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Analyzing Flooding Dynamics and Resilience of a Social-Ecological System

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ABSTRACT

Amid escalating climate change and other factors, communities in vulnerable areas like Tagum City, Davao del Norte, Philippines, face increasing risks of severe flooding, threatening their safety, livelihoods, and well-being. This highlights the urgent need for comprehensive analysis of flood dynamics and community resilience within a social-ecological system framework, addressing the critical gap in local-level research to inform effective flood risk management strategies. This study employed a combined systematic literature review, Fuzzy Delphi Method, and Analytical Hierarchy Process to develop a Flood Resilience Index (FRI) and resilience map using QGIS. The findings underscore that a significant portion of Tagum City exhibits medium resilience to flooding, with an FRI of 3.221. Notably, several towns identified as medium resilient, including Bincungan (2.801), Pandapan (2.661), Busaon (2.910), and Liboganon (2.660), face heightened vulnerability due to the potential for high flood water levels, exceeding critical thresholds, with a peak level of 11 meters for a projected 5-year return period. The study highlights the interconnectedness of social-ecological components, emphasizing that overall system resilience depends on its weakest elements. To enhance resilience in flood-vulnerable areas, it is crucial to strengthen economic, institutional, and socio-cultural support systems through targeted activities, policies and programs. This research provides crucial insights into the intricate relationship between flooding and resilience, serving as a foundation for informed decision-making and proactive measures to mitigate flood risks, enhance community well-being, and advance climate action for a more resilient and sustainable Tagum City and similar environments.

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1. Introduction

Social-ecological systems are intricate and adaptive, necessitating a deep comprehension of their dynamics and characteristics (Lucas, 2004). These systems are composed of interconnected human and biophysical subsystems, interacting in a mutually influential feedback loop (Berkes, 2011). The framework delineates two subsystems: social and ecological, wherein significant structures and processes interact, forming both positive and negative relationships that impact the overall system (Carpenter, 1999). The social subsystem encompasses economic, political, and socio-cultural support systems, shaping societal dynamics within a given locale. Conversely, the ecological subsystem encompasses natural features, geophysical elements, and physical infrastructure that collectively constitute the environment, influencing and being influenced by the entire system (Gunderson, 2000). The ecosystem services provided by this system, including provisioning, regulating, cultural, and supporting services, are integral to meeting human needs and sustaining the system's viability. Human activities, such as those contributing to stresses like flooding, can affect the ecological system (Di Baldassarre, 2001), highlighting the interconnectivity between the two subsystems and the importance of understanding data to develop resilience indices and indicators.
In Tagum City, Davao del Norte, flooding poses significant risks to social and economic activities, reflecting the vulnerability of the social-ecological system in the area (Holling, 1973; Walker et al.,

2004). Various factors contribute to this vulnerability, including climate change, rapid urbanization, land use changes, and urban infrastructure expansion (Holling, 2001). Tagum City's geographical location, situated in a sedimentary basin surrounded by rivers and a gulf, exposes it to frequent floods during adverse weather conditions.

Approximately 26.54% of the city's land area is flood-prone, with concentrated human activities exacerbating the vulnerability. Human activities in the upstream catchments have contributed to increased flood risks downstream, despite local government efforts to implement flood control measures (IRBMDMP, 2015). Coastal and riverine communities bear the brunt of flooding, aggravated by high tides, exacerbating the inundation of low-lying areas. Despite efforts to mitigate flooding, persistent challenges remain, necessitating further scientific research to understand underlying causes and improve flood management strategies.

While there is broad consensus on the concept of resilience, there remains a lack of agreement on measurement methods, particularly in social-ecological systems (Sim et al. 2018). Past research has focused on vulnerability rather than resilience outcomes, indicating a need to bridge this gap (Wamsler, 2016; Bottazzi et al., 2018). This study aims to address this gap by developing flood resilience indicators and constructing a Flood Resilience Index (FRI) specific to Tagum City. By analyzing the social-ecological system resilience of flood-prone areas, the study seeks to provide recommendations to enhance community resilience against flooding threats. Improving our understanding of human-nature interactions at the community level is crucial for bolstering local governance and adaptive capacity in the face of environmental challenges (Hunter, 2001).

