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Analyzing Vulnerability Dynamics of the Flood-Prone Landscapes through the Context of Social-Ecological System Framework

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Abstract
The study aimed to comprehensively analyze the vulnerability and dynamics of flood-prone landscapes in Carmen, Davao del Norte, using a social-ecological system framework. It utilized twenty-one indicators categorized into exposure, sensitivity, and adaptive capacity developed through combined comprehensive methodologies including systematic literature review, Fuzzy Delphi Method (FDM), and Analytical Hierarchy Process (AHP). To derive data from the barangays, informant interviews, expert surveys, and onsite observations were conducted. The flood vulnerability index (FVI) categorized vulnerability as low (0<V<0.45), medium (0.45<V<0.70), or high (0.70<V<1.00). The findings revealed that Barangays Ising and Mabaus exhibited high vulnerability with FVI scores of 0.75 and 0.72, respectively. The remaining barangays were classified as having medium vulnerability, except for Mabuhay, which demonstrated a low vulnerability score of 0.45. The study underscored the collective influence of social-ecological exposure, sensitivity, and adaptive capacity on vulnerability. It emphasized the imperative of reducing exposure and sensitivity while bolstering adaptive capacity. High levels of exposure and sensitivity coupled with low adaptive capacity correlated with elevated vulnerability. Conversely, efforts to diminish exposure and sensitivity and enhance adaptive capacities were associated with increased resilience. The study highlighted the necessity for collaborative interventions spanning from household to municipal and national levels. It stressed the importance of enhancing community knowledge, preparedness, and adaptive capacity to mitigate social-ecological vulnerabilities, necessitating comprehensive cooperation and participation across diverse levels.

Keywords
Adaptive capacity, Exposure, Sensitivity, Resilience, Flood vulnerability index, Davao del Norte

INTRODUCTION

The Philippines, situated within the Pacific Ring of Fire, is inherently vulnerable to a multitude of natural hazards, presenting significant risks to its population and infrastructure (World Economic Forum, 2018). Its geographical location exposes it to a convergence of various hazards, including typhoons, earthquakes, and floods, which are further exacerbated by climate change. Coastal communities, in particular, face heightened vulnerability to typhoons and storm surges, given the extensive coastline of the archipelago, leaving many settlements susceptible to devastation. The

Philippines' vulnerability is compounded by its dense population and rapid urbanization, leading to increased exposure and susceptibility to disasters. Additionally, hydro-meteorological events, such as floods, are pervasive, affecting a significant portion of the populace and contributing to the majority of natural disasters in the country (Jha, 2018).

Flooding stands as one of the most devastating climate-related disasters globally, inflicting profound challenges upon both society and the environment (WMO, 2021; Zhou et al. 2024). It has emerged as a prominent and recurring threat in the Philippines, causing substantial social, economic, and environmental ramifications. Among natural disasters, floods stand out for their widespread impact, affecting more individuals and causing greater financial losses annually than any other hazard (Takeuchi, 2002). Despite concerted efforts in flood control and mitigation, certain regions, such as the Province of Davao del Norte, grapple with persistent flooding due to various geographical factors, including low-lying terrain and proximity to major river systems.

The consequence is inherent in the place as it is geographically situated in a low-lying area and hosts the Tagum-Liboganon River Basin, one of the major river systems in the Philippines (CLUP, 2011-2025). The case of Typhoon Bopha in 2012 serves as a poignant example of the devastating consequences natural disasters can inflict on communities. Davao del Norte bore the brunt of this calamity, witnessing extensive flooding and the displacement of thousands of families. This event underscores the urgent imperative to delve into the vulnerability of social-ecological systems in such contexts. Understanding the intricate interplay between social dynamics, environmental factors, and disaster preparedness is crucial for devising effective strategies to mitigate the impacts of floods and enhance resilience in flood-prone areas like Davao del Norte.

The concept of social-ecological vulnerability offers a vital perspective for understanding the intricate relationships between ecosystems and societies. It highlights the importance of recognizing the dependencies and feedback loops within these systems, shedding light on the complex web of connections between human communities and their surrounding environments. However, it has to be clearly stated that social-ecological vulnerability is still a very new concept, and only a few applied approaches can be found in the literature (Eakin and Luers, 2006; Luers, 2005; Luers et al., 2003; Turner et al., 2003). Moreover, despite its significance, applying this framework at local scales has been challenging due to a lack of studies and tools for spatially representing social-ecological vulnerability, which hampers efforts to fully grasp the nuanced dynamics and localized manifestations of vulnerability within specific communities (Thiault, 2018). Understanding social-ecological system vulnerability involves examining the interconnectedness between human societies and their surrounding environments, particularly concerning natural hazards like floods. Thus, this study delves into the application of a social-ecological framework to analyze the vulnerability of local flood-prone communities in the chosen area.

