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Development of Science and Significance-based Indicators for Social-ecological System Flood Resilience

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In flood-prone landscapes, assessing the resilience of the local social-ecological system is imperative, yet established indicators are lacking. This research aims to fill this gap by employing a comprehensive and scientific approach within the social-ecological systems (SES) framework from Berkes (2011) and Ostrom (2009). The methodology encompasses a systematic literature review, Fuzzy Delphi Method (FDM), and the Analytical Hierarchy Process (AHP) to develop science and significance-based indicators for flood resilience assessment. Based on the results, key indicators include natural wetland management, drainage systems, employment rates, disaster management budgets, and community linkages. Supported by data-driven insights, these indicators collectively contribute to the establishment of a robust and sustainable flood risk management framework. Recommendations extend to the incorporation of additional indicators such as capacity building activities, ecological conservation, infrastructure enhancements, measures for economic stability, increased budget allocations, and enhanced stakeholder engagement. Overall, this holistic approach is designed to assist policymakers and practitioners in formulating sustainable flood management practices, ultimately fostering greater resilience in flood-prone areas.

Keywords: resilience, flood, indicators, social-ecological systems, fuzzy Delphi method

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Introduction

Flooding is a common natural disaster that exerts widespread and profound impacts across various aspects of communities and ecosystems. Its effects extend far beyond damage to infrastructure, encompassing social, economic, and environmental dimensions. In the aftermath of a flood, houses and businesses may suffer structural damage, leading to the displacement, loss of livelihoods, and economic setbacks for individuals and communities. In Tagum City, Davao del Norte, Philippines, flood challenges require a holistic flood risk management approach, recognizing the interconnectedness of social and ecological systems. The concept of resilience in social-ecological systems is widely acknowledged, yet there exists a notable lack of consensus regarding appropriate measurement methods especially in standard indicators for the assessment in a local context. Most flood-related studies have largely focused on identifying the causes of vulnerability, with comparatively less emphasis placed on evaluating the effectiveness of flood management initiatives in fostering resilience (Wamsler, 2016; Bottazzi et al., 2018).

The present study is driven by an awareness of the intricate interplay between human activity and natural systems, necessitating a thorough understanding of their interactions, particularly within local communities. This understanding is increasingly crucial in light of the mounting challenges posed by population growth and environmental degradation, as emphasized by Hunter (2001). Therefore, the main objective of this study is to develop a set of indicators founded on scientific principles and practical significance. These indicators are intended to serve as vital tools for the comprehensive management of flood risk within a framework that considers the complex relationship between humans and their environment.

Building upon the foundational work of Cutter et al. (2008) and Renaud et al. (2013), the indicators proposed in this study seek to consolidate various dimensions essential for effective flood risk management. Specifically, they incorporate

measures of social vulnerability, resilience, ecosystem services, and human well-being. By integrating these diverse elements, the approach aims to provide a holistic understanding of flood risk dynamics, accounting for both the vulnerabilities and capacities inherent within communities and their surrounding ecosystems.

Furthermore, the significance of conducting this study extends beyond mere academic curiosity; it serves as a vital tool for addressing real-world challenges in Tagum City, Davao del Norte. By delving into the dynamics of social-ecological system (SES) resilience, as outlined by Berkes (2011) and Ostrom (2009), this provides concrete, evidence-based recommendations for sustainable flood risk management. This research is crucial in light of the increasing frequency and severity of flood events in the area, which threaten both human settlements and the surrounding ecosystems. Through the development of flood resilience indicators grounded in the SES framework, this can unravel the intricate interplay between social and ecological factors shaping the city's vulnerability to floods. These indicators not only deepen understanding of the city's adaptive capacity but also serve as practical tools for policymakers, urban planners, and emergency management professionals.

Materials and Methods

Location

Tagum City, nestled in the heart of Davao del Norte, Philippines, lies between 7°13' 38" and 7°32' 23" north latitude and 125° 43' 30" and 125° 53' 13" east longitude. It shares borders with the municipalities of New Corella, Asuncion, and Mawab to the north, northwest, and northeast, respectively. Moreover, the municipalities of Dujali and Carmen flank it to the west, while the south is bordered by the municipality of Maco in Davao de Oro (**Figure 1**). With 23 barangays spanning 19,580 hectares, Tagum City is celebrated for its agricultural richness and its proximity to vital waterways like the Tagum-Libuganon and Hijo Rivers, flowing towards the Davao Gulf.

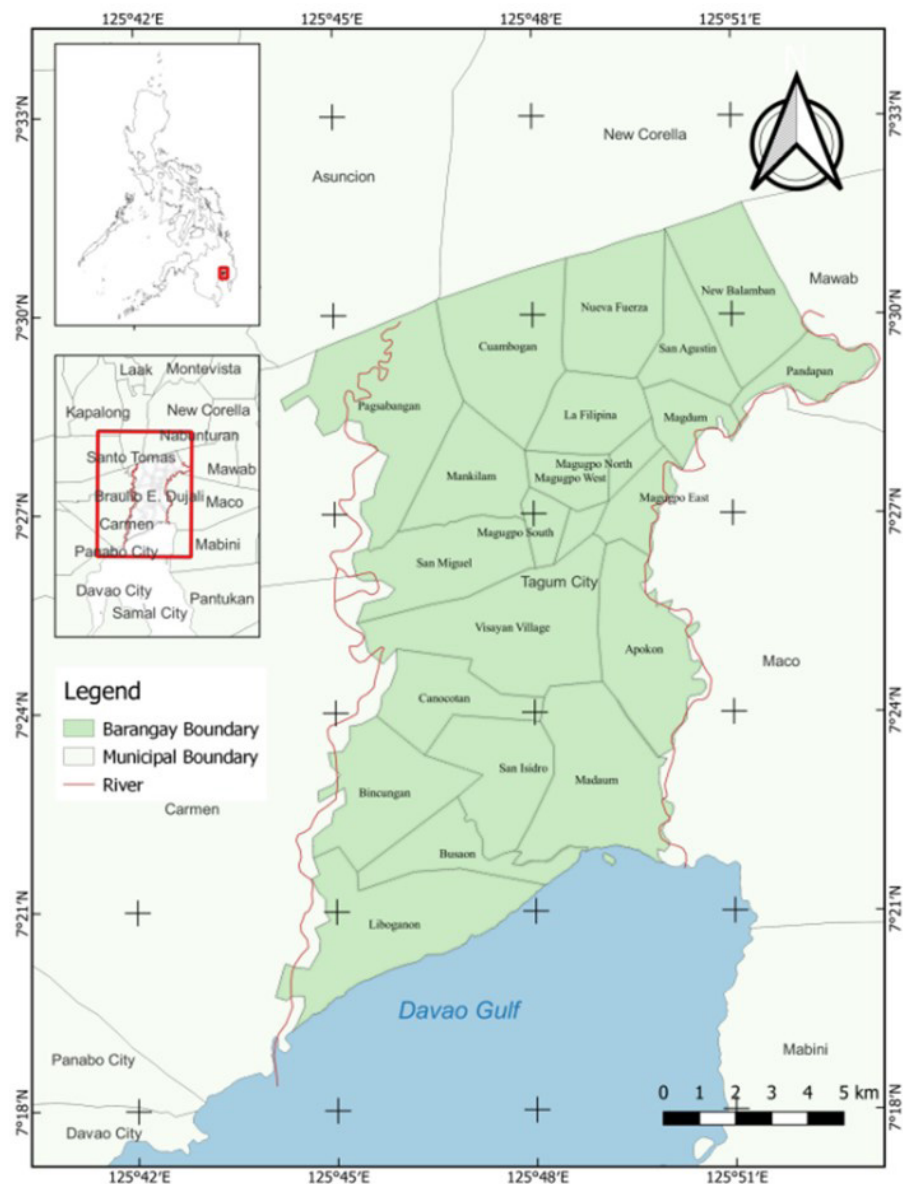


Figure 1. Map of Tagum City, Davao del Norte (Global Administrative Areas, 2015)

