Terbit *online* pada laman web jurnal :http://jurnaldampak.ft.unand.ac.id/

Dampak: Jurnal Teknik Lingkungan Universitas Andalas

| ISSN (Print) 1829-6084 |ISSN (Online) 2597-5129|

Artikel Penelitian

Screening of Water Supply Systems' Resilience Variables Using the Fuzzy Delphi Method (FDM)

R. Hari Yuliandra[1,2], Nurhamidah Nurhamidah[1,] Puti Sri Komala[3], Vera Surtia Bachtiar[3]*

[1]*Department of Civil Engineering, Faculty of Engineering, Andalas University, West Sumatra Province, Indonesia*

[2]*Regional Settlement Infrastructure Center of West Sumatra, Ministry of Public Works*

[3]*Department of Environmental Engineering, Faculty of Engineering, Andalas University, West Sumatra Province, Indonesia*

*Koresponden: nurhamidah@eng.unand.ac.id

Diterima: 30 Juli 2025 Diperbaiki: 20 September 2025 Disetujui: 2 Oktober 2025

ABSTRACT

This study examines the resilience variables of urban Drinking Water Supply Systems (WSS) in responding to floods, with a focus on West Sumatra Province, Indonesia, using the Fuzzy Delphi Method (FDM). The study identifies three main resilience properties: robustness, recovery, and learning, within a temporal framework. Thirteen sub-properties and 41 indicators were validated using FDM by 10 experts in fields relevant to the research topic. As a result, 12 sub-properties were accepted by expert consensus, while one sub-property, namely governmental situation awareness, was rejected because all three of its indicators failed to meet the validation criteria. A total of 33 out of 41 indicators were considered significant, relevant, and useful by the expert panel. This study contributes by developing a context-specific resilience indicators framework for urban water supply systems in a developing-country setting. Furthermore, the findings emphasize the critical role of the governmental dimension in determining the resilience level of SPAM in West Sumatra Province. These results will serve as a guide for policymakers in prioritizing resilience-based decisions to mitigate flood threats.

Keyword: Urban Water Supply System, Resilience's properties, Floods, Fuzzy Delphi Method (FDM), Indicators.

1. INTRODUCTION

Implementing the Water Supply System (WSS) in Indonesia fundamentally differs from that in many other countries. In Indonesia, the management of WSS by Drinking Water Regional Owned Enterprises is a delegated responsibility from the government; thus, the role of these enterprises is primarily that of an operator. All regulations governing the implementation of WSS are entirely controlled by the government at both central and regional levels, delineated by the division of authority for mandatory affairs. However, this policy is often counterproductive, as it is frequently used as a political instrument. A notable instance is the establishment of drinking water tariffs, which remain significantly low, impeding system maintenance and renewal funding. Concurrently, the government cannot provide subsidies that would fully compensate for these low tariffs. This circumstance directly affects the disaster management capabilities of WSS, particularly in the context of recurring floods.

West Sumatra is one of the provinces in Indonesia highly vulnerable to floods. Access to clean water that meets quality, quantity, continuity, and affordability standards is critical in the aftermath of flood disasters. However, urban WSS in West Sumatra Province, where raw water sources are predominantly surface water, are highly susceptible to flood impacts. The frequency and intensity of floods, which are becoming increasingly unpredictable, require a paradigm shift in flood risk management (McClymont et al., 2020). Traditional risk management approaches focus on understanding disaster characteristics and preventing system failures by enhancing reliability. These approaches often fail to address the inherent complexity of system interactions and dynamics in disaster contexts (Balaei et al. 2020; Shin et al. 2018). Furthermore, conventional risk analysis does not account for the evolving performance of systems over time, especially in the context of recurrent or long-term disruptions Balaei et al. 2020. Hashimoto et al. (1982), Mottahedi et al. (2021), Shin et al. (2018) emphasized that the sustainability of system functionality depends not only on its reliability but also

on its ability to recover from disruptions. They introduced the concept of resilience as a metric to evaluate water resource systems' recovery and adaptive performance after disasters.

As defined by the IPCC (2022), resilience is the ability of social, economic, and ecosystem systems to cope with hazardous events or adverse trends and respond or reorganize systems to maintain vital functions, identities, and structures while remaining able to adapt, learn, and transform. In the context of water supply systems, resilience refers to a system's capacity to withstand pressure while managing to operate, deliver minimal service during disruptions, and rapidly recover its functions (Balaei et al. 2020; Bruneau et al. 2003; Quitana et al., 2020; Shin et al. 2018). Ungar (2018), identified resilience as a dynamic process, and five processes contribute to sustainable system resilience: persistence, resistance, recovery, adaptation, and transformation. Rehak et al. (2019) also describe resilience as a cyclic process involving continuous improvement through four phases of resilience: prevention, absorption, recovery, and adaptation. Several researchers define resilience as a system's absorptive, adaptive, and recovery capacities (Bruneau et al., 2003; Quitana et al., 2020; Zhou et al., 2022). A system with resilience capacity has robustness, redundancy, rapidity, and resourcefulness properties (Bruneau et al., 2003; Guo, et al., 2021; Sweya et al., 2020). However, until now, there hasn't been any agreement among researchers regarding the definition of resilience. In addition, most existing studies on WSS resilience to floods focus on developed countries with well-designed and maintained infrastructure systems, leaving a notable gap in research on developing countries (Guo et al., 2021; Lukuba et al., 2018).

In light of the urgency of implementing WSS resilience in flood-prone areas of West Sumatra Province, further studies are necessary to develop the WSS resilience concept and indicators that address the region's unique challenges to floods. Several researchers also explain that adapting resilience indicators to the local context can significantly enhance the relevance and effectiveness of strategies to improve resilience (McClymont et al., 2020). Currently, there are significant empirical and conceptual gaps in WSS resilience research, particularly in developing countries. The application of WSS resilience concepts in Indonesia, especially in West Sumatra Province, faces substantial challenges because existing resilience assessment frameworks do not fully reflect local conditions. Most available frameworks are derived from studies conducted in developed countries and tend to emphasize technical aspects, while giving limited attention to the institutional and governance dimensions crucial for enhancing the resilience of the WSS in Indonesia (Yuliandra et al., 2025). Research by Yuliandra et al. (2025) emphasizes the crucial role of institutional capacity and governance processes in shaping the resilience of drinking water supply systems (WSS) in regions with low fiscal capacity and operator scheme managed by Drinking Water Company (Perumda Air Minum). Therefore, this study addresses the identified gap by structuring resilience properties according to the temporal sequence of disaster management phases and incorporating the governance dimension based on context-specific resilience indicator framework in a developing-country setting.