This approach recognizes that vulnerability is shaped not only by physical exposure to hazards but also by social, economic, and institutional factors. In the context of floods in Davao del Norte, studying social-ecological system vulnerability would involve assessing how socio-economic factors influence communities' ability to prepare for, respond to, and recover from flood events. It would also consider ecological factors and their role in mitigating flood impacts. Furthermore, understanding social-ecological system vulnerability can inform the development of more effective disaster risk reduction strategies that account for the complex interactions between human and natural systems. This may include measures such as improved early warning systems, sustainable land use planning, and community-based adaptation initiatives that build resilience at the local level.

MATERIALS AND METHODS

Research Locale

Carmen, a coastal municipality nestled in the province of Davao del Norte, Philippines, holds a significant presence within the region. With a land area of 166.00 square kilometers, it contributes approximately 4.85% to the total land area of Davao del Norte. This land area encompasses a diverse landscape, including coastal areas, urban developments, and rural expanses. According to the 2020 Census, Carmen boasted a population of 82,018 residents, indicating its importance as a residential hub within the province. This population size accounted for 7.29% of Davao del Norte's total population and 1.56% of the broader Davao Region's population. Such figures translate to a population density of 494 inhabitants per square kilometer, underscoring the municipality's status as a densely populated area.

Strategically located, Carmen enjoys proximity to key urban centers in the region. Situated approximately 38 kilometers from Davao City and merely 17 kilometers from Tagum City, the capital of Davao del Norte, Carmen serves as a crucial link between these major cities. Its position within the Davao Metropolitan Area (DMA) further enhances its connectivity and economic significance. The municipality comprises twenty barangays, each contributing to the vibrant tapestry of Carmen's community. These barangays serve as the foundational units of local governance and community engagement, fostering social cohesion and development initiatives across the municipality.

Data Collection

This research employed a quantitative method. The research design is firmly anchored within a methodological framework that prioritizes ethical considerations and community engagement. It commences with a foundational step of initiating a courtesy call, an act that underscores respect and collaboration with the local community. This initial contact serves as a platform for building rapport and establishing trust, essential elements for any successful research endeavor. Subsequently, the procedure involves seeking official approval and consent from the local government unit.

This step not only ensures compliance with regulatory requirements but also acknowledges the authority and jurisdiction of the local governance structure. By securing endorsement at this level, the study demonstrates its commitment to responsible and accountable research practices, valuing the perspectives and interests of the community being studied. Overall, this approach not only strengthens the validity and reliability of the data gathered but also fosters a mutually beneficial relationship between the researchers and the local community, laying a solid foundation for collaborative knowledge production and positive social impact.

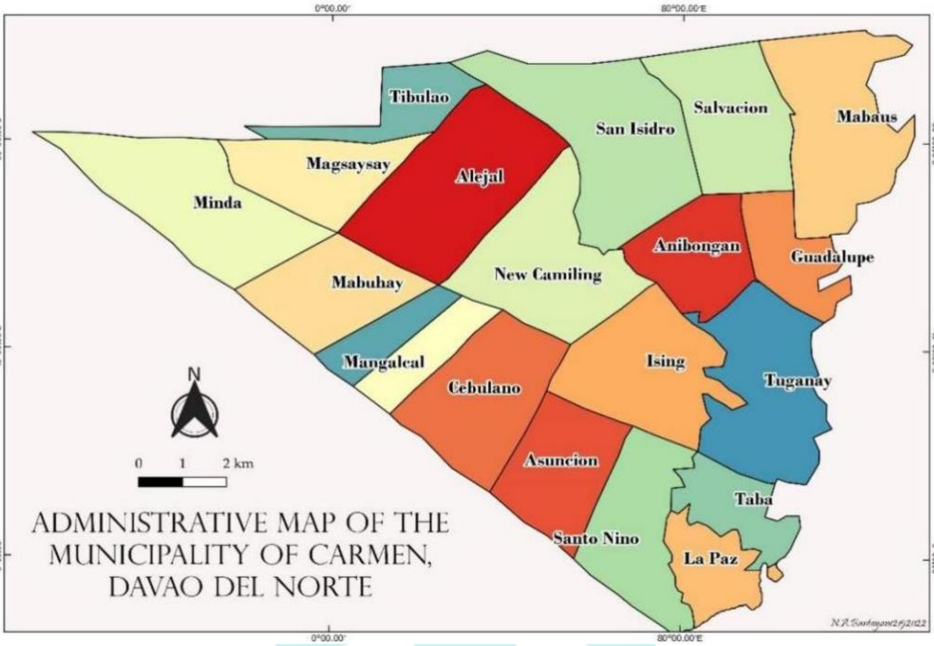

Fig. 1 Map of the Municipality of Carmen, Davao del Norte

Systematic Literature Review through PRISMA

A systematic literature review was conducted to critically analyze the social-ecological system vulnerability indicators in the flooding context. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Pittway, 2008; Wood, 2003) was used to select the indicators for a detailed review (**Table 1**). It is an established method used in conducting a systematic academic literature review based on four significant steps: identification, screening, eligibility, and inclusion.

