figure 17, reveal that the vulnerability level of each household varies from moderate to high. Notably, Purok 2 and Purok 4 stand out with the highest number of households classified at high to very high vulnerability levels, which is in line with their larger barangay populations. These puroks also demonstrate the highest vulnerability rates within the exposure domain, likely due to their greater susceptibility to high flood depths, and generally moderate levels of sensitivity and adaptive capacity across their households.

4. CONCLUSIONS AND RECOMMENDATIONS

Barangay Panaytayon's flood vulnerability reveals varied sensitivity levels, from low to high, with many facing significant risks due to environmental factors like low elevation and river proximity. However, households generally show readiness to cope with floods, indicating potential for effective response. The overall household flood vulnerability map indicates a diverse range of vulnerabilities, with some households classified as very vulnerable while others remain relatively resilient. This distribution highlights the intricate relationship between exposure, sensitivity, and adaptive capacity in determining each household's vulnerability level.

Additionally, while many households in Barangay Panaytayon demonstrate resilience and readiness to handle flooding, most of the households have a moderate to high vulnerability level due to the high exposure of the households. Therefore, there is a need for targeted interventions and strategies to support those with higher exposure and vulnerability levels. This could include infrastructure improvements, community awareness programs, and enhanced disaster preparedness measures to minimize the impact of future flood events on vulnerable households.

To provide a more detailed result, the researchers recommend adding more factors relating to environmental and physical components such as rainfall volume, predominant land use in riparian areas, soil types, and any other factors that can affect the vulnerability of households. Moreover, it is advisable to conduct a pre- and post-assessment approach of the household's vulnerability before and after implementing flood mitigation measures, such as the construction of dikes, barriers, or improved drainage systems, to measure the impact and efficacy of these interventions effectively.

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