The difficulty in obtaining reliable quantitative data for constructing resilience properties and indicators assessment is one of the reasons why a qualitative or semi-quantitative research approach is used (Cantelmi and Patriarca 2021). One semi-quantitative resilience properties and indicators assessment method is the Fuzzy Delphi Method (FDM). This approach is relevant because the increasing uncertainty heightens the importance of expert opinions and evaluations (Cantelmi and Patriarca 2021; Mottahedi et al. 2021b). The FDM method allows researchers to identify variations in values within a panelist's perception that may be missed in conventional statistical analysis. This study explains how to assess and refine the WSS resilience hypothesis variables against floods. Unlike earlier studies that primarily used the Fuzzy Delphi Method (FDM) as a tool for aggregating expert opinions, this study positions FDM as a mechanism for screening and validating indicator content that captures uncertainty, variations in expert perceptions, and flood risk characteristics specific to West Sumatra, where quantitative data remain scarce. Thus, this study contributes by highlighting the importance of a contextualized, governance-based resilience assessment approach for strengthening SPAM infrastructure resilience and by opening pathways for developing resilience measurement instruments that can capture differences in risk perception and policy priorities among stakeholders.

2. METHODOLOGY

2.1. Research Design

This study uses a semi-quantitative approach to improve WSS resilience hypothesis variables. Hypothesis variables were obtained from previous literature studies to build an initial conceptual definition, an analysis of the existing conditions of WSS, and interviews with managers at Padang City Drinking Water Company (One

of BUMD for Drinking Water in West Sumatra Province). FDM and thematic analysis are applied to assess and refine relevant indicators based on expert insight.

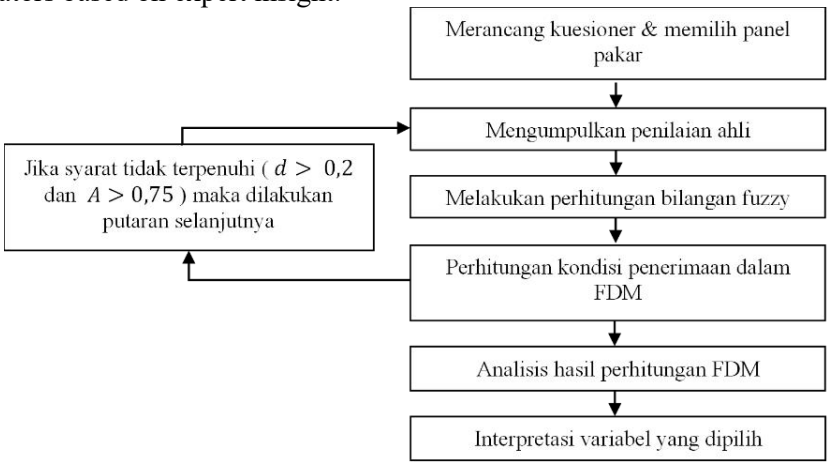


Figure. 1. Research methods

The expert panel was selected using purposive sampling, with selection criteria including a minimum of 15 years of experience in resilience or risk management, Drinking Water Supply System (WSS) implementation, water resources management, and the formulation of policies or regulations related to disaster management. Ten experts participated in this phase, with detailed information presented in **Table 1**. The panel of ten experts was selected based on criteria including a minimum of ten years of executive-level experience, familiarity with the study area, and expertise in resilience and/or risk management, Water Supply System (WSS) management, watershed management, and relevant policies and regulations. Previous studies suggest that an expert panel consisting of 3 to 15 participants is sufficient for evaluating and prioritizing variables (Noori et al., 2020).

Table 1. Expert qualifications

Items	Categories	Frequency
Educatio-nal background	Bachelor	-
	Master	8
	Doctoral	2
Experience related to research topic	10-19 years	3
	20-29 years	5
	≥30 years	2
institution	Municipal Drinking Water Company	2
	Academics	3
	River Basin Organization of Sumatera V	3
	Province and local Government	2
Organizatio-nal services	Academic	3
	Management services in WSS	2
	Water Central Water resources management	3
	Provincial Water resources management	1
	Local/regional public works	1
Number of Experts	10	

2.2. Screened WSS Resilience Variables

The study results show three resilience properties, 13 sub-properties, and 41 indicators, summarized in Table 8 as a comprehensive description of the resilience measurement framework. **Table 2** explains the expert's expertise qualifications at the preliminary assessment phase.

Table 2. Resilience Variables

1. Robustness property		
Number	**Sub-properties**	**Indicators**
1.1.1	Organizational Crisis preparedness	Recovery planning
1.1.2		Dynamic emergency response planning
1.1.3		Emergency response team preparedness
1.2.1	Governmental Crisis preparedness	Government dynamic contingency plan