Research Design

The study employed a quantitative methodology, integrating a systematic literature review, Fuzzy Delphi Method (FDM), and Analytical Hierarchy Process (AHP) to establish and validate significance-based indicators for bolstering social-ecological system resilience. The review process gathered existing knowledge, while FDM expert surveys identified indicators, and AHP prioritized them based on importance. Data from Scopus-indexed journals, Comprehensive Development Plan (CDP), and the Comprehensive Land Use Plan (CLUP) of Tagum City were used for this purpose. The FDM employed a sample size of sixteen respondents to ensure a comprehensive and reliable selection process. On the other hand, AHP utilized purposive sampling, intentionally selecting 7 individuals based on specific criteria or characteristics deemed

relevant to the study's objectives.

Data Collection

Researchers obtained permission from the mayor's office and consent from barangay leaders to conduct a study on flood resilience. Data collection involved coordination with the LGU, using informed consent forms for voluntary participation and data privacy. Scopus-indexed publications were systematically reviewed for relevant indicators to measure flood resilience in the context of social-ecological system. Secondary data from LGUs, including Comprehensive Land Use Plan (CLUP) and Comprehensive Development Plan (CDP), were also utilized. Primary data were gathered through expert opinion surveys involving two sets of experts on topics pertaining to flood disaster risk reduction and management for the Fuzzy Delphi and Analytical

Hierarchy Process methods.

Data Analysis

In conducting a comprehensive analysis, a methodical approach was employed. Initially, a systematic literature review was conducted to gather insights and trends on identified indicators. Subsequently, the fuzzy Delphi method engaged domain experts to refine indicator selection through iterative consensus-building, accommodating uncertainties. Lastly, the analytical hierarchy process systematically evaluated and ranked indicators based on their importance, offering a prioritized list aligned with the study's objectives. This multi-step process ensured rigor and accuracy in the analysis. The step-by-step process of data analysis was presented and explained below.

Systematic Literature Review

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method (Pittway, 2008), the study systematically identified, screened, and assessed studies for inclusion based on resilience indicators. Relevant data from the CLUP (2011-2025) and CDP (2020-2026) were used as significant flood resilience indicators thoroughly reviewed for reliability in identifying pertinent resilience indicators (Figure 2). The reliability of these sources lies in their official and authoritative status, having undergone rigorous planning processes involving community input, expert consultations, and government approvals.

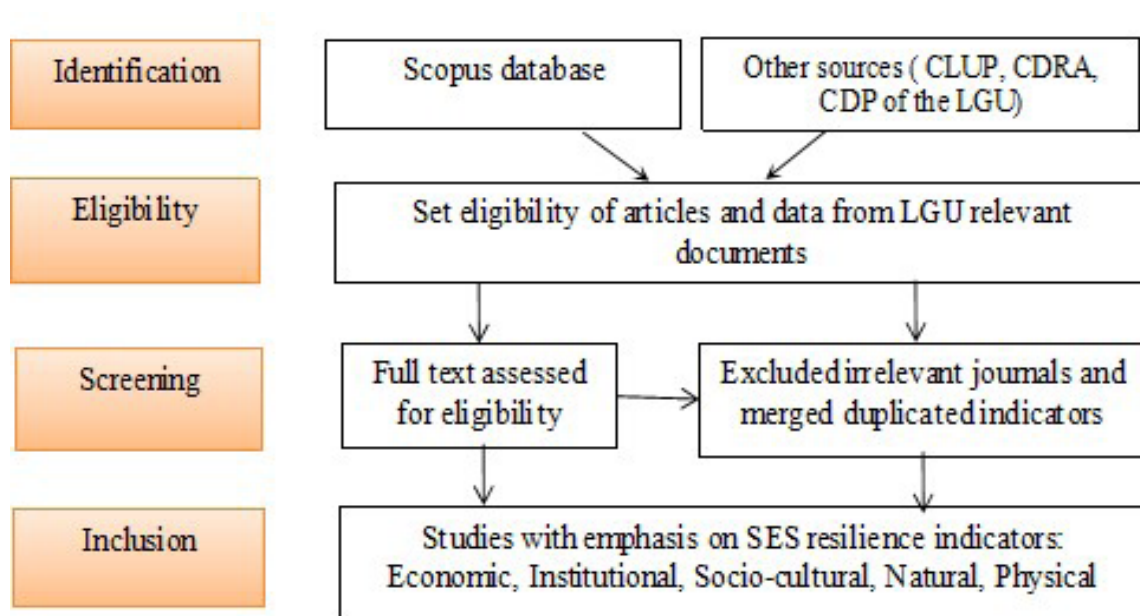


Figure 2. Summary of a systematic review of the literature (Pittway, 2008)

Integrated Fuzzy Delphi Method (FDM) and Analytical Hierarchy Process (AHP)

The research adopted a hybrid methodology by combining the Modified Fuzzy Delphi Method and the Analytical Hierarchy Process, as outlined by Zhong et al. (2020). This approach was employed to systematically identify and establish resilience indicators for social-ecological systems in the context of flooding. The Modified Fuzzy Delphi Method facilitated expert opinions and consensus building, ensuring a comprehensive and

nuanced understanding of relevant factors. Subsequently, the analytical hierarchy process was utilized to prioritize and structure these indicators, enabling a quantitative assessment of their relative importance within the social-ecological system resilience framework. This integrated approach enhances the robustness and applicability of the developed indicators, providing a valuable tool for assessing and strengthening resilience in the face of flooding events.