Table 1 The process of selection of literature (Pittway, 2008)

Process	**Activities**
Stage 1: Identification	Search electronic databases for relevant papers
Stage 2: Screening	Exclude publications based on titles, abstracts, and results
Stage 3: Eligibility	Obtain papers by reviewing paper content for social-ecological vulnerability.
Stage 4: Inclusion	Primary papers best suited to the research

Expert’s Opinion Survey

Experts were chosen to participate in a survey because of their expertise or specific knowledge of the research topic. It is generally considered that the participants reflect a wide range of views and perspectives to ensure a meaningful exchange of ideas. The main objective of the survey is to acquire the most reliable consensus of a group of experts’ opinions through a series of intensive questionnaires together with controlled feedback (Habibi et al. 2015). The minimum sample of experts in the Fuzzy Delphi studies is 10 to obtain high uniformity among experts (Mohamed Yusoff et al. 2021). Delphi technique calculations are based on experts’ opinions.

Therefore, any error or inconsistency in assessing experts' opinions affects the result of calculations. In traditional Delphi approaches, although experts’ mental competencies and abilities are used for comparisons, quantifying experts’ opinions only partially reflects the human thinking style. Using fuzzy sets is more consistent with human linguistic and sometimes vague descriptions, and it is better for decision-making in the real world by applying fuzzy numbers. This study indicated that the fuzzy Delphi technique could be used in a single round for screening criteria. In the second data-gathering phase, another set of experts was invited to answer questions in the analytical hierarchy process through pairwise comparison.

Barangay Survey

A survey methodology was employed to collect localized data from every barangay, focusing on identified indicators. This involved a blend of secondary research and primary data collection to supplement the information gathered. The data gathering process was comprehensive, adhering to protocols set forth by the Local Government Unit (LGU) to mitigate potential risks.

Data Analysis

Fuzzy Delphi Method

The overall process of the Fuzzy Delphi Method (FDM) is presented in Fig. 2. It is a method for acquiring group knowledge and a simple, easy-to-use, and low-cost tool that can be applied to gaining judgments on complex matters in a lack of precise information. It has a structural process to predict and make decisions through a series of rounds, gather information, and eventually achieve a group consensus. The final set of indicators determined from the systematic literature review was subjected to the Delphi technique. Experts from the field of disaster risk management were invited to answer the 7-point Likert scale survey questionnaire composed of statements anchored to social-ecological vulnerability components: exposure, sensitivity, and adaptive capacity.

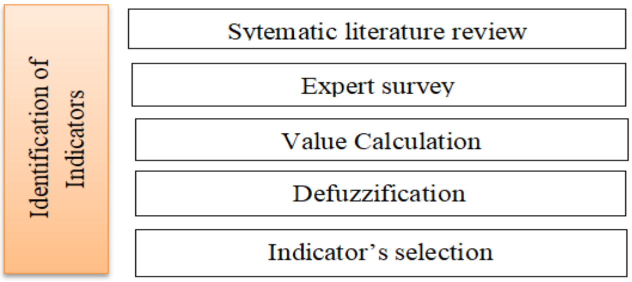

Fig. 2 The systematic flow of the FDM (Modified from Zhong et al. 2015)

This is followed by value calculation through computing for the *d* values. The data analysis process started by getting the triangular fuzzy number by arranging the m_1, m_2, and m_3 values. The value of m_1 represents the minimum value, then the value of m_2 represents the reasonable value, whereas the value of m_3 represents the maximum value. Triangular Fuzzy Number is adopted to produce the Fuzzy scale similar to the Likert scale to translate the linguistic variable to the fuzzy number (Table 2). The level of agreement for the Fuzzy scale comes in odd numbers. The Likert scale data obtained were analyzed using Excel to get a more organized tabulation. All data were converted into a triangular fuzzy number.