2. Methodology

2.1 Description of Study Area

Tagum City is located in the heart of the Davao del Norte province in the Philippines. It is situated between 7° 13′ 38′ and 7° 32′ 23′ north latitude and 125° 43′ 30′ and 125° 53′ 13′east longitude. The city shares borders with the municipalities of New Corella to the north, Asuncion to the northwest, and Mawab to the northeast. In the west, it is bordered by the municipalities of Dujali and Carmen, while in the south, it is bordered by the municipality of Maco in the province of Davao de Oro (Figure 1).

The city is approximately 54 kilometers north of Davao City, 111 kilometers west of Mati City, and 210 kilometers south of Butuan City. It serves as a convergence point for the development and processing centers of agricultural raw materials into finished products. Tagum City is composed of 23 towns and covers a total land area of 19,580 hectares. The study only covers fifteen (15) flood-prone and flood-affected towns that include Apokon, Bincungan, Busaon, Canocotan, Cuambogan, Liboganon, Madaum, Magdum, Magugpo East, Mankilam, New Balamban, Pagsabangan, Pandapan, San Isidro, and San Miguel.

The geographic location, elevation, and presence of significant rivers like the Tagum-Liboganon River (spans on the left side) and the Hijo River (on the right side) contribute to flooding. The city's overall land area with a high susceptibility to flooding is 5,797 hectares. It is expected to reach a depth higher than or equal to one (1) meter and a likelihood of occurrence of 1-3 years. On the other hand, 1,559 hectares, or equivalent to 7.96%, have moderate susceptibility. In comparison, 5,296 hectares, or 27.05% of the total land area, have low susceptibility with an expected flood depth of less than one (1) meter (Comprehensive Land Use Plan, 2011 – 2025)

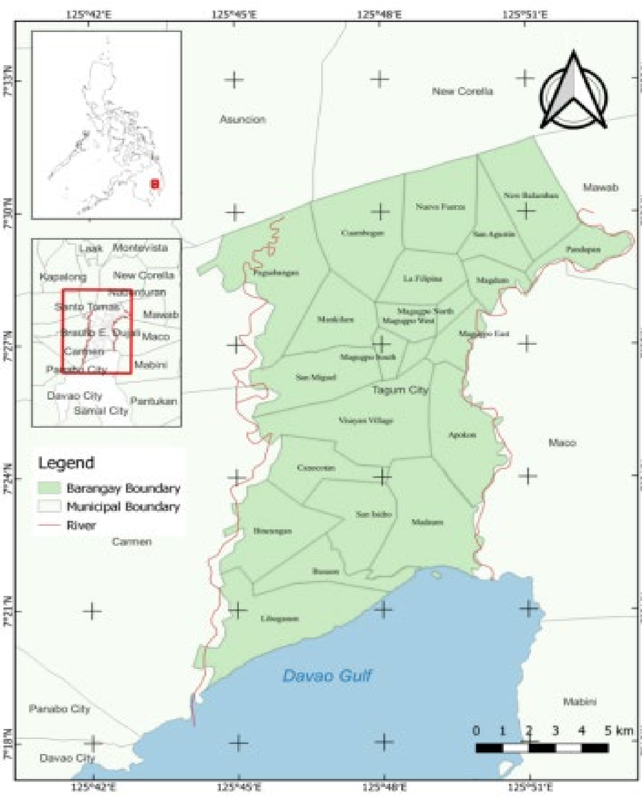

Figure 1. Map of Tagum City, Davao del Norte, highlighting the specific towns where the study was conducted, created using shapefile data sourced from Global Administrative Areas (GADM, (2015)

2.2. Data Collection

2.2.1. Process of Collecting Data

The research methodology employed in this study for identifying, selecting, and finalizing indicators of Social-Ecological System (SES) resilience builds upon the foundational work of Pelone and Sanchez (2024). They conducted systematic literature review across reputable academic journals to identify relevant indicators. Complementary data from Local Government Units (LGUs), including the Comprehensive Land Use Plan (CLUP) and Comprehensive Development Plan (CDP), enriched the dataset with real-world insights.