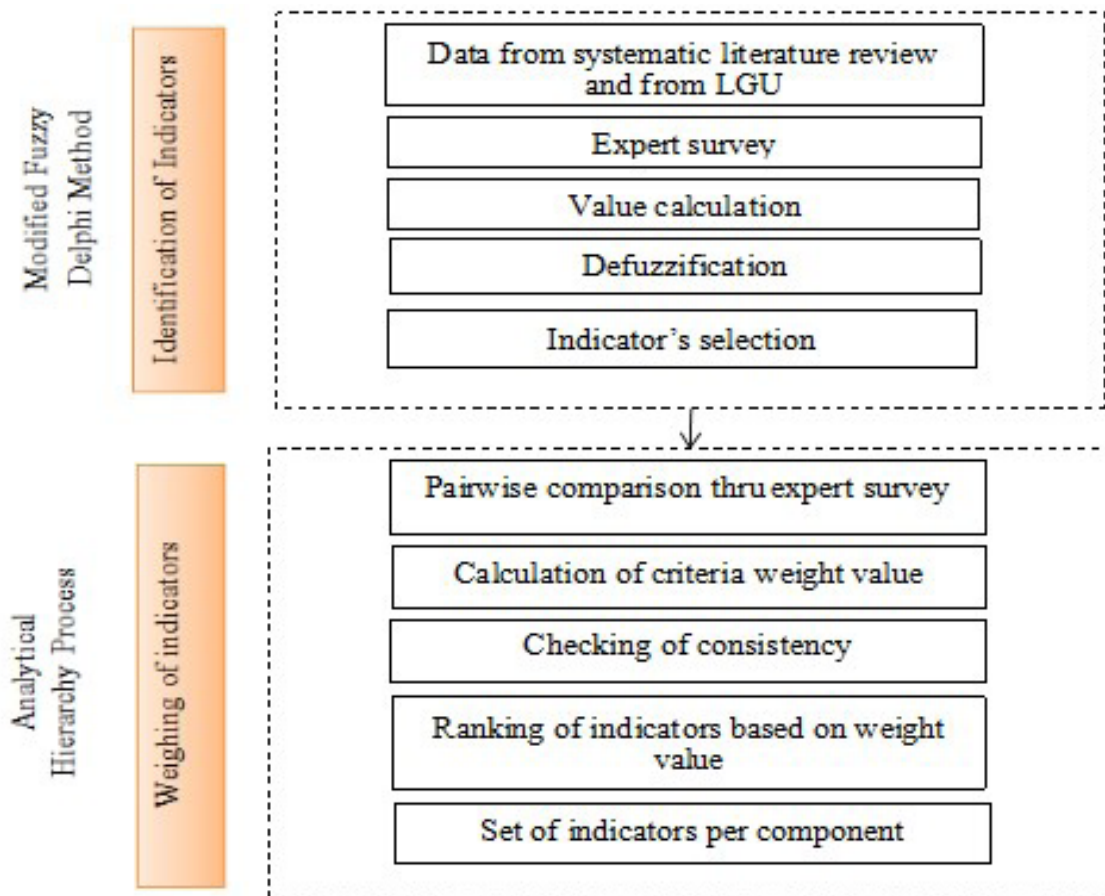


Figure 3. Integrated fuzzy Delphi Method and Analytical Hierarchy Process (Zhong et al. 2020)

Modified Fuzzy Delphi Method (FDM). The study employed the Fuzzy Delphi Method, utilizing a 7-point Likert scale survey for disaster risk management experts. The survey encompassed a diverse range of socio-demographic profiles, delving into individuals' characteristics such as age, gender, education level, and employment status, among other factors. These socio-demographic profiles provided a comprehensive examination of the survey participants, allowing for a nuanced understanding of the sample population. Simultaneously, the survey also addressed social-ecological components, which comprised sets of indicators related to resilience. Participants were invited to rank these indicators based on their preferences

and knowledge. This integration of socio-demographic profiles with social-ecological components facilitated a holistic assessment, enabling researchers to explore the interplay between individual characteristics and perceptions of resilience within various socio-ecological contexts. Triangular fuzzy numbers, representing minimum, reasonable, and maximum values, were derived during data analysis, translating linguistic variables into a fuzzy scale. The Likert scale data, analyzed using Excel, were converted into fuzzy triangular numbers, enhancing the method's precision and reliability in resilience indicator selection (**Table 1**).

Table 1. Seven-Point Fuzzy Scales

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)

Note. Adapted from Mohd. Ridhuan Mohd. Jamil et al. (2013)

The threshold value (d) should be at most 0.2 to get the experts' consensus on every item. This particular threshold is carefully selected to promote a high level of agreement among experts regarding each item under consideration. By setting the threshold at 0.2, a stringent criterion is established, indicating that experts must closely align in their opinions for a consensus to be achieved. This stringent criterion serves to prevent the inclusion of items where there might be significant disagreement among the experts involved in the evaluation process. The equation below was used to get the threshold value (d).

$$d = (\bar{m}, \bar{n})$$

$$= \sqrt{1/3[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]}$$

Equation 1 (Abdullah and Yusof, 2018)

The threshold value (d) should be at most 0.2 to get the experts' consensus on every item. This particular threshold is carefully selected to promote a high level of agreement among experts regarding each item under consideration. By setting the threshold at 0.2, a stringent criterion is established, indicating that experts must closely align in their opinions for a consensus to be achieved. This stringent criterion serves to prevent the inclusion of items where there might be significant disagreement among the experts involved in the evaluation process. The equation below was used to get the threshold value (d).

$$A = 1/3 * (m_1 + m_2 + m_3)$$

Equation 2 (Abdullah and Yusof, 2018)

The percentage of experts' consensus needs to be more than the value of 75% to be considered acceptable. This percentage ensures a robust level of agreement, indicating a strong convergence of expert opinion. Achieving consensus beyond this value reinforces the reliability and validity of the conclusions drawn, bolstering the credibility of the findings within the respective field or discipline. It can be computed by dividing the accepted indicators by the total number of indicators and multiplying them by 100, as shown below.

$$\text{Percentage of expert consensus} = \frac{(\text{Number of accepted indicators})}{(\text{Total number of indicators})} \times 100\%$$

Equation 3 (Abdullah and Yusof, 2018)

Lastly, the indicators that met the three prerequisite conditions of the Fuzzy Delphi Method were extracted and used in the next step for prioritizing and pairwise comparisons. The corrected set of indicators was presented to the experts for pairwise comparison using the Analytical Hierarchy Process.

Analytical Hierarchy Process (AHP). The AHP, introduced by Saaty (1980), serves as a decision-making tool by integrating expert opinions. The process involves five key steps. First, a network of indicators is established based on the outcomes of the FDM to ensure a comprehensive consideration of relevant factors. Second, a comparison matrix is constructed, emphasizing simplicity and a robust position within the consistency framework. This matrix facilitates systematic

evaluations through all conceivable comparisons, providing a basis for analyzing overall priority sensitivity to changes in consideration. The equation below was used to define pairwise comparisons;

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

Equation 4 (Abdullah and Yusof, 2018)

Where;

n denotes the number of criteria compared
 w_i are weights for the i criterion, and
 a_{ij} is the ratio of the weight of i criterion and j .

After knowing the comparison of its criteria, each column was normalized into the matrix form by dividing each value in column i and row j by the largest value in column i , which is done using the formula below;

$$aij = \frac{aij}{\max ai_j}, \forall i, j$$

Equation 5 (Abdullah and Yusof, 2018)

The third step was checking for consistency in the decision-making and choice of indicators by experts. The incorporation of the Consistency Index (CI) and the comparison

with the Random Index (R.I.) by Saaty (2005) is pivotal for ensuring the reliability and validity of the methodology. By introducing the consistency index and aligning it with the R.I. value, the study establishes a quantitative measure to assess the internal coherence of the decision-makers' judgments. This approach is particularly relevant as it focuses on the development of resilience indicators where inconsistencies in the decision-making process could compromise the robustness of the identified indicators. Saaty's Random Index (R.I.) value serves not only as a benchmark but also as a vital tool for enhancing the methodological rigor of a study.