Table 2 Seven-point Fuzzy scales used in the study (Mohd. Ridhuan Mohd. Jamil et al. 2013)

Level	Linguistic Equivalent	Fuzzy Scale
1	Extremely disagree	(0.0,0.0,0.1)
2	Strongly disagree	(0.0,0.1,0.3)
3	Disagree	(0.1, 0.3,0.5)
4	Moderately agree	(0.3, 0.5,0.7)
5	Agree	(0.5,0.7,0.9)
6	Strongly agree	(0.7,0.9,1.0)
7	Extremely agree	(0.9,1.0,1.0)

To ensure experts' consensus on every item, the threshold value (*d*) should be at most 0.2. To obtain the threshold value (*d*), the equation shown below was used.

$$d(\bar{m},\bar{n}) = \sqrt{\frac{1}{3}\left[(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2\right]}$$

Equation 1 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

The defuzzification process has been made in the data analysis process in the FDM. It is the process of determining the relative weight value of each criterion to decide the sequence of the weight value and the importance level of each indicator. The defuzzification value for every item has to be more than the α-cut value=0.5. In this process, the equation presented below was used.

$$A = 1/3 * (m1 + m2 + m3)$$

Equation 2 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

The percentage of experts' consensus needs to be more than the value of 75%. It was computed by dividing the accepted indicators by the total number of indicators and multiplying them by 100 (Equation 3).

$$\text{\% of expert consensus} = \frac{\text{\# of accepted indicators}}{\text{Total number of indicators}} \times 100\%$$

Equation 3 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

At the end of the process, the indicators that passed the three prerequisite conditions of the FDM were extracted and used for prioritizing and pairwise comparisons in the next step. A corrected set of indicators was sent again to the experts for pairwise comparison between the criteria through the Analytical Hierarchy Process (AHP).

Analytical Hierarchy Process

The AHP is a multiple-criteria decision-making tool that has been used in almost all applications related to decision-making (Vaidya & Kumar, 2006). It was proposed for the first time by Saaty (2005). The AHP follows a systematic procedure presented in Fig. 3.

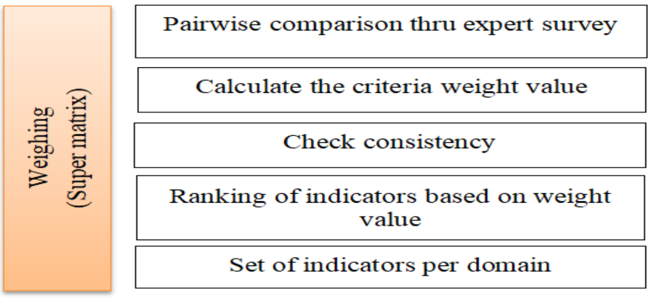

Fig. 3 Flow of AHP in the study (Modified from Saaty, 2005)

The process starts with setting up the network of indicators identified from the FDM. Once indicators have been identified, setting up the network involves organizing these indicators into a coherent framework. This framework typically includes categorizing indicators based on their relevance, interdependencies, and hierarchical relationships. It was followed by the creation of the comparison matrix. The process involves organizing data into a structured format to facilitate comparison between different options or criteria. Typically, this involves listing the options or criteria in rows and columns and then filling in the cells with relevant data, such as ratings, scores, or descriptions. To define pairwise comparisons, the equation below was used;

$$a_{ij} = \frac{w_i}{w_j}, \quad i, j = 1, 2, \ldots, n$$

Equation 4 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

where:

n denotes the number of criteria compared

W1 are weights for the i criterion, and

aij is the ratio of the weight of the i criterion and j.

After knowing the comparison of its criteria, the following process was normalizing each column into the matrix form by dividing each value in column ***i*** and row ***j*** by the most significant value in column ***i***, which was done using the formula below;

$$a_{ij} = \frac{a_{ij}}{\max a_{ij}}, \quad \forall i, j$$

Equation 5 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

The next step is checking for consistency. The comparison of the consistency index with a random index (RI) value by Saaty (2005) is listed in Table 3. This value depends on the matrix order n.

Table 3 Ratio Index (Saaty, 2005)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Consistency is expected to be near perfect to produce a close to valid decision. It is necessary to first recognize the value of the eigenvector, which is the weighted value of the criterion. To calculate the eigenvector, the following equation was used:

$$w_i = \frac{\hat{a}_i}{n}, \quad \forall i$$

Equation 6 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

where;

wi is the eigenvector

â is the sum of the matrix normalization values and is divided by the number of criteria ***(n)***

After obtaining the maximum lambda value, the value of CI was determined using the formula below.

$$CI = \frac{\lambda maks - n}{n - 1}$$

Equation 7 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

Where ***CI*** is the consistency index, and maximum lambda is the largest eigenvalue of the n-order matrix.

The results adhere to the condition that if the value of CI is zero (0), the matrix is consistent. If the value of CI obtained is greater than 0 (CI> 0), then the limit of inconsistency applied by Saaty is tested. Testing is measured using Consistency Ratio (CR), i.e., index value, or comparison between CI and RI.

$$CR = \frac{CI}{RI}$$

Equation 8 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

Additionally, the ***RI*** value used follows the order ***n*** matrix. If the ***CR*** of a smaller matrix is 10% (0.1), each opinion's inconsistency is considered acceptable. The equation below is used to obtain the normalization of vector weight values,

$$W' = \left(d'(A1), d'(A2), \ldots, d'(An)\right)T$$

Equation 9 (Abdullah & Yusof, 2018; Pelone & Sanchez, 2024)

The last step in AHP is the ranking and selection of the indicators. An alternative value calculation where the alternative settlement measures are the same as the completion steps on the criteria. Each alternative element's weight value was calculated by the weight of the criteria element and directed to get the final result.