The Fuzzy Delphi Method (FDM) engaged experts to evaluate and rate indicators, ensuring their relevance. Subsequently, the analytical hierarchy process (AHP) facilitated the prioritization and finalization of indicators. Formal approval was obtained from the mayor's office before initiating field data collection, involving consent-seeking from town leaders. Surveys and Key Informant Interviews (KII) gathered data from town officials, encompassing social, ecological, economic, institutional, and cultural aspects. Additionally, flood inundation data from UN-Habitat for Humanity was incorporated, enhancing the analysis of flood resilience and environmental factors. This comprehensive methodology aims to provide valuable insights for enhancing flood resilience strategies and interventions, drawing from empirical evidence and expert judgment.

2.2.2. Selection of Respondents

The study recruited town officials including the Leader, Secretary, and Health Workers, chosen for their access to relevant data and familiarity with SES resilience indicators. Selection criteria ensured diversity across demographics while participants were required to be of legal age and in good health. Measures were taken to prevent bias and discrimination, prioritizing inclusivity and obtaining informed consent from each participant.

2.2.3. Ethical Considerations

During the research process, stringent measures were implemented to ensure the privacy and confidentiality of participants. Informed consent forms were provided to each participant, emphasizing voluntary participation and the confidentiality of their data, with the option to decline participation. Any concerns raised were disclosed to relevant entities. Data collection and storage adhered to strict protocols, with participant identities anonymized in all reports and publications. The construction of a flood resilience index involved collecting and integrating various indices and indicators, selected based on prior research, expert input, and established frameworks. This ensured specificity, quantifiability, and relevance to assessing flood resilience within the social-ecological system.

2.3 Data Analysis

2.3.1. Flood Resilience Indicators

The study conducted by Pelone and Sanchez (2024) utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) technique, involving four stages: identification, screening, eligibility, and inclusion. Initially, 361 relevant publications were identified from electronic databases and secondary data from LGU Tagum City. After thorough examination of titles, abstracts, discussions, and conclusions, 184 publications and 114 indicators were considered pertinent. Eligibility of each publication was meticulously assessed, resulting in the inclusion of 105 studies and 24 indicators categorized into natural, geophysical features and physical infrastructure, economic, institutional, and social-cultural support system components (Table 1). The FDM was employed to refine indicator selection, while the AHP assigned weights to indicators based on their relative importance. Through these rigorous methodologies, the study developed a robust framework for assessing and enhancing social-ecological system resilience.

Table 1. Identified socio-ecological system (SES) flood resilience indicators from the study by Pelone & Sanchez (2024)

COMPONENT	INDICATORS	AUTHORS
Natural	Watershed management	Duffy et al. 2018; Sasaki et al. 2015; Davenport and 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
Geophysical features and physical infrastructure	Evacuation shelters	Cajucom et al.2019; Xie et al.2017; Saja et al.2018
	Proximity to river	Fuller et al.2019; Chen et al.2020;
	Solid waste facility	Ikhlayel and Nguyen, 2017; Nuchcha and Chanathip, 2019; Lamond et al.2012
	Drainage system	Kourtis and Tsihrintzis, 2021; Nguyen et al.2019, Mensah and Ahadzie, 2020; Yan et al. 2020; Manawi et al.2020; Efiong and Uzoezie, 2017; Zheng et al. 2016; Goudie, 1981; Slamaker, 2000; Liu, 2016
	Elevation	Eze, 2008; Offiong and Eni, 2008; Abil et al.2019; Singh et al.2021
Economic	Employment	Hanazaki et al.2013; Goulden et al.2013; Kwazu et al.2021; Speranza et al. 2014; Quandt, 2018
	Income	UNDRR, 2015
	Local industries	Sempier et al. 2010; Saja et al.2019
	Agricultural production	Ansah et al.2019; Raheem, 2018; Rao, 2019
	Financial capacity	McKnight and Rucci, 2020
Institutional	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 and Li, 2018; O'Sullivan et al.2012; Alshehri, 2015; Adger, 2005; Saja et al. 2018; Woolf et al. 2016.
	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.
	Multi-sectoral 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
Social-cultural support system	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
	Flood-resilient housing	Fayazi and Lizarralde, 2013
	Financial assistance	Lovell and Le Masson, 2014; 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 and Hamlen, 2015
	Spirituality	Oxfam, 2005; Masten, 2008; Alshehri, 2015; Qasim et al. 2016; Saja et al. 2018