Ultimately, the use of these values contributes to the overall validity of the study by ensuring that the derived indicators for social-ecological system resilience are based on logically coherent and consistent decision-making processes. In the computation of the consistency ratio, it is crucial to consider that the value of the ratio index is contingent upon the matrix order, denoted as ' n '. (**Table 2**). This acknowledgment underscores the importance of considering the size and complexity of the decision-making matrix when assessing the consistency of pairwise comparisons.

Table 2. 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

Using the above table, consistency is expected to be near perfect to produce a close to correct decision. First, recognize the value of the eigenvector, which is the weighted value of the criterion. To calculate the eigenvector, the following equation was used:

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

Equation 6 (Abdullah and Yusof, 2018)

Where;

w_i is the eigenvector
 \hat{a} is the sum of the matrix normalization values and is divided by the number of criteria (n)

After obtaining the maximum eigenvalue value (λ), the value of CI can be determined. The eigenvalue represents the extent to which the matrix satisfies the criteria of consistency. The CI is calculated by comparing λ to a theoretical value based on the matrix size and structure as presented in the equation below.

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

Equation 7 (Abdullah and Yusof, 2018)

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

If the value of the CI is zero (0) for a matrix, it indicates perfect consistency (Saaty, 2005). However, if the value of CI obtained is greater than 0 ($CI > 0$), it implies that the matrix might be inconsistent. In such cases, further testing is necessary to determine the extent of inconsistency. This is typically done by comparing the CI value with the Random Index (RI) and calculating the Consistency Ratio (CR) presented in the equation below.

$$CR = \frac{CI}{RI} \quad \text{Equation 8 (Abdullah and Yusof, 2018)}$$

The RI value used follows the order n matrix. If the C.R. of a smaller matrix is 10% (0.1), each opinion's inconsistency is considered acceptable.

The fourth step was the normalization of vector weight values obtained by the equation below,

$$W1 = (d^1(A1), d^1(A2), \dots, d^1(An)) T$$

Equation 9 (Abdullah and Yusof, 2018)

In the final step of the AHP, the ranking and selection of decisions occur. This involves synthesizing the information gathered from the comparison matrix, where preferences and priorities were established through pairwise comparisons. The AHP algorithm calculates the relative importance of each criterion and alternative, allowing for the determination of the overall ranking.

Results and Discussion

Analytical Hierarchy Process (AHP)

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) techniques was carried out to critically choose social-ecological system resilience indicators from diverse authors in the context of floods. A systematic review of literature is undertaken through a well-established method comprising four primary steps: identification, screening, eligibility assessment, and inclusion. During the identification phase, relevant papers were found using legitimate electronic databases such as Google Scholar and Web of Science. There were 361 related publications, most of which came from international sources. These publications listed 290 indicators and was temporarily saved in separate files. Additionally, secondary data from the LGU Tagum City was also considered.

The next step involves a comprehensive review of the titles, abstracts, discussions, and conclusions of all collected papers. Through this process, 184 publications were identified alongside 114 indicators. Subsequently, each paper's eligibility was assessed based on its abstract, keywords, and potential redundancy. As a result, 105 studies were used as references, with 64 indicators subjected to expert surveys. There were 24 relevant indicators gained experts approval, which were divided into 4 for natural components and 5 for geophysical features and physical infrastructure, economic, institutional, and social-cultural support system components (**Table 3**).

Table 3. Identified resilience indicators through a systematic literature review

COMPONENT	INDICATORS	AUTHORS
Natural	Watershed management	Duffy et al., 2018; Sasaki et al., 2015; Davenport & Seekamp, 2013; Thapa et al., 2022
	Green spaces	Semeraro et al., 2022; Sapkota et al., 2022; Huff et al., 2020; Tzoulas et al., 2007
	Well-managed wetlands	Alikhani et al., 2021; Zhao et al., 2016; Singh et al., 2021; Fremiera et al., 2015
	Healthy river	Adini et al., 2017; Pol, 2020; Jacinto et al., 2020
	Evacuation shelters	Cajucum et al., 2019; Xie et al., 2017; Saja et al., 2018
	Proximity to the river	Fuller et al., 2019; Chen et al., 2020;
	Solid waste facility	Ikhlayel & Nguyen, (2017). Nuchcha & Chanathip, 2019; Lamond et al., 2012
	Drainage system	Kourtis & Tsihrintzis, (2021). Nguyen et al., 2019, Mensah & Ahadzie, 2020; Yan et al., 2020; Manawi et al., 2020; Efiog & Uzoezie, 2017; Zheng et al., 2016; Goudie, 1981; Slamaker, 2000; Liu, 2016
	Elevation	Eze, 2008; Offiong & Eni, 2008; Abil et al., 2019; Singh et al., 2021
	Employment	Hanazaki et al., 2013; Goulden et al. 2013; Kwazu et al., 2021; Speranza et al., 2014; Quandt, 2018
Economic	Income	UNDRR, 2015
	Local industries	Sempier et al., 2010; Saja et al., 2019
	Agricultural production	Ansah et al., 2019; Raheem, 2018
	Financial capacity	McKnight & Rucci, 2020
	Early warning systems	Baudoin et al., 2014; Gladfelter, 2018; Henriksen et al., 2018; Sufri et al., 2020
	Flood risk communication	Ink, 2006; Rohrmann; 2000; Khalili, 2015; Bene et al., 2017; Henriksen et al., 2018; Salman & Li, 2018; O'Sullivan et al., 2012; Alshehri, 2015; Adger, 2005; Saja et al., 2018; Woolf et al., 2016.
Institutional	Budget for DRM	Adger, (2000). Béné et al., 2017; Butler and Walker, 2016; Cutter et al., 2014; Schelfaut et al., 2011; Adini et al., 2017; Rahman et al., 2016; Khalili et al., 2015a; Tanner et al., 2014; Jacinto et al., 2020; Dale et al., 2016.
	Multisectoral participation	Bene et al. 2017; Rahman et al., 2016; Tanner et al., 2014; Tiller et al., 2021; Jacinto et al., 2020; Agogo et al., 2019; Khangale et al., 2020
	Training/seminar	Berkes, 2007; Obrist et al., 2010, UNDRR, 2015
	Health insurance	Sharifi, 2016; Joerin, 2014, Saja et al., 2018; Cutter et al., 2014; Khalili et al., 2015; Jacinto et al., 2020; Copeland et al., 2020
Social-cultural support system	Flood-resilient housing	Fayazi & Lizarralde, 2013
	Financial assistance	Lovell and Le Masson, 2014; Saja et al. 2018; Chakraborty et al., 2005; Kwok, 2016; Saja et al., 2018; Ainuddin et al., 2015
	Community linkages	Paton et al. 2001; Wilkin et al., 2019; Saja et al., 2018; Cox & Hamlen, 2015
	Spirituality	Oxfam, 2005; Masten, 2008; Alshehri, 2015; Qasim et al., 2016; Saja et al., 2018

Other Indicators

In this study, a meticulous selection process was employed, narrowing down the initially considered 64 indicators to a set of 24. These specific indicators were chosen based on the rigorous evaluation criteria established through expert consensus, utilizing the FDM. It is noteworthy that all selected items surpassed the threshold (d) of 0.2, affirming their expert-approved status (Chen and Lin, 2002). Importantly, the expert agreement percentage for each of the chosen indicators exceeded an impressive 75%, attesting to the robust consensus among the experts involved in the study. Furthermore, all defuzzification values for these items consistently surpassed the critical value of 50%, reinforcing the reliability and consensus-driven nature of the selected indicators. This careful validation process enhance the credibility and relevance of the indicators included in the study. Meanwhile, the rejected 40 indicators and their FDM results are presented in **Table 4**.