1. Robustness property		
Number	**Sub-properties**	**Indicators**
1.3.1	Organizational situation awareness	Organization's data acquisition and monitoring system (DAMS)
1.3.2		Organizational detection ability
1.3.3		Organizational sensemaking and prediction ability
1.4.1	Governmental situation awareness	Government's data acquisition and monitoring system (DAMS)
1.4.2		Governmental detection ability
1.4.3		Governmental sensemaking and prediction ability
1.5.1	Physical resistance	Comprehensive feasibility studies
1.5.2		System design
1.5.3		System renewal
1.5.4		System maintenance
1.6.1	Organizational flexible response	System redundancy
1.6.2		System decentralization and interconnetion
1.6.3		Internal procedural adjustment capacity
1.6.4		Dynamic emergency response implementation
1.6.5		Budgeting flexibility
1.7.1	Governmental flexible response	Government coordination capacity
1.7.2		Government commitment
2. Recoverability property		
Number	Sub-properties	Indicators
2.1.1	Governmental recovery	River basin authority-based recovery
2.1.2		Fast Financing Access
2.1.3		Availability of human resource
2.1.4		Governmental recovery processes
3. Learning property		
Number	Sub-properties	Indicators
3.1.1	Risk governance transformation	Risk management structure
3.1.2		Risk assessment
3.1.3		Incident evaluation
3.1.4		Risk management implementation audit
3.2.1	Education and development processes	Improve knowledge and skills
3.2.2		Training Effectiveness Evaluation
3.3.1	Process and organizational innovation	Level of Involvement in Science and Research
3.3.2		Extent of Implementation of Technological Innovations
3.4.1	Organizational transformation	Reform of Governance and Policy
3.4.2		Flexible culture
3.5.1	Governmental transformation	Policy reforms for resilience
3.5.2		Reform for Public Sector Governance
3.5.3		Transformation of disaster management financing
3.5.4		Government's ability to understand local contexts
3.5.5		Codes/Standards allowing controlled improvisation
3.5.6		Political Will of Local Government

The same flood event can be considered a disaster, depending on a system's capacity or resilience property. Resilience properties indicate how capable the system is in resisting or withstanding, absorbing, recovering, adapting, and transforming from the flood event. The resilience properties encompass:

1. Robustness property

Robustness is a system characteristic that resists or withstands the initial impact of a disturbance and then absorbs its impact without significant loss of function. The robustness sub-properties are:

a) Organizational Crisis preparedness: The system's ability to design and implement strategies to improve the organization's preparedness to face disruptions dynamically, quickly, and effectively.
b) Governmental Crisis preparedness: The government's preparation in managing the crisis and being responsible for leading it if a severe crisis occurs to the WSS infrastructure. Currently, the contingency plan

guidelines refer to BNPB Regulation Number 2 of 2023 concerning the preparation of disaster contingency plans.

c) Organizational situation awareness: The organization's capacity to recognize early signs of system disruption, analyze that data to understand how the disruption is developing, and predict risks swiftly and accurately.
d) Governmental situation awareness: The ability of central and regional governments to detect and report flood incidents and infrastructure damage transparently, to understand the ongoing situation, and to predict potential risks to raw water units based on their authority.
e) Physical resistance: Technical efforts (such as system design) and organizational actions (such as system maintenance) designed to increase the physical resilience of critical infrastructure elements to disruptive events.
f) Organizational flexible response: The capability of an organization to respond flexibly to disruptions by utilizing alternative resources, modifying operational strategies, and adjusting internal procedures.
g) Governmental flexible response: The contingency plan outlines the government's ability to coordinate and actively contribute. Government Regulation Number 122 of 2015 concerning the Drinking Water Supply System states that managing natural disasters is one of the government's authorities and responsibilities in organizing WSS.

2. Recoverability property

Recoverability is WSS's characteristic to restore its function to the initial performance level after the flood's impact ends. The experts assert that managing flood damage to raw water units in Indonesia should be the government's responsibility, as the WSS's FCR tariff does not include a recovery budget. The recoverability sub-property is:

a) Governmental recovery: The government's responsibility is to manage, coordinate, and lead post-crisis recovery activities for WSS infrastructure. This includes a clear division of authority for handling WSS infrastructure between the central and regional governments, strategic decision-making, resource provision, and cross-sector collaboration. Experts argue that for districts/cities with high disaster risk, the government needs to allocate easily accessible funds for the recovery of critical infrastructure.

3. Learning property

Learning from past events is a key aspect of resilience, yet no critical infrastructure resilience research considers the influence of learning (Mottahedi et al. 2021b). This characteristic allows WSS to accumulate insights from past experiences, making disasters catalysts for adaptation and transformation, which can change resilience strategies. According to Helfgott (2018) the ideas of adaptation and transformation challenge the traditional paradigm of system stability by emphasizing the system's response to dynamic change. Several international case studies demonstrate how disasters and post-disaster responses affect development trajectories and the underlying values of development. This momentum can drive structural change in the development system. Resilient organizations create systems that enable them to learn from mistakes and strengthen resilience through continuous evaluation and improvement. The learning sub-properties are:

a) Risk governance transformation: This represents a fundamental shift in managing risk and uncertainty, transitioning from a traditional response-and-recovery-based approach to a more proactive, adaptive, and risk analysis-driven decision-making system.
b) Education and development processes: Initiatives designed to increase the knowledge, skills, and attitudes of the workforce to bolster the WSS resilience.
c) Process and organizational innovation: The creation, development, and implementation of new ideas, methods, or technologies for adaptation and transformation.
d) Organizational transformation: Fundamental change that includes reforms in governance and policies that support WSS resilience and the formation of a flexible culture to increase long-term organizational resilience.
e) Governmental transformation: Changes in governance systems aimed at increasing resilience. This transformation includes systemic changes in governance, funding, infrastructure, and regulations that underpin WSS implementation policies. Disasters often create opportunities to drive significant change that can strengthen governments' ability to meet future challenges.

2.3. Questionnaire and Variables Screening Criteria

The screening of WSS resilience variables was carried out based on three main criteria, as listed in **Table 3.** Data collection was conducted through a questionnaire consisting of a five-point Likert scale and a short essay

explaining the reasons behind the assessment, obtained through structured interviews with 10 experts. A five-point Likert scale was used to evaluate each component in the FDM questionnaire, with linguistic expressions ranging from "very unimportant" to "very important." The use of this five-point scale is commonly applied in Delphi method-based research. It should be noted that the use of a five-point scale or more in the Delphi questionnaire is highly recommended to maintain measurement accuracy, considering that the sample size in this method is generally relatively small (Ameyaw et al. 2014; Mottahedi et al. 2021a; Noori et al. 2020).