2.3.2. GIS Mapping

The quantitative data of each of the indicators of the five subsystems namely: natural, geophysical features and physical infrastructure, economic, institutional, and social-cultural support system were converted to a data set and processed in the QGIS software for mapping. Consequently, the resilience index that came out in the study was presented in a relationship;

$$FRI_{total} = FRI_{natural} + FRI_{physical} + FRI_{economic} + FRI_{institutional} + FRI_{sociocultural}$$

The outcomes of the fuzzy Delphi method were examined seven days after all the data had been gathered. Data analysis for the results of the analytical hierarchy process was completed in 7 days. The results of the barangay survey were examined for 15 days. Additionally, the GIS mapping process took between 15 and 20 days.

3. Results and Discussion

3.1. SES Resilience Indicators and Their Level of Significance

The flood resilience assessment encompassed various components; each assigned weights based on expert evaluations. In Table 2, it is stated that all items in the subsystem received expert approval with a threshold value (d) of 0.2. The expert agreement percentage for all items is above 75%, and the defuzzification values for items are higher than the value of -cut = 0.5 (Chen and Lin, 2002). The general consistency ratio, obtained after performing the analytical hierarchy process should be less than 10% (Saaty, 2005), indicating consistency among the indicators. The importance of each indicator is determined by the AHP criteria weights assigned by experts.

Table 2. Indicators of the Five Components Showing Threshold Values, Percent of Expert Consensus, Fuzzy Scores, Criteria Weights, and Ranks

	COMPONENT	INDICATORS	THRESHOLD VALUE, d	PERCENTAGE OF EXPERT CONSENSUS	FUZZY SCORE	EXPERT CONSENSUS	WEIGHT	RANK
1	Natural	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		Managed wetland	0.190	81.25%	0.813	Accepted	0.270	1
4		Healthy river	0.149	87.50%	0.860	Accepted	0.233	4
						CR: 0.06		
1	Geophysical features and physical infrastructure	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
						CR: 0.05		
1	Economic	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
						CR: 0.04		
1	Institutional	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		Multi-sectoral participation	0.123	93.75%	0.863	Accepted	0.173	3
5		Training/seminar	0.170	87.50%	0.833	Accepted	0.163	4
						CR: 0.04		
1	Social-cultural support system	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
						CR: 0.05		

The results show natural components, such as wetlands, green spaces, watershed management, and healthy river systems, were deemed critical, with wetlands receiving the highest weight of 0.270, followed closely by green spaces at 0.252. Geophysical features and physical infrastructure, particularly the drainage system (0.363), were highlighted as pivotal for flood resilience in urban areas. In terms of the economic component, the employment rate (0.277) was prioritized due to its significant impact on economic development and food security. Among institutional factors, the budget for disaster risk management (DRM) was identified as paramount (weight: 0.309), emphasizing the importance of investing in DRM to enhance community well-being.

Social-cultural support systems, including community linkage (0.323) and financial assistance (0.213), were underscored for fostering collaboration and aiding vulnerable families during floods. Additionally, flood-resilient housing (0.184), spirituality (0.147), and health insurance (0.133) were recognized as essential contributors to community resilience. These findings underscore the multifaceted nature of flood resilience and provide a comprehensive framework for policymakers and stakeholders to prioritize interventions effectively.