Table 4. Other Indicators (rejected by experts)

No	Characteristics/ Indicators	Condition of Triangular Fuzzy numbers		Condition of Defuzzification process	Expert Consensus
		Threshold value, d	Percentage of Expert consensus	Fuzzy Score	
1	River basin management	0.211	81.25%	0.783	Rejected
2	Protected areas	0.216	75.00%	0.819	Rejected
3	River channels	0.220	81.25%	0.783	Rejected
4	Urban land expansion	0.191	68.80%	0.758	Rejected
5	Reduction rate of arable land	0.201	43.80%	0.771	Rejected
6	Maintained land cover	0.209	37.50%	0.756	Rejected
7	Water storage reservoir	0.218	81.25%	0.802	Rejected
8	Availability of resources and basic social services	0.243	47.75%	0.715	Rejected
9	Number of the hotel industry	0.244	47.75%	0.546	Rejected
10	Search and rescue team to flooded community	0.215	81.25%	0.790	Rejected
11	Functional Incident command center	0.222	75.00%	0.802	Rejected
12	Rescue operation center	0.206	81.25%	0.815	Rejected
13	Functional warehouse	0.222	75.00%	0.802	Rejected
14	Disaster preparedness plan	0.214	75.00%	0.813	Rejected
15	LGU extension programs	0.202	81.25%	0.808	Rejected
16	LGU infrastructure projects	0.206	81.25%	0.825	Rejected
17	Disaster risks integration	0.229	87.50%	0.779	Rejected
18	Access and exchange risk-related information	0.220	81.25%	0.813	Rejected
19	Continue critical functions	0.219	81.25%	0.779	Rejected
20	Coordinated rescue and evacuation system	0.211	81.25%	0.790	Rejected
21	Sufficient lead time for rescue and evacuation work	0.205	81.25%	0.802	Rejected
22	Sufficient capacity to evacuate from flooding	0.229	81.25%	0.779	Rejected
23	Learning from other cities	0.244	43.75%	0.717	Rejected
24	Zoning and structural design standards	0.205	81.25%	0.802	Rejected
25	Availability of adaptation regulations	0.251	12.50%	0.771	Rejected

Table 4. (continuation)

No	Characteristics/ Indicators	Condition of Triangular Fuzzy numbers		Condition of Defuzzification process	Expert Consensus
		Threshold value, d	Percentage of Expert consensus	Fuzzy Score	
26	Regulation of Urban expansion control	0.218	75.00%	0.796	Rejected
27	Technology for DRM	0.215	75.00%	0.777	Rejected
28	Available committee of flood risk-related stakeholders	0.219	25.00%	0.779	Rejected
29	Protection to IP communities	0.247	56.25%	0.679	Rejected
30	Informal coordination within the community	0.230	43.75%	0.760	Rejected
31	Respect to rights of religion	0.203	43.75%	0.760	Rejected
32	Presence of diverse religious groups	0.246	43.75%	0.702	Rejected
33	Participation of various religious groups in DRRM	0.195	56.25%	0.769	Rejected
34	Unity between the church and government	0.278	31.25%	0.633	Rejected
35	Available physical fitness facilities	0.255	25.00%	0.727	Rejected
36	Available sports and development	0.209	56.25%	0.733	Rejected
37	Wellness programs	0.257	81.25%	0.798	Rejected
38	Access to community gatherings	0.214	31.25%	0.773	Rejected
39	LGU-recognized IP groups	0.217	75.00%	0.779	Rejected
40	Capacity and willingness to retrofit or relocate	0.215	37.50%	0.773	Rejected

Measuring social-ecological system resilience to flooding is a complex task that involves considering a wide range of indicators. While each of the indicators plays a crucial role in understanding and addressing vulnerabilities to flooding, there might be various reasons why some experts may not prioritize them equally. One challenge lies in the availability and standardization of data for these indicators. Some areas may lack comprehensive and reliable data, making it difficult for the experts to use certain indicators consistently across different regions. Another thing is that resilience is context-specific, and the importance of indicators can vary based on the local context. Experts may prioritize certain indicators based on the unique characteristics and needs of a particular area, leading to variations in the emphasis. Also, many indicators are interlinked, and the relationships between them can be complex. For example, river basin management is closely tied to protected

areas and urban land expansion. In focusing with one indicator may indirectly address. Additionally, experts may face constraints in terms of policy priorities and resource allocation. Limited resources may force them to prioritize certain indicators over others based on immediate concerns or overarching policy goals. Moreover, experts working in disaster risk reduction and resilience may have specific expertise in certain areas, influencing the emphasis on particular indicators. The interdisciplinary nature of resilience requires collaboration among experts with diverse backgrounds, and this may impact the holistic consideration of all indicators. Lastly, prioritizing certain indicators might be influenced by the ease of communication and stakeholder engagement. Experts may choose indicators that are more easily understood by the public, leading to a better community involvement and support for resilience initiatives.

Expert's Demographic Information

Table 5 displays demographic data for 16 experts in indicator identification via the FDM and seven experts in ranking indicators through the AHP. While the FDM requires a minimum of 10 experts, no specific minimum is stipulated for AHP, as its reliability depends on responses from individuals knowledgeable about the subject, ensuring representativeness even with a smaller sample size (Adler & Ziglio, 1996).

Table 5. Demographic Profile of Experts undergone FDM and AHP

VARIABLES	FREQUENCY	
	Fuzzy Delphi Method	Analytical Hierarchy Process
SEX		
Male	7	4
Female	9	3
Total	16	7
AGE BRACKET		
20-30 years old	11	3
31-40 years old	2	4
41 years old and above	3	0
Total	16	7
EDUCATION LEVEL		
Vocational	2	0
Bachelor's degree	10	2
Master's degree	3	4
Doctoral degree	1	1
Total	16	7
YEARS IN SERVICE		
1-5 years	11	3
6-10 years	3	2
11-15 years	1	0
16-20 years	0	1
21 years and above	1	1
Total	16	7
FIELD OF EXPERTISE		
Rescuer/Responder	3	0
DRRM Staff/Trainer	6	0
DRRM Faculty	3	3
DRRM Head of Office	3	3
DRRM EMS Provider	1	1
Total	16	7

The data indicate a predominance of women among experts conducting the fuzzy Delphi Method. Most practitioners who had undergone FDM were aged 20-30, while those employing the Analytical Hierarchy Process were predominantly aged 31-40. Following the recommendation of Gambatese et al. (2008) for relevant expertise, the majority held bachelor's degrees and had 1-5 years of experience in disaster risk management. One expert who had undergone AHP had 16-20 years in service, and another had 21 years or more. All experts belonged to similar fields in disaster risk reduction and management, holding roles such as responders, trainers, EMS providers, staff, head of the office, or faculty.