Table 3. Key criteria in variable screening and validation

Key criteria	Description	References
Significance/Priority	The extent to which a variable is considered important or prioritized in enhancing WSS resilience.	(Balaei et al. 2021)
Relevance	The degree to which a variable is appropriate and applicable to the context of WSS flood resilience in West Sumatra Province.	(Sweya et al. 2020), (Balaei et al. 2021)
Benefits/ usefulness	The extent to which a variable provides tangible benefits in strengthening the system's resilience capacity against disruptions.	(Sweya et al. 2020), (Balaei et al. 2021)

2.4. Expert-based data collection using FDM

The linguistic scale is used to evaluate the level of agreement on the resilience variables as presented in **Table 4.** Furthermore, the linguistic values given by the experts are converted into Triangular Fuzzy Numbers (TFN).

Table 4. Agreement level and TFN five-point likert scale (Habibi, Firouzi, and Sarafrazi 2015)

Likert scale	Level of agreement	Fuzzy number
1	Very not important	(0, 0, 0,25)
2	Not important	(0, 0.25, 0.5)
3	Moderately important	(0.25, 0.5, 0,75)
4	Important	(0.5, 0.75, 1)
5	Very important	(0.75, 1, 1)

The steps for data analysis using the FDM method are as follows (Hasim et al. 2021):

The Fuzzy-Likert method applies fuzzy operations to convert Likert scale responses into triangular fuzzy numbers (TFNs). The first step is to carry out fuzzy aggregation of the collected opinions. Each expert's opinion is expressed as a TFN (l, m, u). Aggregation is employed to merge the information provided by the respondents. The method for computing the fuzzy average of the experts' opinions is computed using the formula shown in equation (1).

$$F_{AVE} = \left(\frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n}\right) \quad (1)$$

F_{AVE} = The fuzzy average TFN of all experts' opinions

n = The total number of experts whose opinions were elicited.

A statement or opinion that can be accepted through fuzzy Likert analysis must fulfill three conditions. These conditions are necessary to reach a consensus conclusion among the experts:

1) Threshold value. Compute the threshold between two triangular fuzzy numbers (L,M,U) and (l_1,m_1,u_1) using the formula (2)

$$d\,(m,n) = \sqrt[2]{\frac{1}{3}\left[(L-l1)^2 + (M-m1)^2 + (U-u1)^2\right]} \quad (2)$$

Experts m and n, their TFNs are (L,M,U) and (l_1,m_1,u_1)

d (m,n)= the threshold distance between the triangular fuzzy numbers (TFNs) provided by expert m and expert n for the same item

d ≤ 0,2: Indicator/item accepted

d > 0,2: Indicator/item rejected

2) Expert agreement percentage. The second condition to determine the expert agreement value is to ensure that the expert agreement percentage is > 75% based on Hsu and Sandford (2007)

3) Defuzzified score (A). The third condition ensures that the average fuzzy number's fuzzy score (A) value or defuzzification is greater than or equal to the median fuzzy number value. The median value of fuzzy numbers 0 and 1 is 0.5 28,29). Determining the fuzzy score (A) aims to validate items, assess their level of importance and relevance, and identify the most significant items in the research context based on expert opinion. Fuzzy score (A) converts fuzzy values back to crisp values for a more straightforward interpretation.

The fuzzy score value can be calculated using equation (3) when each expert's opinion is displayed as TFN (l, m, u).

$$Amax = (L+M+U)/3 \quad (3)$$

If the A value is less than 0.5, the item will be rejected because there is no expert agreement.

2.5. Expert-based data collection using FDM

Identification of urban WSS in seven districts and cities in West Sumatra Province (Padang, Padang Panjang, Limapuluh Kota, Pasaman, Pesisir Selatan, Sijunjung, and Tanah Datar) by the Regional Settlement Infrastructure Center of West Sumatra, Ministry of Public Works and Housing in 2024, revealed significant vulnerabilities to flood impacts. The flash floods in Padang City on August 18, 2021, damaged the WSS intake of the Padang City Drinking Water Company, resulting in the water supply being cut off to three sub-districts and around 45,000 customers not receiving clean water. Flash floods in South Solok Regency on November 21, 2019, caused damage to the network, Water Treatment Plant (WTP), and intake. In March 2024, 10 regencies/cities in West Sumatra Province experienced flash floods accompanied by landslides. The most impacted areas were Padang City, Padang Pariaman Regency, and Pesisir Selatan. According to the Meteorological, Climatological, and Geophysical Agency, the region experiences above-normal annual rainfall. The flood that occurred on March 7, 2024, in Padang City resulted in significant damage to the Raw Water intake and transmission pipe with a diameter of 300 mm at the Lubuk Paraku WSS Unit, which is under the operation of the Padang Municipal Drinking Water Company.



Figure 2. Location of research in West Sumatra Province

3. RESULTS AND DISCUSSION

The results of the study show that 33 indicators meet three eligibility criteria, namely the level of significance, relevance, and usefulness. **Tables 5** to **13** present the results of the calculation of the FDM acceptance conditions. Four indicators of the robustness property did not pass the relevance criterion: Government's data acquisition and monitoring system (DAMS), Governmental detection ability, Governmental sensemaking and prediction ability, and System redundancy. All four indicators have an expert agreement level below 75%. Meanwhile, the River basin authority-based recovery indicator proposed in the recovery property did not meet the threshold value (d), expert agreement (%), and fuzzy score (A) for the three main criteria (significance, relevance, and usefulness). In addition, three indicators out of 15 indicators in the learning property: Training effectiveness evaluation; Level of involvement in science and research; and Flexible culture, were eliminated because two of this indicators did not meet the level of significance criteria, and three indicators did not pass the relevance and usefulness aspects.