3.2. Flood Resilience Index

The Flood Resilience Index (FRI) is a tool used to assess the flood resilience of a system based on the above definition and properties. The FRI incorporates a set of indicators that represent the different subsystems of the system being assessed, including natural, geophysical features and physical infrastructure, economic, institutional, and social-cultural support systems. The FRI is designed to provide a comprehensive assessment of the system's ability to tolerate and recover from flooding by considering both the physical and non-physical aspects of resilience. The FRI can be used to identify the strengths and weaknesses of a system and provide recommendations for improving its flood resilience. The following equations below show the key indicators considered for the natural, geophysical features and physical infrastructure, an economic, institutional, and social-cultural support system of the flood resilience index:

$$\text{FRI natural} = x_1\,(\text{WTR}) + x_2\,(\text{GRN}) + x_3\,(\text{WLD}) + x_4\,(\text{HRS})$$

Where;
WTR: watershed management; GRN: green spaces; WLD: well-managed wetlands, and RVS: proximity of river system

FRI physical= x_1 (EVC) + x_2 (RIV) + x_3 (WAS) + x_4 (DRN) + x_5 (ELV)

Where;
EVC: Evacuation shelter; RIV: proximity to river; WAS: solid waste facility; DRN: drainage system; ELV: elevation

FRI economic= x_1(EMP) + x_2 (INC) + x_3 (IND) + x_4 (AGR) + x_5 (FIN)

Where;
EMP: Employment rate; INC: Income, IND: local industries; AGR: agricultural production; FIN: financial capability

FRI institutional= x_1 (EWS) + x_2 (COM) + x_3 (BDT) + x_4 (PAR) + x_5 (TRN)

Where;
EWS: early warning system, COM: flood risk communication; BDT: budget for DRM; PAR: Multisectoral participation; TRN: training

FRI sociocultural= x_1 (INS) + x_2 (HOU) + x_3 (AST) + x_4 (LNK) + x_5 (SPT)

Where;
INS: health insurance; HOU: flood-resilient housing; AST: financial assistance (AST); LNK: community linkages; SPT: spirituality

Thus, the final equation for the flood resilience index is shown below.

$$FRI_T = FRI_N + FRI_{GP} + FRI_E + FRI_I + FRI_{SC}$$

Where;

FRI_T: Total, FRI_N: natural, FRI_{GP}: geophysical features and physical infrastructure, FRI_E: economic, FRI_I: institutional, FRI_{SC}: social-cultural support system

The flood resilience index (FRI) is calculated as the sum of five resilience indices corresponding to natural and geophysical features, physical infrastructure, economic factors, institutional support, and socio-cultural systems. The system-scale index ranges from 1 to 5, while the indicator scale ranges from 0 to 1, representing low to high flood resilience, respectively. To assess the flood resilience level of each barangay, the computed system value is evaluated using the rating scale adapted from McLeod (2019), as shown in Table 3.

Table 3. Flood resilience index scale for the socio-ecological system (adapted and modified from McLeod, 2019)

SYSTEM SCALE	INDICATOR SCALE	LEVEL OF RESILIENCE
4.51-5.00	0.80-1.0	High resilience
3.51-4.50	0.60-0.79	Moderately high resilience
2.51-3.50	0.40-0.59	Medium resilience
1.51-2.50	0.20-0.39	Moderately low resilience
1.00-1.50	0-0.19	Low resilience

3.3. *Mapping Flood Resilience*

Figure 2 presents the Flood Resilience Map of Tagum City, Davao del Norte, Philippines. This map visually represents the varying levels of flood resilience across different areas within the city, providing a detailed assessment of each area's ability to withstand and recover from flood events. The analysis is based on a comprehensive evaluation of natural and geophysical features, physical infrastructure, economic conditions, institutional support, and socio-cultural factors.

The map identifies the top towns with higher FRI scores: Apokon (3.592), Magugpo East (3.697), and Cuambogan (3.821), which are all classified as having moderately high flood resilience. These areas demonstrate a stronger capacity to cope with and recover from flooding. However, the map also reveals that certain regions exhibit moderately low resilience to flooding. For instance, large portions of Canocotan show moderately high resilience, but almost half of Apokon and parts of Magugpo East are classified as moderately low resilient.

This variation in resilience levels suggests that while interventions and projects targeting the various components of the socio-ecological system are present, they may not be fully effective in enhancing community-wide resilience. The limited scope and impact of these actions could potentially weaken the overall resilience of the system, indicating a need for more comprehensive and targeted strategies to improve flood resilience across all areas of Tagum City.