Social Ecological System (SES) Resilience Indicators to Flooding and Their Level of Significance

Ecological Subsystem

Natural component. All items in **Table 6** achieved expert approval, meeting a consensus threshold (d) of 0.2, with expert agreement surpassing 75% and defuzzification values exceeding the cut value of 0.5, that is based on the standard in the study of Chen et al. (2020). The results of the AHP demonstrated a consistency ratio of 0.08, affirming indicator consistency according to Saaty (2005). Typically, a consistency ratio below a certain threshold (often 0.1 or 0.1) indicates an acceptable level of consistency. If the consistency ratio exceeds this threshold, it suggests that the judgments are

inconsistent, and the decision-maker may need to revise their judgments.

AHP criteria weights revealed the order of importance, with wetland presence and management ranking in the top spot with a value of 0.270, green spaces, watershed management, and a healthy river system with values of 0.252, 0.244, and 0.233, respectively. Wetlands, often overlooked, play a pivotal role in flood resilience due to their innate capacity for water absorption during heavy precipitation. This intrinsic quality makes them vital components of effective flood mitigation strategies. Hence, prioritizing the management of wetlands is paramount to sustain their flood mitigation capacity and ensure the protection of vulnerable areas from inundation.

Table 6. Indicators for Natural Component Showing Threshold Value, Percent of Expert Consensus, Fuzzy Score, Criteria Weight, and Rank

NO	INDICATORS	THRESHOLD VALUE, d	PERCENTAGE OF EXPERT CONSENSUS	FUZZY SCORE	EXPERT CONSENSUS	WEIGHT	RANK
1	Watershed management	0.173	87.50%	0.825	Accepted	0.244	3
2	Green spaces	0.182	81.25%	0.815	Accepted	0.252	2
3	Presence of wetland	0.190	81.25%	0.813	Accepted	0.270	1
4	Healthy river	0.149	87.50%	0.860	Accepted	0.233	4
C.R.: 0.06 (consistent if C.R. <10%)							

Geophysical features and physical infrastructures. **Table 7** demonstrate expert approval, exceeding a 75% agreement threshold (d) and defuzzification values above the cut value of 0.5 based on Chen et al. (2020). The drainage system emerges as the top priority with a criteria weight of 0.363, underscoring its critical role in determining flood resilience, particularly in rapidly developing urban areas like Tagum City. Smith & Johnson (2014) highlighted the importance of integrated urban water management strategies, including well-maintained drainage systems, to enhance flood resilience in a rapidly

developing urban areas. The efficient removal of excess water through well-designed drainage can significantly mitigate the impact of heavy rainfall and reduce the likelihood of flooding. Various crucial indicators influencing flood resilience include elevation, evacuation shelter availability, solid waste facility management, and river proximity. These factors collectively contribute to comprehensive urban planning, emphasizing the importance of addressing multiple aspects for effective flood risk reduction and resilience in rapidly developing areas.

Table 7. Indicators for Geophysical Features and Physical Infrastructure Showing Threshold Value, Percent of Expert Consensus, Fuzzy Score, Criteria Weight, and Rank

NO	INDICATORS	THRESHOLD VALUE, d	PERCENTAGE OF EXPERT CONSENSUS	FUZZY SCORE	EXPERT CONSENSUS	WEIGHT	RANK
1	Evacuation shelter	0.186	87.50%	0.821	Accepted	0.166	3
2	Proximity to river	0.165	81.25%	0.827	Accepted	0.119	5
3	Solid waste facility	0.108	100.00%	0.875	Accepted	0.125	4
4	Drainage system	0.179	87.50%	0.838	Accepted	0.363	1
5	Elevation	0.182	87.50%	0.850	Accepted	0.227	2
C.R.: 0.05 (consistent if C.R. <10%)							

Social Subsystem

Economic component. **Table 8** highlights experts' prioritization of the employment rate as the foremost factor in attaining resilience. Recognized for driving economic growth and bolstering individuals' self-worth, a higher employment rate correlates strongly with increased production, reinforcing food security and economic development. The study also underscores income as significant economic indicator, followed by agricultural production, financial capacity, and local industries—collectively contributing to resilient economic systems. These indicators enable communities to persist, adapt, and recover independently amidst recurrent flood events, emphasizing the importance of assessing multiple indicators for building economic resilience in flood-prone areas.

Table 8. Indicators for Economic components Showing Threshold Value, Percent of Expert Consensus, Fuzzy Score, Criteria Weight, and Rank

NO	INDICATORS	THRESHOLD VALUE, d	PERCENTAGE OF EXPERT CONSENSUS	FUZZY SCORE	EXPERT CONSENSUS	WEIGHT	RANK
1	Employment rate	0.140	87.50%	0.842	Accepted	0.277	1
2	Income	0.139	93.75%	0.850	Accepted	0.229	2
3	Local industries	0.149	87.50%	0.860	Accepted	0.136	5
4	Agricultural production	0.182	87.50%	0.815	Accepted	0.200	3
5	Financial capability	0.149	87.50%	0.840	Accepted	0.159	4
C.R.: 0.04 (consistent if C.R. <10%)							

Institutional component. The expert survey highlights the critical significance of budget allocation for disaster risk management (DRM), assigning it a weight of 0.309. It aligns with United Nations Office for Disaster Risk Reduction (2019) recommendation of investing 5% of estimated income in disaster risk reduction to mitigate losses. The allocated budget facilitates proactive measures like pre-disaster preparedness, training, life-saving equipment acquisition, and disaster risk reduction financing. This approach supports crucial initiatives such as

early warning systems, land-use planning, building codes, and infrastructure development, collectively reducing vulnerability and exposure to hazards. The survey emphasizes the importance of early warning systems (0.199), multisectoral participation (0.173), community disaster resilience training (0.163), and flood risk communication (0.155) as critical contributors to community resilience, underscoring the essential roles of strong local governance and community support in effective disaster risk management (**Table 9**).

Table 9. Indicators for Institutional Component Showing Threshold Value, Percent of Expert Consensus, Fuzzy Score, Criteria Weight, and Rank

NO	INDICATORS	THRESHOLD VALUE, d	PERCENTAGE OF EXPERT CONSENSUS	FUZZY SCORE	EXPERT CONSENSUS	WEIGHT	RANK
1	Early warning system	0.185	93.75%	0.835	Accepted	0.199	2
2	Flood risk Communication	0.126	93.75%	0.869	Accepted	0.155	5
3	Budget for DRM	0.099	81.25%	0.842	Accepted	0.309	1
4	Multisectoral participation	0.123	93.75%	0.863	Accepted	0.173	3
5	Training/ seminar	0.170	87.50%	0.833	Accepted	0.163	4
C.R.: 0.04 (consistent if C.R. <10%)							

Social-cultural support system. In **Table 10**, the study highlights community linkage as the most crucial flood resilience indicator, weighted at 0.323. It fosters connections, fortifies community bonds, and expands collaboration networks during flooding. Financial assistance, the second vital indicator (0.213), is essential for identifying and supporting affected families, relying on community linkages ingrained in Filipino culture. Ranked third values of 0.184, flood-resilient housing tackles exposure and sensitivity, crucial for community resilience. Spirituality with a generated value of 0.147 ranked fourth and this enhances emotional well-being, aiding coping during and after floods. At fifth spot is the health insurance with a value of 0.133 thereby proving that this component is pivotal for managing unforeseen medical expenses post-flooding..