Table 5. Expert consensus on the significance of robustness indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
1.1.1	0.07	100.00	0.70	0.95	1.00	0.88	Accept	14

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
1.1.2	0.04	100.00	0.73	0.98	1.00	0.90	Accept	8
1.1.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.2.1	0.09	100.00	0.68	0.93	1.00	0.87	Accept	17
1.3.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	8
1.3.2	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.3.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.4.1	0.15	80.00	0.60	0.85	0.95	0.80	Accept	19
1.4.2	0.15	80.00	0.58	0.83	0.95	0.78	Accept	20
1.4.3	0.04	100.00	0.73	0.98	1.00	0.90	Accept	8
1.5.1	0.11	100.00	0.73	0.98	0.90	0.87	Accept	17
1.5.2	0.04	100.00	0.73	0.98	1.00	0.90	Accept	8
1.5.3	0.07	90.00	0.70	0.95	1.00	0.88	Accept	14
1.5.4	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.6.1	0.18	80.00	0.55	0.80	0.93	0.76	Accept	21
1.6.2	0.04	100.00	0.73	0.98	1.00	0.90	Accept	8
1.6.3	0.04	100.00	0.73	0.98	1.00	0.90	Accept	8
1.6.4	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.6.5	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.7.1	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.7.2	0.08	90.00	0.70	0.95	0.98	0.88	Accept	16

Table 6. Expert consensus on the relevance of robustness indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
1.1.1	0.07	100.00	0.70	0.95	1.00	0.88	Accept	9
1.1.2	0.09	100.00	0.68	0.93	1.00	0.87	Accept	13
1.1.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.2.1	0.09	100.00	0.68	0.93	1.00	0.87	Accept	13
1.3.1	0.07	100.00	0.70	0.95	1.00	0.88	Accept	9
1.3.2	0.07	100.00	0.70	0.95	1.00	0.88	Accept	9
1.3.3	0.10	90.00	0.68	0.93	0.98	0.86	Accept	15
1.4.1	0.18	70.00	0.55	0.80	0.93	0.76	Reject	18
1.4.2	0.15	70.00	0.50	0.75	0.93	0.73	Reject	19
1.4.3	0.13	70.00	0.48	0.73	0.93	0.71	Reject	20
1.5.1	0.14	80.00	0.65	0.90	0.95	0.83	Accept	17
1.5.2	0.04	100.00	0.73	0.98	1.00	0.90	Accept	6
1.5.3	0.07	100.00	0.70	0.95	1.00	0.88	Accept	9
1.5.4	0.10	90.00	0.68	0.93	0.98	0.86	Accept	15
1.6.1	0.23	60.00	0.50	0.75	0.88	0.71	Reject	20
1.6.2	0.04	100.00	0.73	0.98	1.00	0.90	Accept	6
1.6.3	0.04	100.00	0.73	0.98	1.00	0.90	Accept	6
1.6.4	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.6.5	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.7.1	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.7.2	0.00	90.00	0.75	1.00	1.00	0.92	Accept	1

Table 7. Expert consensus on the usefulness of robustness indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
1.1.1	0.07	100.00	0.70	0.95	1.00	0.88	Accept	17
1.1.2	0.04	100.00	0.73	0.98	1.00	0.90	Accept	11
1.1.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.2.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	11
1.3.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	11
1.3.2	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.3.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.4.1	0.15	90.00	0.60	0.85	0.95	0.80	Accept	20
1.4.2	0.15	80.00	0.58	0.83	0.95	0.78	Accept	21
1.4.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.5.1	0.11	100.00	0.73	0.98	1.00	0.90	Accept	11
1.5.2	0.04	100.00	0.73	0.98	1.00	0.90	Accept	11
1.5.3	0.07	100.00	0.70	0.95	1.00	0.88	Accept	17
1.5.4	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.6.1	0.12	90.00	0.65	0.90	0.98	0.84	Accept	19
1.6.2	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.6.3	0.04	100.00	0.73	0.98	1.00	0.90	Accept	11
1.6.4	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.6.5	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.7.1	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
1.7.2	0.00	90.00	0.75	1.00	1.00	0.92	Accept	1

Among the 18 robustness indicators, the lowest consensus, approximately 80 percent, was recorded for Government's data acquisition and monitoring system (DAMS) (141), Governmental detection ability (142), and System redundancy (161). This disparity highlights a gap between conceptual urgency and field practice. Expert from academics and River Basin Agency V (BWS V) assigned high significance and usefulness scores, whereas Drinking waters and local governments rated the practical benefits lower because of limited funding, resources, data access, and technical capacity, thus lowering the average agreement. These three indicators, along with Governmental sense-making and prediction ability (143), were also considered irrelevant. Their perceived irrelevance is largely contextual: as Expert 4 observed, "Operations are run by organizations, while government-owned monitoring devices can only be accessed in a limited way so that the hope of becoming an early warning system is not achieved." As a result, these indicators are considered less appropriate for the current WSS resilience. The system redundancy indicator obtained the lowest relevance value (d = 0.23; expert agreement = 60%; A = 0.71) because the majority of Drinking water BUMD in West Sumatra Province do not have a reserve of raw water units, tariffs are not optimal, NRW is high, and fiscal limitations of the Local government budget make investment in intake or reserve pipes almost impossible. Thus, although these four indicators are theoretically important, expert consensus indicates that their implementation is currently misaligned with the local context and priorities for enhancing WSS flood resilience in West Sumatra.

The five property robustness indicators with the highest level of agreement are:

a) Emergency response team preparedness is the readiness of the emergency team to implement the mechanisms and procedures needed to respond to an incident. (Labaka et al., 2015; Rehak et al., 2019; Sweya et al., 2021) have identified Emergency response team preparedness as an important indicator of critical infrastructure resilience.
b) Dynamic emergency response implementation is the idea of protocol-driven resilience. According to (Francis and Amodeo 2018), the protocol ensures that emergency actions are not trapped in rigid procedures, but can be updated and adjusted quickly to minimize the impact of disruptions and accelerate the recovery of critical infrastructure.
c) Budgeting flexibility is the ability of an organization to adjust budget management quickly and efficiently in the face of a disaster, without disrupting the organization's core operations. Budgeting flexibility is an important indicator to support critical infrastructure resilience and ensure effective response to urgent needs (Balaei et al. 2021; Guo et al., 2021).

d) Government coordination capacity refers to organising the roles and responsibilities of the various agencies involved in emergency management and making strategic decisions on priorities, task distribution, and resource allocation (logistics, personnel, and budget). According to Labaka (2015), effective crisis-response coordination requires a formal structure, clearly defined roles, and an operational plan, elements that should be specified in government emergency plans. Within this framework, the government serves as the principal coordinator and liaison among technical units, communication teams, and frontline responders.
e) Organizational detection ability denotes an organisation's capacity to conduct thorough asset monitoring and physical validation of infrastructure through regular, manual inspections and observations, and to issue timely reports when early-stage incidents occur. Rehak et al., (2019) employ this indicator to assess the robustness dimension of system resilience.