Flood Vulnerability Index

The general formula for the Flood Vulnerability Index (FVI) calculation categorizes the components into three groups: exposure, sensitivity, and adaptive capacity or resilience indicators (Balica, 2012). The formula used to calculate the FVI developed by Balica et al. (2009) is presented in equation 10, where E stands for exposure, S for sensitivity or susceptibility, and R for resilience or adaptive capacity.

$$FVI = \frac{E \times S}{R} \text{ or } FVI = (E + S) - R \qquad \text{Equation 10}$$

FVI is equal to the sum of exposure and susceptibility minus resilience or adaptive capacity. The index gives a number on a scale from 0 to 1, signifying low to high flood vulnerability, respectively. The ranges of FVI used in this study are based on the IPCC (2001).

$0 < V < 0.45$	low vulnerability
$0.45 < V < 0.70$	medium vulnerability
$0.70 < V < 1.00$	high vulnerability

RESULTS AND DISCUSSION

Social-Ecological Vulnerability Indicators for Flooding

Social-ecological vulnerability is defined as the extent to which environmental degradation and climate change cause negative changes in exposure, susceptibility, and the capacity of the social-ecological system to anticipate, cope with, and recover from the hazard (Ruiz-Diaz et al. 2020). It is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt (Adger, 2006). Ford and Smith (2004) suggested assessing current vulnerability by documenting exposures, sensitivity, and adaptive strategies. Their vulnerability framework utilized historical information, including how communities have experienced and addressed hazards, with information on what conditions are likely to change and what constraints and opportunities there are for future adaptation.

Before assessing vulnerability, indicators for measuring the different components of the social-ecological system were developed first. It was done following a comprehensive systematic literature review, fuzzy Delphi method, and analytical hierarchy process. In the identification process (**Table 4**), there were 120 related papers and articles found in Google Scholar related to the current topic. These research studies were published in different international journals. After screening these papers by reading and analyzing titles, abstracts, results, and discussion, only 55 papers and articles remained. After going through the overall process of the PRISMA, only 39 related papers were retained and selected.

Table 4 Process of literature selection

Process	Number of Studies
Stage 1: Identification. Search electronic databases for relevant papers and articles	120
Stage 2: Screening. Exclude publications based on titles and abstract	92
Stage 3: Eligibility. Obtain papers by reviewing paper content for social-ecological vulnerability	55
Stage 4: Inclusion. Indicators gleaned from remaining primary papers and articles	39

Social Indicators

According to the fuzzy Delphi method's standard requirements, indicators must have values of 0.2 for threshold (d), > 75% for expert agreement percentage, and > - cut = 0.5 for defuzzification values (Chen & Lin, 2002). The outcome demonstrates that all the items in Table 5 met all the requirements and were considered reliable indicators for determining social vulnerability. Additionally, the analytical hierarchy method yielded general consistency ratios of 0.064, 0.057, and 0.050 for social exposure, sensitivity, and adaptive capacity, respectively, which are all considered consistent. As a result, about twelve (12) indicators are generally regarded as accepted indicators as they passed all the criteria of FDM. These consist of four indicators for exposure, four for sensitivity, and another for adaptive capacity.

In addition, because the analytical hierarchy process is a powerful yet simple method for making decisions, prioritization, and selection (Saaty, 2009), the weight values of indicators represent the options and decisions of the experts. Thus, accordingly, indicators considered significant (highest) are population (0.383) for exposure, children under five years old (0.327) for sensitivity, and training and seminars (0.350) for adaptive capacity. Adaptive capacities must be intensified while exposure and sensitivity should be lessened to lower vulnerability. These social indicators need attention among the LGU and community to address vulnerabilities in this context.