Table 10. Indicators for Social-Cultural Support System Showing Threshold Value, Percent of Expert Consensus, Fuzzy Score, Criteria Weight, and Rank

NO	INDICATORS	THRESHOLD VALUE, d	PERCENTAGE OF EXPERT CONSENSUS	FUZZY SCORE	EXPERT CONSENSUS	WEIGHT	RANK
1	Health insurance	0.073	93.75%	0.900	Accepted	0.133	5
2	Flood-resilient housing	0.183	81.25%	0.798	Accepted	0.184	3
3	Financial assistance	0.118	93.75%	0.856	Accepted	0.213	2
4	Community linkages	0.198	75.00%	0.785	Accepted	0.323	1
5	Spirituality	0.157	81.25%	0.798	Accepted	0.147	4
C.R.: 0.05 (consistent if C.R. <10%)							

Figure 4 depicts twenty-four indicators, categorized under ecological and social subsystems. The natural component includes watershed management (WTR), green spaces (GRN), wetlands (WLD), and a healthy river system (HRS). Geophysical features and physical infrastructure comprise evacuation shelters (EVC), river proximity (RIV), solid waste facilities (WAS), drainage systems (DRN), and elevation (ELV). On the other hand, the economic indicators include employment rate (EMP), income (INC), local industries (IND), agricultural production (AGR), and financial capabilities (FIN).

Furthermore, to effectively address flooding resilience, it is essential to enhance both institutional frameworks and social-cultural support systems. The institutional component encompasses early warning systems (EWS) to provide timely alerts and preparedness measures, flood risk communication (COM) strategies to disseminate information effectively, allocation of budget for DRRM (BDT) to fund necessary initiatives, promotion of multisectoral participation (PAR) for comprehensive engagement, and provision of training (TRN) to build capacity and expertise within communities.

Concurrently, the social-cultural support component plays a crucial role in fostering resilience. This component encompasses spirituality (SPT) to provide emotional and psychological support, financial assistance (AST) to aid in recovery efforts, establishment of community linkages (LNK) for collaborative efforts, implementation of flood-resilient housing (HOU) measures to mitigate structural risks, and provision of health insurance (INS) to ensure access to healthcare in the aftermath of disasters.

Overall, the collective integration of various indicators serves to fortify social-ecological systems against the impacts of flooding, effectively mitigating both social and ecological consequences. Through the preservation and restoration of natural indicators such as wetlands and vegetation, alongside the development of resilient infrastructure and effective governance mechanisms, communities can

substantially reduce vulnerabilities to flooding, as evidenced in studies by Brander (2014). Economic indicators, including insurance coverage and investments in flood resilience measures, play a pivotal role in enhancing communities' capacity to prepare for and recover from flood events, thereby minimizing social and ecological vulnerabilities (Kunreuther, 2013). Furthermore, institutional indicators, such as policies and regulations governing flood risk management, and social-cultural support systems characterized by community cohesion and mutual aid networks, are crucial for facilitating collective responses and adaptation strategies, as highlighted by Tierney (2014). Through the synergistic implementation of these indicators, communities can bolster their resilience, diminish flood-related damages, and sustainably manage flood risks, ultimately safeguarding both human well-being and ecological integrity.

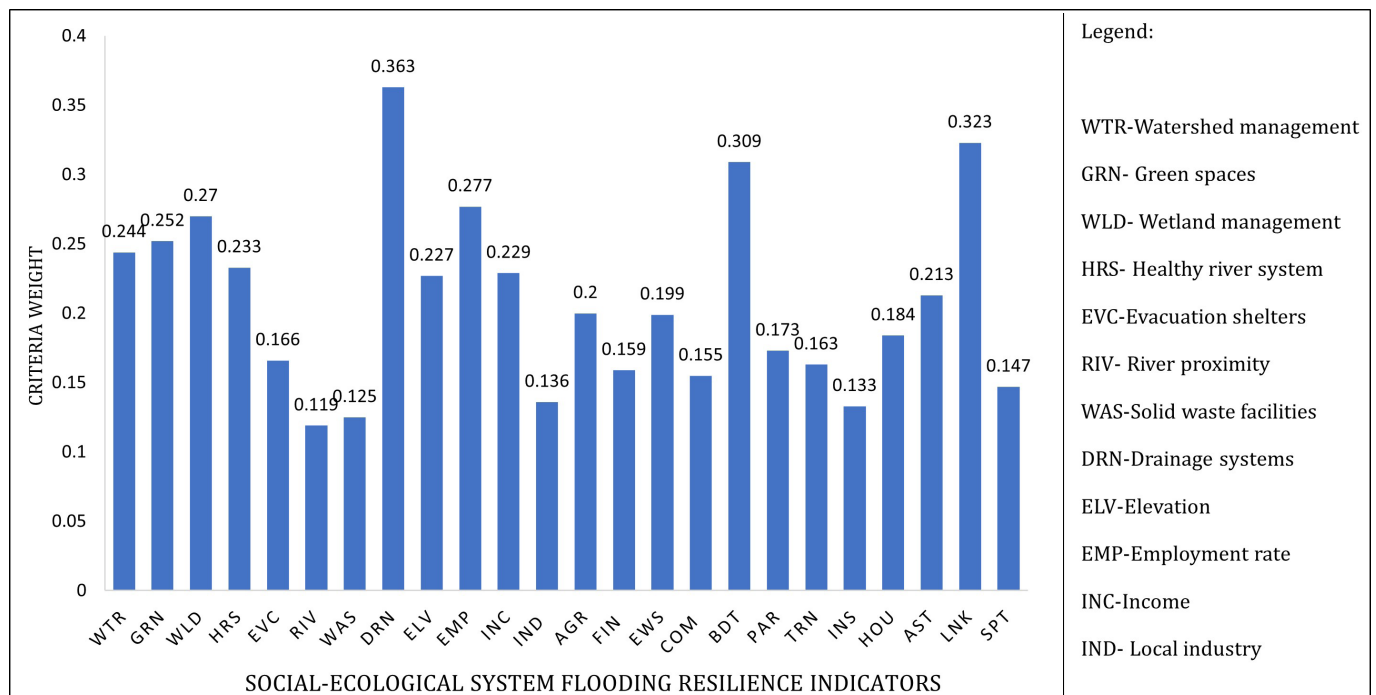


Figure 4. Social-Ecological System Resilience Indicators of Flooding

Conclusion and Recommendations

Recognizing the escalating impact of climate change on the frequency and intensity of extreme weather events globally, it is imperative to comprehend and fortify social-ecological system flood resilience. This necessitates a comprehensive framework that encompasses ecological, geophysical, economic, institutional, and social-cultural indicators applicable across diverse regions. Under the ecological priorities encompass wetland management, green spaces, and the promotion of a healthy river

system. Geophysical and physical infrastructure indicators focus on drainage, elevation, evacuation shelters, and river proximity. On the other hand, the economic factors encompass aspects such as employment opportunities, income levels, and support for local industries. Meanwhile, institutional priorities encompass the allocation of resources for disaster management, the implementation of early warning systems, and community preparedness training. Social-cultural support systems emphasize community linkage, financial aid, resilient housing, spirituality, and health insurance.