Table 8. Expert consensus on the significance of recovery indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
2.1.1	0.23	40.00	0.43	0.68	0.83	0.64	Reject	4
2.1.2	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
2.1.3	0.14	90.00	0.65	0.90	0.95	0.83	Accept	3
2.1.4	0.04	100.00	0.73	0.98	1.00	0.90	Accept	2

Table 9. Expert consensus on the relevance of recovery indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
2.1.1	0.21	50.00	0.48	0.73	0.88	0.69	Reject	4
2.1.2	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
2.1.3	0.15	90.00	0.63	0.88	0.95	0.82	Accept	3
2.1.4	0.07	100.00	0.70	0.95	1.00	0.88	Accept	2

Table 10. Expert consensus on the usefulness of recovery indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
2.1.1	0.25	40.00	0.40	0.65	0.80	0.62	Reject	4
2.1.2	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
2.1.3	0.15	90.00	0.63	0.88	0.95	0.82	Accept	3
2.1.4	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1

Regarding the recovery property, the experts achieved their highest consensus on the indicators fast financing access and governmental recovery processes. Balaei et al., (2021) identify rapid access to funding as the most significant economic factor influencing water-supply resilience, because securing resources within the first few weeks after a disaster is crucial. In high-income countries, the central government typically shoulder a portion of post-disaster costs through tax revenues, and local authorities or owners of infrastructure networks (if privately owned) are required to make financial arrangements to cover the remaining recovery costs (Balaei et al., 2021). This perspective aligns with the panel's views: Expert 4 remarked that "recovery should be the government's responsibility, as tariff revenues do not cover recovery costs," and Experts 1, 2, and 5 even suggested that a single central-government agency could manage WSS recovery, thereby accelerating the process. Consequently, the river-basin-authority-based recovery indicator did not reach consensus on any of the three criteria. As Expert 1 explained, "Post-disaster rehabilitation ought to be under national authority because most districts and cities in West Sumatra have limited fiscal capacity and are not yet prepared for autonomous disaster management." The governmental recovery processes indicator ensures that recovery is executed correctly and on time, with funding decisions prioritising what should be restored and how resources are allocated. Rehak et al., 2019 likewise highlight recovery processes as a key factor determining the speed of post-disaster restoration.

Table 11. Expert consensus on the significance of learning indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
3.1.1	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
3.1.2	0.13	90.00	0.60	0.85	0.98	0.81	Accept	12
3.1.3	0.09	100.00	0.68	0.93	1.00	0.87	Accept	8
3.2.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.2.2	0.11	80.00	0.50	0.75	0.95	0.73	Accept	14
3.3.1	0.14	40.00	0.38	0.63	0.85	0.62	Reject	15
3.3.2	0.09	100.00	0.68	0.93	1.00	0.87	Accept	8
3.4.1	0.10	90.00	0.68	0.93	0.98	0.86	Accept	10
3.4.2	0.18	70.00	0.55	0.80	0.93	0.76	Reject	13
3.5.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.5.2	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.5.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
3.5.4	0.00	90.00	0.75	1.00	1.00	0.92	Accept	1
3.5.5	0.10	100.00	0.63	0.88	1.00	0.83	Accept	11
3.5.6	0.04	90.00	0.73	0.98	1.00	0.90	Accept	4

Table 12. Expert consensus on the relevance of learning indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
3.1.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.1.2	0.13	90.00	0.60	0.85	0.98	0.81	Accept	11
3.1.3	0.12	100.00	0.58	0.83	0.98	0.79	Accept	12
3.2.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.2.2	0.15	60.00	0.45	0.70	0.90	0.68	Reject	14
3.3.1	0.16	40.00	0.35	0.60	0.83	0.59	Reject	15
3.3.2	0.09	100.00	0.68	0.93	1.00	0.87	Accept	8
3.4.1	0.10	90.00	0.68	0.93	0.98	0.86	Accept	9
3.4.2	0.20	60.00	0.53	0.78	0.90	0.73	Reject	13
3.5.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.5.2	0.07	100.00	0.70	0.95	1.00	0.88	Accept	7
3.5.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
3.5.4	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
3.5.5	0.10	100.00	0.63	0.88	1.00	0.83	Accept	10
3.5.6	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1

Table 13. Expert consensus on the usefulness of learning indicators

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
3.1.1	0	100.00	0.75	1.00	1.00	0.92	Accept	1
3.1.2	0.13	90.00	0.60	0.85	0.98	0.81	Accept	12
3.1.3	0.10	100.00	0.65	0.90	1.00	0.85	Accept	9
3.2.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.2.2	0.15	60.00	0.45	0.70	0.90	0.68	Reject	14
3.3.1	0.12	20.00	0.30	0.55	0.78	0.54	Reject	15
3.3.2	0.12	90.00	0.65	0.90	0.98	0.84	Accept	10
3.4.1	0.10	90.00	0.68	0.93	0.98	0.86	Accept	8
3.4.2	0.20	60.00	0.53	0.78	0.90	0.73	Reject	13
3.5.1	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.5.2	0.07	100.00	0.70	0.95	1.00	0.88	Accept	7

Indicators	Condition of TFNs		Condition of Defuzzification Process			Fuzzy Score (A)	Experts Consensus	Ranking
	Threshold value (d)	Expert agreement (%)	m1	m2	m3			
3.5.3	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1
3.5.4	0.04	100.00	0.73	0.98	1.00	0.90	Accept	4
3.5.5	0.10	100.00	0.63	0.88	1.00	0.83	Accept	11
3.5.6	0.00	100.00	0.75	1.00	1.00	0.92	Accept	1

Three learning-property indicators:

a) Training effectiveness evaluation; Level of involvement in science and research; and flexible culture, failed to reach consensus on all three FDM criteria (significance, relevance, and usefulness). By contrast, the panel registered the highest agreement for four indicators, in descending order: Transformation of disaster-management financing; Risk-based decision-making mechanism; Government's ability to understand local contexts; Political will of local government.
b) Transformation of disaster-management financing refers to revising funding mechanisms to guarantee adequate and timely resources, and embedding these arrangements in broader financing policies. UNDRR (2022) stresses that disaster-risk investments remain low, especially in vulnerable developing countries, and that long-term resilience will be difficult to attain without policy change, given the combined effects of cognitive biases, political pressures, and distorted risk perceptions.
c) Risk-based decision-making mechanism is part of the Risk governance transformation subproperty. According to Gibson et al., (2016), one of the risk governance transformations is implementing a Risk-based decision-making mechanism where organizations can move from the paradigm of "responding to damage" to "managing risk". The SDG's agenda will be hampered if decision-making and development planning do not include data and knowledge about risk into the entire policy, planning, implementation, and evaluation process (UNDRR 2022).