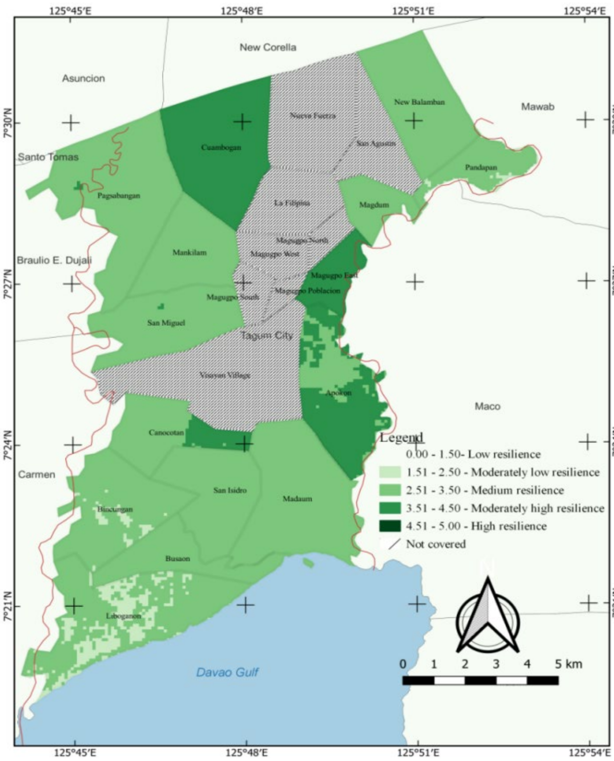

Figure 2. Flood Resilience Map in Tagum City, Davao del Norte

The figure also shows that a more significant proportion of Tagum City is medium resilient to flooding with a total FRI of 3.221. These cover towns with the FRI scores: Madaum (3.412), Magdum (3.404), Pagsabangan (3.329), Mankilam (3.196), San Miguel (3.271), San Isidro (3123), Busaon

(2.910), New Balamban (2.861), portions of Bincungan (2.801), portions of Pandapan (2.661), and more significant portions of Liboganon (2.660). This means that the five components of the social-ecological system have improved significantly in towns with medium resilience to flooding. The actions and interventions of the community and local government are more frequent and prolonged. It addresses the need of the community to anticipate, withstand, persist, and reorganize during and after the flooding events.

Meanwhile, Bincungan, Pandapan, and Liboganon have lower FRI values and are also classified as low resilience. The town of Bincungan had a total FRI of 2.081, divided into 0.792 natural, 0.822 physical, 0.290 economic, 0.650 institutional, and 0.248 social-cultural support components. On the other hand, the total FRI for town Pandapan is 2.661, of which 0.827 is for the natural component, 0.909 is for the physical component, 0.252 is for the economic component, and 0.505 is for the institutional component, 0.168 is for the social-cultural support component.

Lastly, only a few areas in Canocotan and Pandapan and a few areas in Liboganon and Bincungan fall into the category of low flood resilience. Significantly, the FRI for the town of Liboganon is 2.660, which is the lowest. The low FRI value is attributed to poor values of the three components, namely: economic (0.462), institutional (0.478), and social-cultural support (0.257). It means that the three components of social-ecological resilience need to be better emphasized for towns that fall under low resilience to flood. This signifies that some community and local government initiatives and projects fell short of meeting the community's needs. Although they lived in flood-prone areas, the people's capacities for coping, adapting, and transforming are less robust than those of other communities in the city. The diverse circumstances of the risks and hazards contribute to the variable resilience conditions in some of these towns.

Thus, some indicators needed to meet all the requirements to be classified as resilient. This affects the overall index demonstrating the social-ecological system's resilience, thus needs to be addressed immediately by the communities and the local government. Resilience recognizes the deep relationships between the built, natural, and social environments and their influence on how resilient communities are to disasters, according to Norris et al. (2008). Therefore, measuring the community's resilience requires including and emphasizing resilience at many levels and analyzing the dynamic relationships between each level (Buckle, 2006). Akin to this study, consideration is given to the various social-ecological system components that interact with one another and contribute to the system's overall resilience.