Moreover, assessing resilience to flooding in social-ecological systems involves various indicators, with experts potentially choosing them differently due to challenges such as data availability, context specificity, and interconnectivity. Local context, data reliability, and resource constraints influence prioritization, while the interdisciplinary nature of resilience necessitates collaboration. Additionally, experts may emphasize indicators based on communication ease and stakeholder engagement for better community support in resilience initiatives.

The study's insights provide a clear understanding of crucial indicators for flood resilience, guiding effective resource allocation. Recommendations include fostering diverse expert participation, capacity building, ecological preservation, infrastructure improvement, economic stability, adequate disaster risk management budgets, and collaboration. Addressing these multifaceted aspects enables stakeholders to develop comprehensive, sustainable flood management strategies, fostering resilient communities capable of mitigating the impacts of flooding on individuals, infrastructure, and the environment. The study underscores the interdisciplinary nature of resilience, emphasizing the importance of collaborative efforts, with experts and stakeholders from various regions contributing their unique perspectives and expertise.

Consent

Following international and college standards, the authors have obtained and securely preserved written consent from expert survey participants.

Ethical Approval

Approval was sought from the City Mayor's Office to conduct a study in Tagum City. The respondents expressed their agreement to participate, and the informed consent forms were duly approved by them.

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Author Contribution

First author led research tasks, manuscript preparation; second author provided mentorship. Both approved final manuscript. No competing

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Appendix 1. Informed Consent Form

INFORMATION SHEET

Introduction

I am _____, the principal investigator of the study titled "Development Of Science and Significance-Based Indicators for Social-Ecological System Flood Resilience". I am a faculty from _____. I would like to invite you to take part in this research study. Before you decide, it is important that you understand why the research is being done and what it would involve for you. Please take time to read this information; and discuss it with others if you wish. If there is anything that is not clear, or if you would like more information, please ask me.

Purpose of the Research

The purpose of this research is to develop indicators for the social-ecological system (SES) resilience to flooding dynamics in Tagum City, Davao del Norte, Philippines

Type of Research

This research is a quantitative descriptive study that involves survey to experts, barangay officials, direct ground observation and mapping. This type of study that will be conducted for a period of 1-2 months for data gathering and analysis. Also, a qualitative information will be asked to supplement the quantitative data.

Participant Selection

You are asked to take part in this study because you are seen as qualified based on my respondents' criteria. The study will involve 10-20 participants who are legal age of any gender; working in the disaster risk reduction and management field; teaching disaster risk reduction and management as a member of the faculty; and; researcher, expert, or consultant in disaster risk reduction and management. (For Fuzzy Delphi Method and Analytical Hierarchy Process)

Voluntary Participation

Taking part in this research project is voluntary. If you refuse to participate, it will not in any way cause a negative effect on your present job.

Procedures

As a participant, you will be asked to do/provide the following:

- Your personal information such as name, age, sex, education, length of service and expertise
- Your personal thoughts about the topic in the questionnaire
- The location where research activities/procedures will take place
- Description of all research interactions
- Data collection procedures (questionnaire surveys, interviews)

Participation in the surveys/interview will take about 20-30 minutes to complete.

Risks

This study may involve some risks that can be anticipated or that are possible. Specifically, the procedure that involves asking in survey or interview questions can cause possible harm or risk in the form of mild anxiety (likelihood is seldom and severity is insignificant), and uncertainty to provide answers (likely and severity is insignificant).

The researcher will try to minimize these risks by giving proper orientation to the participants about the objectives and significance of the study and let them feel free and comfortable in answering surveys and questions; proper coordination with the LGU, barangay and purok and ask assistance/guidance from the barangay captain and purok president (for a possible physical harm and other health related risks);

and always work with ethical standards anywhere and all the time. Additionally, to minimize/mitigate the risks, you do not have to answer any questions you do not want to answer or questions that you are not comfortable to answer.

Benefits

You may not receive any personal benefits from participating in this study. However, others may benefit from the knowledge gained from this study.

Reimbursements

As a participant, you will not be given any payment for being a part of the study. However, expenses incurred as a result of your participation will be reimbursed. In such a case, you will be reimbursed for a back and forth travel fare.

Compensation

You will receive no compensation for your participation in the study.

Right to Refuse or Withdraw

Your participation in this study is voluntary and you may cancel this consent at any time and without any reason. If you do so, your participation in the study will end and the study staff will stop collecting information from you.

If you withdraw from the study I will destroy all data collected from you.

Confidentiality

Any personal information that you will provide including the data that will be obtained as part of your involvement in the study will be kept private and confidential. Written records will be kept in a cabinet with lock and can be accessed only by the principal investigator and/or the research team which includes my thesis adviser. Your identity will also be anonymized and coded and only the persons mentioned above will have access to the codes. Collected data from participants shall be kept and stored as long as it is being used up for research purposes. The data will be stored for at least five years after final publication then destroy them.

Collected raw data will be disposed once it is no longer usable and once the research study is completed, presented and published. Hard copies will be disposed of through shredding or cutting them into pieces, while soft copies will simply be deleted in folders and files.

If you agree to your data being used in future research, your consent form will be held until the data have been depleted or destroyed.

Sharing the Results

You will be informed of the results through sending you a copy of it 6 months after the collection of data.

In addition, the results of this study could be published in an article or be presented in a conference, but would not include any information that would let others know who you are without your permission.

I may use or share your research information for future research studies. If I share your information with other researchers, it will be de-identified, which means that it will not contain your name or other information that can directly identify you. This research may be similar to this study or completely different. I will not ask for your additional informed consent for these studies.

Research Ethics Approval

This study observes and upholds the 2022 National Ethical Guidelines for Research Involving Human Participants.

CERTIFICATE OF CONSENT

I, _____, agree to participate in the research project titled "Development of Science and Significance-Based Indicators For Social-Ecological System Flood Resilience, conducted by _____ who has discussed the research project with me.

I have received, read and kept a copy of the information letter/plain language statement. I have had the opportunity to ask questions about this research and I have received satisfactory answers. I understand the general purposes, risks and methods of this research.

I consent to participate in the research project and the following has been explained to me:

- _____ the research may not be of direct benefit to me
- _____ my participation is completely voluntary
- _____ my right to withdraw from the study at any time without any implications to me
- _____ the risks including any possible inconvenience, discomfort or harm as a
- _____ consequence of my participation in the research project
- _____ the steps that have been taken to minimize/mitigate any possible risks
- _____ what I am expected and required to do
- _____ whom I should contact for any complaints with the research or the conduct of the research
- _____ I am able to request a copy of the research findings and reports
- _____ security and confidentiality of my personal information.

Print Name of Participant: _____

Signature of Participant: _____

Date [MM/DD/YYYY]: _____

If Illiterate

I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Print name of witness _____

Signature of witness _____

Date: [MM/DD/YYYY] _____

Thumb print of participant:

STATEMENT BY THE RESEARCHER OR PERSON TAKING CONSENT

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands when and where to use the data that will be gathered in the discussions.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this Informed Consent Form has been provided to the participant.

Print Name of Researcher or person taking the consent

Signature of Researcher or person taking the consent

Date: <MM/DD/YYYY>