Table 5 Social Indicators Resulting from FDM and AHP

Indicator	d Value	% of Consensus	Fuzzy Score	AHP Weight	Consistency Ratio
Population*	0.128	93.30%	0.891	0.383	
Informal settlers*	0.126	86.70%	0.838	0.191	
Infrastructures *	0.101	80.00%	0.887	0.239	
Agriculture*	0.126	93.30%	0.851	0.187	
Total				1.000	0.064
Children under five years old**	0.067	93.30%	0.929	0.327	
Elderly above 65 years old**	0.057	100.00%	0.933	0.241	
PWD **	0.104	86.70%	0.898	0.216	
Population living in light materials**	0.065	93.30%	0.889	0.216	
Total				1.000	0.057
Employment rate ***	0.119	93.30%	0.807	0.232	
Annual income***	0.116	86.70%	0.778	0.194	
Equitable social services ***	0.067	93.30%	0.929	0.225	
Training and seminars***	0.059	93.30%	0.936	0.350	
Total				1.000	0.050

Legend**:** ***-** Exposure, **-** Sensitivity, ***- Adaptive capacity

Ecological Indicators

Ecological vulnerability indicators are measurements used to assess the susceptibility of ecosystems to various environmental stressors or disturbances. Identifying ecologically vulnerable areas is a significant aspect of disaster risk reduction management and climate change adaptation interventions. It is a helpful tool to help decision-makers understand the various impacts of natural and factitious elements on the ecosystem. Ecological vulnerability is the potential of an ecosystem to modulate its response to stressors over time and space, where that potential is determined by characteristics of an ecosystem that include many levels of the organization. It is an estimate of the inability of an ecosystem to tolerate stressors over time and space (De Lange et al. 2010). It also describes the sensitivity of people, places, ecosystems, and species to stress or perturbation, including their capacity to anticipate and cope with the stress and the resilience of the exposed people, places, ecosystems, and species in terms of their capacity to absorb shocks and perturbations while maintaining function.

In this study, indicators for assessing ecological vulnerability in the context of flooding were determined. Like in the identification of social indicators, ecological indicators should pass the criteria in the fuzzy Delphi technique, such as having a value of ≤ 0.2 for threshold (d); above 75% for expert agreement percentage, and defuzzification values for items exceeding the value of α - cut = 0.5 (Chen & Lin, 2002). Based on the data presented in Table 6, all indicators passed the criteria and thus were considered significantly accepted. There were nine (9) indicators being accepted which include flooded areas, land elevation, and the number of rivers for exposure; the number of typhoons/year, flood water level, and the number of floods/year for sensitivity; and green spaces; hydraulic measures, and efficient solid waste management for adaptive capacities.

Table 6 Ecological Indicators Resulting from FDM and AHP

Indicator	d Value	% of Consensus	Fuzzy Score	AHP Weight	Consistency Ratio
Flooded areas *	0.119	80.00%	0.887	0.477	
Land elevation*	0.112	93.30%	0.818	0.227	
Number of rivers*	0.096	93.30%	0.838	0.295	
Total				1.000	0.026
Number of typhoons/year**	0.030	100.00%	0.953	0.248	
Flood water level**	0.119	80.00%	0.887	0.504	
Number of floods/year**	0.057	100.00%	0.933	0.249	
Total				1.000	0.024
Green spaces***	0.065	93.30%	0.889	0.316	
Hydraulic measures***	0.095	93.30%	0.871	0.444	
Efficient SWM***	0.075	93.30%	0.902	0.241	
Total				1.000	0.038

Legend**:** ***-** Exposure, **-** Sensitivity, ***- Adaptive capacity

In addition, consistency ratios reached the standard, which tallied 0.026, 0.024, and 0.038 for ecological exposure, sensitivity, and adaptive capacity, respectively. Consideration of the role of the environment in disaster risk management efforts like nature-based solutions emphasized an excellent strategy for lessening vulnerabilities. Nature-based solutions such as conserving forests and wetlands can help communities prepare for, cope with, and recover from disasters like flooding (IUCN, 2022).

Flood Vulnerability Index (FVI)

The information collected from interviews, surveys, field observations, and records was input into the FVI. The FVI is a parametric approach suitable for evaluating vulnerability to floods because it incorporates socio-economic and environmental components. This index was used to measure the extent of flood vulnerability in the study area. Exposure, sensitivity, and adaptive capacity are the three main factors of FVI, aligned with the social, and economic to reveal relevant indicators. Selected indicators were thoroughly reviewed and merged to be relevant in the communities.

The interplay between exposure, sensitivity, and adaptive capacity significantly impacts vulnerability within social-ecological systems, particularly in the face of climate change (Cutter, 1996). According to Munyai et al. (2019), these dimensions exert varying influences on vulnerability. In assessing vulnerability, exposure is the primary factor of concern that makes people or places vulnerable to natural hazards (Chang & Huang, 2015). It is delineated by the IPCC (2007) which signifies the level of stress a system experiences due to climatic factors such as extreme weather events or temperature anomalies. It encompasses factors like the frequency, magnitude, and duration of these events (Adger, 2006). For example, communities residing in coastal areas are often highly exposed to risks associated with sea-level rise and storm surges.