Government's ability to understand local contexts refers to the capacity of local governments to identify regional characteristics, disaster risks, infrastructure conditions, WSS institutional structures, and community needs, and then integrate all of this information into policies. Expert 8 asserted: "this indicator is very important, relevant, and useful for improving WSS resilience, because each region has different infrastructure characteristics, levels of vulnerability, local culture, and knowledge capacity. Understanding local contexts allows governments to respond to disasters more appropriately, channel resources effectively, and strengthen cross-stakeholder collaboration". Shaw (2012) also emphasized that he resilience of public service institutions is supported by the ability of local authorities to acquire, interpret, and utilize region-specific knowledge in adaptive and transformative decision-making processes. In addition, the existence of flexible guiding principles allows central and regional governments to make strategic decisions on infrastructure investment through a contextual approach that is technically and economically feasible, and long-term sustainability. The Government's ability to understand local contexts indicator is key to ensuring that every infrastructure intervention is truly relevant, effective, and resilient to local risks.

Political Will of Local Government according to Zhou et al., (2022), refers to the political commitment to allocate resources (budget, regulations) for risk reduction, without the support of local leaders, early warning and mitigation efforts are difficult to implement. However, according to expert 3, political will at the local level is often constrained by the pattern of the new local head election cycle, expert 3 stated: "This indicator is important, but policy orientation tends to follow short-term campaign promises and the need for "visible projects" that quickly give an image of political success. The budgeting structure is largely program-based (line-item budgeting), which drives local agencies to compete for new programs to secure a share of the regional budget (APBD), while ongoing programs do not always receive sustained funding." Gibson et al., (2016) explained that political decisions and development policies can reduce or even worsen infrastructure vulnerability, and disasters are events that can reveal accumulated development policy failures. Therefore, policy makers need to take a long-term view of the impact of compromises or trade-offs between development options, and integrate Disaster risk reduction (DRR) into all sustainable development goals (SDGs).

4. CONCLUSION

We integrate two temporal aspects into the WSS resilience framework in West Sumatra Province. First, this study applies a temporal sequence approach to resilience strategies in responding to disturbances, starting from the withstand and absorption impact stage through the robustness property, then the recovery property, and

adaptation and transformation through the learning property. This approach ensures that each resilience property and sub-property are implemented strategically and sequentially. Second, this study adopts a short-term and long-term resilience perspective, where the temporal concept helps understand how systems can develop, adapt, and transform over time. In the short term, the focus is on maintaining operational sustainability and accelerating the post-disruption recovery process, while in the long term, attention is directed to adaptation and transformation efforts to improve system resilience.

This study has successfully screened sub-properties and indicators that are considered significant, relevant, and useful for improving WSS resilience. However, further validation is required to ensure that the identified properties, sub-properties, and indicators are suitable for constructing a conceptual framework of WSS resilience to floods. Some indicators are interdependent, where implementing one strategy requires a readiness from another strategy to function optimally. For example, a backup infrastructure development strategy may not be effectively implemented without a financial capacity-building strategy to support long-term investment. Therefore, future research needs to assess the temporal sequence of indicator implementation so this framework can be realistically applied to improve WSS resilience in West Sumatra Province. In addition, this study has not yet conducted a weighting assessment to develop a WSS resilience instrument; therefore, the findings remain conceptual and have not yet been operationalized to support practical decision-making and strategic actions for improving WSS resilience to flood hazards.

ACKNOWLEDGEMENTS

The author would like to thank the experts involved in the interviews, the expert panel, the dissertation examination team, and the department and study program teams for their time and insights.

REFERENCES

Ameyaw, E. E., Hu, Y., Shan, M., Chan, A. P. C., Le, Y., Ernest, E., … Le, Y. (2014). Application of Delphi method in construction engineering and management research : a quantitative perspective. JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT, 3730(January). https://doi.org/10.3846/13923730.2014.945953

Balaei, B., Noy, I., Wilkinson, S., & Potangaroa, R. (2021). Economic factors affecting water supply resilience to disasters. Socio-Economic Planning Sciences, 76(August), 100961. https://doi.org/10.1016/j.seps.2020.100961

Balaei, B., Wilkinson, S., Potangaroa, R., Hassani, N., & Alavi-Shoshtari, M. (2018). Developing a Framework for Measuring Water Supply Resilience. Natural Hazards Review, 19(4), 04018013. https://doi.org/10.1061/(asce)nh.1527-6996.0000292

Balaei, B., Wilkinson, S., Potangaroa, R., & McFarlane, P. (2020). Investigating the technical dimension of water supply resilience to disasters. Sustainable Cities and Society, 56(March 2019), 102077. https://doi.org/10.1016/j.scs.2020.102077

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., … Von Winterfeldt, D. (2003). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. Earthquake Spectra, 19(4), 733–752. https://doi.org/10.1193/1.1623497

Cantelmi, R., & Patriarca, G. D. G. R. (2021). Reviewing qualitative research approaches in the context of critical infrastructure resilience. In Environment Systems and Decisions (Vol. 41). https://doi.org/10.1007/s10669-020-09795-8

Francis, R., & Amodeo, D. (2018). On the Role of Protocol-Driven Resilience in Coupled Infrastructure and Natural System Resilience. Integrated Environmental Assessment and Management, 14(5), 578–580. https://doi.org/10.1002/ieam.4074

Gibson, T. D., Pelling, M., Ghosh, A., Matyas, D., Siddiqi, A., Solecki, W., … Du Plessis, R. (2016). Pathways for Transformation: Disaster Risk Management to Enhance Resilience to Extreme Events. Journal of Extreme Events, 03(01), 1671002. https://doi.org/10.1142/s2345737616710020

Guo, D., Shan, M., & Owusu, E. K. (2021). Resilience assessment frameworks of critical infrastructures: State-of-the-art review. Buildings, 11(10), 1–18. https://doi.org/10.3390/buildings11100464

Habibi, A., Firouzi, F., & Sarafrazi, A. (2015). Fuzzy Delphi Technique for Forecasting and Screening Items. 5(2), 130–143.