Despite living in flood-prone areas, the capacity of these communities to cope, adapt, and transform is less robust compared to other communities in the city. Thus, the community and local government have yet to fully address all five components of resilience, as some programs, projects, and activities have not adequately met the needs of the people. Based on the results of the study, most communities with low resilience to flooding dynamics are attributed to lower FRI values of social subsystem comprising economic, institutional, and social-cultural support systems. These communities may need more economic resources, adequate institutional support, and robust social-cultural support system foundations to cope effectively, adapt, and transform in the face of flooding. It indicates that community initiatives and government projects implemented thus far have yet to fully address these communities' specific needs and vulnerabilities, despite their high exposure to flood risks.

3.4. *Flooding versus Flood Resilience*

Tagum City is a flood-prone urban area characterized by flat and surrounded by the Hijo River, Tagum-Liboganon River, and Davao Gulf. The 15 towns experience the most flooding events within the floodplains and coastal areas. The city's overall land area with a high susceptibility to flooding is 5,797 hectares, which accounts for 26.54% of the total land area. It is expected to reach a depth higher than or equal to one (1) meter and a likelihood of occurrence of 1-3 years. On the other hand, 1,559 hectares, or equivalent to 7.96%, have moderate susceptibility. In comparison, 5,296 hectares, or 27.05% of the total land area, have low susceptibility with an expected flood depth of less than one (1) meter.

According to a simulation study conducted by the UN-Habitat in 2020 shown in Figure 3, 15 of Tagum City's 23 towns are at risk of being affected by floods. Among these towns, San Miguel, New Balamban, Magdum, Magugpo East, Canocotan, Apokon, and San Isidro are vulnerable to low to moderate river flooding. On the other hand, Busaon, Libuganon, Cuambogan, Mankilam, and Madaum are more vulnerable to moderate to high river flooding. Pagsabangan, Pandapan, and Bincungan are particularly at risk of significant flooding if a rainfall event with a 5-year probability were to occur today. During such an event, flood water could reach heights of up to 11 meters at the peak stage or the maximum level of the water.

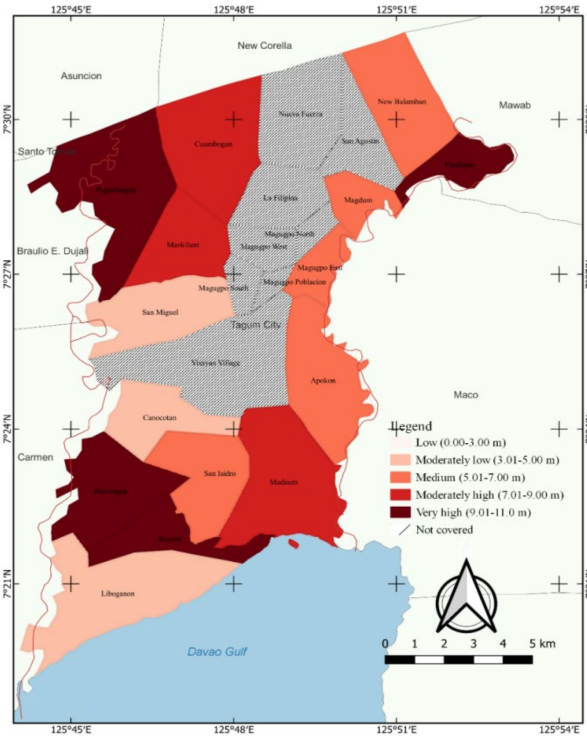

Figure 3. Flood Water Level in Tagum City At a 5-Year Return Period (UN-Habitat, 2020)

The floodwater level is a critical factor in assessing communities' resilience to flooding events. When water levels rise, particularly in low-lying areas or near bodies of water such as rivers and streams, the risk of severe damage to infrastructure and homes increases significantly. This risk escalates as water levels continue to rise, complicating evacuation efforts and heightening the potential for loss of life and property.

Furthermore, figure 4 presents the web map illustrating the relationship between the FRI and floodwater levels across various towns in Tagum City. This interactive map provides a dynamic visualization of how flood resilience varies in relation to different floodwater levels experienced in the area. By examining this relationship, the map highlights areas where resilience may be insufficient relative to the severity of flooding. It offers insights into which towns are better equipped to handle higher floodwater levels and which may require more targeted interventions to improve their resilience.