Sensitivity measures the system's susceptibility to the impacts of exposure, which can be influenced by factors such as awareness and preparedness. Communities with limited resources or inadequate infrastructure to deal with climate-related hazards tend to exhibit higher sensitivity. Adaptive capacity, as elucidated by Balica (2010), gauges the system's ability to cope with and recover from the impacts of exposure and sensitivity. It encompasses measures taken before, during, and after an event to mitigate its effects, including infrastructure improvements, early warning systems, or community-based adaptation strategies. Communities with higher adaptive capacity can better absorb shocks and adapt to changing conditions, thereby reducing vulnerability.

In this research endeavor, the vulnerability assessment reveals that Barangays Ising and Mabaus exhibit high vulnerability, as evidenced by their respective FVI scores of 0.75 and 0.72, both falling within the high vulnerability range, as illustrated in Fig. 4. The elevated vulnerability levels in these barangays can be attributed to their notably high exposure values, with Barangay Ising recording a value of 0.63 and Barangay Mabaus recording a value of 0.61.

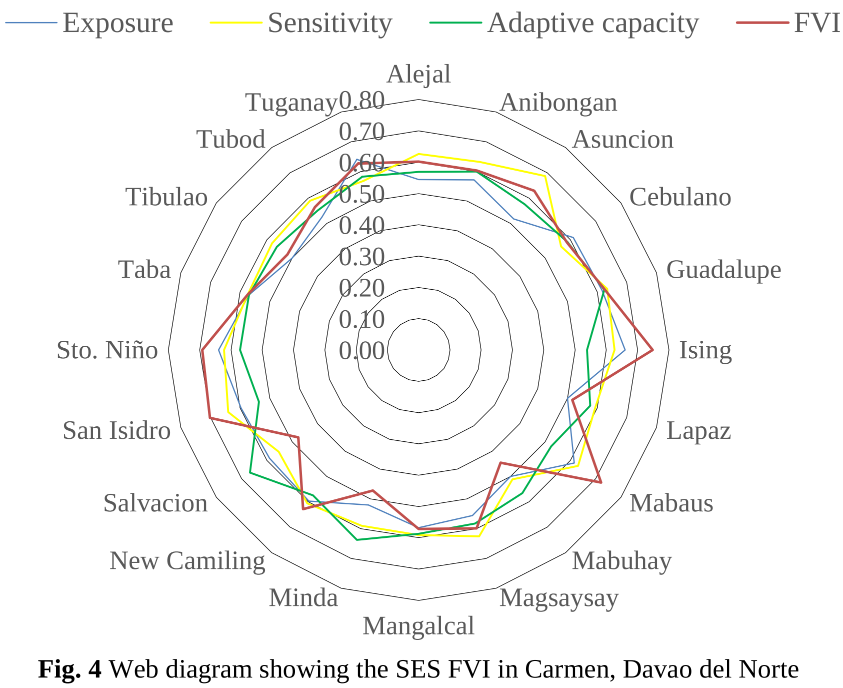

Fig. 4 Web diagram showing the SES FVI in Carmen, Davao del Norte

Barangay Mabaus stands at a critical juncture, facing heightened susceptibility to flooding owing to its geographical proximity to the Liboganon River. Like numerous other waterways, the Liboganon River undergoes seasonal fluctuations in water levels, with factors such as heavy rainfall and deforestation upstream exacerbating these variations. Consequently, Barangay Mabaus frequently grapples with recurrent flooding as the river swells beyond its banks during periods of heightened precipitation. The resultant expansion of flooded areas not only disrupts livelihoods and infrastructure but also amplifies the overall vulnerability of the area. The displacement of residents, damage to crops, and interruption of essential services further compound the socio-economic repercussions of flooding, underscoring the pressing need for comprehensive mitigation strategies (Munyai et al., 2020).

Moreover, the vulnerability of Barangay Ising is primarily linked to its substantial population size and significant presence of informal settlers. Rapid and unplanned urbanization, coupled with the impacts of climate change, accentuates the vulnerability of the urban poor to natural hazards (Williams et al., 2019). Notably, the barangay's dense population exacerbates the challenges posed by its vulnerability, rendering it a salient aspect of the overarching assessment. The convergence of these factors underscores the imperative for targeted interventions aimed at bolstering resilience and safeguarding vulnerable communities against the adverse impacts of flooding and urbanization.

The Liboganon River stands as a vital lifeline, coursing through the barangays of Mabaus and Guadalupe with a significance that transcends mere geography. However, its importance comes hand in hand with a stark reality – both social and ecological facets of Barangay Guadalupe bear a weighty burden of vulnerability, as reflected by their FVI scores of 0.62 and 0.63, respectively. This high vulnerability paints a sobering picture of the potential risks posed by floods, encompassing a spectrum of potential losses ranging from property and human lives to livelihoods and environmental integrity.