Hashimoto, T., Stedinger, J. R., & Loucks, D. P. (1982). Reliability, Resiliency, and Vulnerability Criteria. Water Resources Research, 18(1), 14–20.

Hasim, M. A., Jabar, J., Sufian, A., Ibrahim, N. F., & Khalid, F. A. (2021). Employing Fuzzy Delphi Techniques to Validate the Components and Contents of E-Learning Antecedents and Usage Behavior Towards E- Learning Performance. 12(1), 467–480.

Helfgott, A. (2018). Operationalising systemic resilience. European Journal of Operational Research, 268(3), 852–864. https://doi.org/10.1016/j.ejor.2017.11.056

Hsu, C. C., & Sandford, B. A. (2007). The Delphi technique: making sense of consensus. Practical Assessment, Research & Evaluation, 12(1), 55–56. https://doi.org/10.1080/02688867.1988.9726654

IPCC. (2022). Climate Change 2022_ Impacts, Adaptation and Vulnerability_Working Group II contribution to the Sixth Assessment Report of the Intergovernamental Panel on Climate Change. Working Group II Contribution to the Sixth Assessment Report of the Intergovernamental Panel on Climate Change, (August), 37. https://doi.org/10.1017/9781009325844.Front

Labaka, L., Hernantes, J., & Sarriegi, J. M. (2015). Resilience framework for critical infrastructures: An empirical study in a nuclear plant. Reliability Engineering and System Safety, 141, 92–105. https://doi.org/10.1016/j.ress.2015.03.009

McClymont, K., Morrison, D., Beevers, L., & Carmen, E. (2020). Flood resilience: a systematic review. Journal of Environmental Planning and Management, 63(7), 1151–1176. https://doi.org/10.1080/09640568.2019.1641474

Mottahedi, A., Sereshki, F., Ataei, M., Qarahasanlou, A. N., & Barabadi, A. (2021a). Resilience estimation of critical infrastructure systems: Application of expert judgment. Reliability Engineering and System Safety, 215(September 2020), 107849. https://doi.org/10.1016/j.ress.2021.107849

Mottahedi, A., Sereshki, F., Ataei, M., Qarahasanlou, A. N., & Barabadi, A. (2021b). The resilience of critical infrastructure systems: A systematic literature review. In Energies (Vol. 14). https://doi.org/10.3390/en14061571

Noori, A., Bonakdari, H., Morovati, K., & Gharabaghi, B. (2020). Development of optimal water supply plan using integrated fuzzy Delphi and fuzzy ELECTRE III methods—Case study of the Gamasiab basin. Expert Systems, 37(5), 1–24. https://doi.org/10.1111/exsy.12568

Quitana, G., Senante, M., & Chamorro, A. (2020). Resilience of critical infrastructure to natural hazards : A review focused on drinking water systems. International Journal of Disaster Risk Reduction, 48(September 2019), 101575. https://doi.org/10.1016/j.ijdrr.2020.101575

Rehak, D., Senovsky, P., Hromada, M., & Lovecek, T. (2019). Complex approach to assessing resilience of critical infrastructure elements. International Journal of Critical Infrastructure Protection, 25(March), 125–138. https://doi.org/10.1016/j.ijcip.2019.03.003

Shaw, K. (2012). The Rise of the Resilient Local Authority? Local Government Studies, 38(3), 281–300. https://doi.org/10.1080/03003930.2011.642869

Shin, S., Id, S. L., Judi, D. R., Parvania, M., Mcpherson, T., & Burian, S. J. (2018). A Systematic Review of Quantitative Resilience Measures for Water Infrastructure Systems. 1–25. https://doi.org/10.3390/w10020164

Sweya, Lubuka N, Wilkinson, S., Kassenga, G., & Mayunga, J. (2020). Developing a tool to measure the organizational resilience of Tanzania ' s water supply systems In any instance of disaster , it is vital for organizations that are responsible for operating water supply infrastructure to ensure that services are To date. 39(2), 6–19. https://doi.org/10.1002/joe.21985

Sweya, Lukuba N., Manoga, R. P., & Norbert, J. (2021). Resilience to flood hazards: Awareness for the water supply infrastructure. Water and Environment Journal, 35(3), 951–961. https://doi.org/10.1111/wej.12685

Sweya, Lukuba N., Wilkinson, S., & Chang-Richard, A. (2018). Understanding Water Systems Resilience Problems in Tanzania. Procedia Engineering, 212(2017), 488–495. https://doi.org/10.1016/j.proeng.2018.01.063

UNDRR. (2022). Policy Brief: Towards Risk-Informed Implementation of The 2030 Agenda for Sustainable Development.

Ungar, M. (2018). Systemic resilience: principles and processes for a science of change in contexts of adversity. Ecology and Society, 23(4). https://doi.org/10.5751/ES-10385-230434

Yuliandra, R. H., Nurhamidah, N., Komala, P. S., & Bachtiar, V. S. (2025). Enhancing urban water supply systems resilience to floods in West Sumatra Province, Indonesia: A fuzzy Delphi approach. Civil and Environmental Engineering, 21(2), 1097–1112. https://doi.org/10.2478/cee-2025-0082

Zhou, W., Kalonji, G., Chen, C., & Martek, I. (2022). Seismic Resilience of Rural Water Supply Systems; Factor Analysis of Cases Set in Sichuan Province, China. Frontiers in Public Health, 10(February), 1–17. https://doi.org/10.3389/fpubh.2022.840379