The map reveals that the towns of Pagsabangan and Cuambogan exhibit moderately high to high floodwater levels of 4.50 meters and 4.9 meters, respectively. Despite this, these towns have FRI values of 3.329 and 3.821, respectively, indicating medium to moderately high resilience to flooding. However, it is noted that these communities still need to enhance every indicator under the sociocultural and economic components to improve their resilience further and better adapt to flood events.

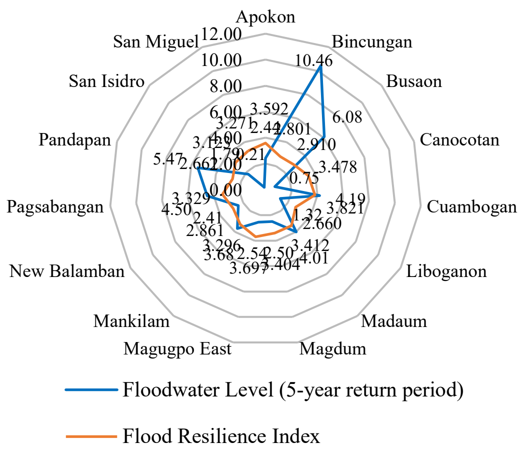

Figure 4. Comparison of Flood Resilience Index (red) and Floodwater Level (blue)

On the other hand, towns like Bincungan and Pandapan experience high floodwater levels (10.46 and 5.47 meters, respectively) and are categorized as having moderately low levels of flood resilience. This highlights the pressing need for these communities to bolster their resilience capacities, particularly given their vulnerability to flooding at critical thresholds. Similarly, while Busaon is rated as having medium flood resilience, it faces high floodwater levels (6.08 meters), necessitating proactive measures to address potential vulnerabilities and enhance resilience.

The formulation of a local-based flood resilience index highlights the significant relationship between various components in social-ecological systems, crucial for effective flood management within local contexts. Tagum City exemplifies how investing in diverse subsystems, including ecological and social components, bolsters resilience to flooding. Well-managed ecosystems like watersheds and wetlands play a vital role in regulating water flow and mitigating inundation, while initiatives such as reforestation upstream reduce downstream flood risks.

Geophysical elements and infrastructure, alongside economic diversification and sustainable livelihoods, contribute to reducing vulnerability to flood disruptions. Effective governance structures and social-cultural resilience foster community engagement and cohesion to collectively address flood risks. An integrative approach recognizes flooding as an ongoing challenge requiring adaptation and management, with strong coping, adapting, and transforming capacities essential for enduring and recovering from flooding's impacts. Thus, comprehensive integration of ecological, physical, and social factors forms the foundation of effective flood resilience strategies.

Nevertheless, a community's ability to withstand and recover from flooding is not solely determined by floodwater levels. Communities with robust flood management strategies, such as the construction of flood walls or levees, the implementation of flood warning systems, and the development of emergency response plans, demonstrate higher resilience levels regardless of fluctuations in water levels. Such preparedness measures can help mitigate the impact of flooding and facilitate quicker recovery, even in the face of high-water levels.

4. Conclusions and Recommendations

The study underscores the urgent need to evaluate and strengthen communities' flood resilience to mitigate the adverse impacts of flooding. Through comprehensive research, 24 indicators of social-ecological resilience were identified, covering natural, infrastructural, economic, institutional, and socio-cultural aspects. These indicators were meticulously developed through literature reviews, expert surveys, and analysis using a flood resilience index. The findings revealed varying levels of resilience among communities, influenced by different flood magnitudes. There's a critical need to enhance institutional, economic, and socio-cultural support to boost resilience levels, and tailored strategies are advocated, integrating these indicators into existing policies and initiatives.

By leveraging insights from previous works by Folke et al. (2019), interventions can effectively empower individuals, households, communities, and ecosystems to confront, adapt to, and recover from flood events. Additionally, the study stresses a holistic, evidence-based, cross-sectoral, and collaborative approach, recognizing the complex interplay between human societies and the natural environment in flood management. Integrating flood resilience within the broader social-ecological context requires a nuanced understanding of various factors, including the resilience of both social and ecological systems in the face of flooding events.

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