In essence, a high vulnerability to floods signifies not just the possibility, but the likelihood of encountering natural disasters. Within this framework, the designation of very high vulnerability underscores a scenario where the specter of loss of life looms ominously, casting a shadow over the delicate balance between human settlement and the capricious forces of nature. Thus, the Liboganon River emerges not only as a physical entity but also as a symbol of the intricate interplay between human existence and the ever-present threat of disaster in a landscape shaped by both its benevolence and its unforgiving temperament.

On the other hand, Barangay Mabuhay emerges as a beacon of resilience amidst environmental challenges, particularly flooding, showcasing a remarkably low vulnerability with an FVI score of 0.45. This commendable resilience stems from a convergence of factors, notably its reduced exposure and sensitivity levels, rated at 0.51 and 0.50 respectively. Despite sharing the same environmental risks as neighboring communities, Barangay Mabuhay distinguishes itself through its robust adaptive capacity. This capacity not only shields socio-economic assets but also safeguards human lives from potential harm and damage. Through proactive measures and community-driven initiatives, Barangay Mabuhay exemplifies how strategic planning and collective action can fortify resilience in the face of adversity.

Conversely, other barangays fall within the category of medium vulnerability, characterized by FVI scores ranging from 0.45 to 0.70. Within this range, there exists a balance between exposure, sensitivity, and adaptive capacities. While these areas may experience moderate harm to assets and lives in the event of flooding, their adaptive capacities play a crucial role in mitigating the overall vulnerability. This equilibrium suggests that while these barangays face significant exposure and sensitivity to flood risks, their capacity to adapt and respond effectively contributes to averting more severe consequences.

The study highlights the intricate interplay between exposure, sensitivity, and adaptive capacity in determining vulnerability to flooding. It underscores the importance of resilience within communities, where even in the face of environmental hazards, strong adaptive capacities can significantly reduce vulnerability. Thus, fostering resilience through community-based initiatives and infrastructural development emerges as a pivotal strategy for enhancing overall resilience and mitigating the impacts of flooding on both people and assets.

Hence, Carmen, despite being a first-class municipality in the province of Davao del Norte, faces a significant challenge in terms of its vulnerability to flooding. This vulnerability stems from a combination of factors, as revealed by a comprehensive study that assessed three key components: exposure, sensitivity, and adaptive capacity. The municipality's geographical characteristics play a crucial role, with its entire area featuring a flat terrain and an elevation of just 6.3 meters above sea level. Moreover, the presence of major rivers such as Liboganon, Tuganay, and Lasang further exacerbates the flooding risks, as these waterways contribute to the variability in flooding patterns across different parts of Carmen.

Lastly, the study emphasizes the nuanced nature of vulnerability, emphasizing that it is not solely determined by geographical factors but is also influenced by socio-economic dynamics such as population density and settlement patterns. As a result, certain barangays within the municipality exhibit heightened vulnerability due to their proximity to natural elements and high population concentrations. Understanding these complex interplay between social, environmental, and socio-economic factors is essential for devising targeted strategies aimed at bolstering resilience and mitigating the impact of flooding and other environmental risks in these communities.

CONCLUSION

The findings of the study underscore notable divergences among barangays in terms of their susceptibility to flooding, underscoring the pivotal influence of social-ecological factors. Barangays Ising and Mabaus have surfaced as particularly susceptible, with a confluence of factors such as elevated exposure and sensitivity, compounded by a restricted adaptive capacity. Conversely, Barangay Mabuhay exhibits comparatively lower vulnerability. These disparities signify the imperative for a multifaceted strategy aimed at bolstering community resilience. Addressing such vulnerability mandates concerted efforts spanning various domains, including infrastructure development, community engagement, and policy interventions. By adopting a holistic approach, tailored to the specific needs and challenges of each barangay, meaningful strides can be made towards mitigating the impacts of flooding and fostering sustainable resilience within these communities. Key strategies include maximizing resources and capacities within the community, raising awareness and preparedness among residents, and leveraging opportunities to mitigate and respond to flood-related consequences.

Furthermore, the study underscores the importance of vulnerability assessment as a tool for informing policy development and adaptation strategies, essential for sustainable management. Given the dynamic nature of the vulnerability, efforts should continually evolve to address changing climatic, environmental, and anthropogenic factors. Recommendations include policy implementation on land use, monitoring of human settlement areas, community education on health and family planning, and initiatives such as solid waste management and tree growing. Structural measures near waterways and drainage systems, along with ongoing education on disaster risk reduction, are also crucial. However, successful implementation of these recommendations necessitates broad collaboration and participation spanning from local households to international levels. By collectively addressing exposure and sensitivity while bolstering resilience and adaptive capacities, communities in the municipality of Carmen can better mitigate the impacts of flooding and build a more sustainable future.

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DECLARATION OF CONFLICT

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