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From Warning to Action: Local Government Capacity Gaps in Last-Mile EWS in Flood-Prone Chiang Rai, Thailand

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Abstract: Last-mile early warning systems (EWS) often fall short not because warnings are missing, but because people cannot act on them in time. This study examines local EWS capacity and its relationship to warning-to-action performance in flood-prone Chiang Rai Province, Thailand, where fast-onset flooding and limited lead times make last-mile actionability especially critical. Using a cross-sectional survey of 50 local government organizations (LGOs) conducted between December 2025 and January 2026, the study assesses capacity across four EWS pillars—disaster risk knowledge and governance, monitoring, dissemination, and preparedness—and examines which enablers and barriers shape actionability along the Receive → Understand → Trust → Act chain. Overall capacity was moderate to high: governance and dissemination/communication were relatively stronger, monitoring/decision support was moderate, and preparedness/response was the weakest pillar. A covariance-based structural equation model suggests a cumulative pathway linking governance, monitoring, dissemination, and preparedness, with preparedness emerging as the most proximate factor associated with fewer warning-to-action constraints ($\beta = -0.364$). The model explains only a modest share of variance in the actionability gap ($R^2 = 0.109$), indicating that effective last-mile EWS depends not only on warning delivery but also on feasible local response and contextual factors beyond institutional capacity. No statistically significant capacity differences were found across LGO types, although subdistrict administrative organizations reported higher average constraints. These findings highlight preparedness as the key operational lever for strengthening last-mile EWS through routine preparedness functions, clearer municipal–community roles, actionable guidance, redundant communication, and inclusive support for vulnerable groups.

Keywords: early warning systems; last-mile; local government capacity; preparedness; actionability; structural equation modeling; Thailand

1. Introduction

Early warning protects people only when it changes what they do [1]. In many last-mile early warning settings, warnings may disseminate rapidly, yet protective action still lags [2] because recommended measures are not feasible given local constraints—limited lead time, uncertain triggers, fragile communication channels [3], and uneven support for households facing mobility and resource barriers. This study examines these last-mile gaps by assessing whether warnings are clear, timely, and trusted, and whether they are backed by feasible options and resources that enable people to act before, during, and after hazard impacts [4,5].

In northern Thailand, flooding re-emerged in 2024–2025 as a recurring risk that disrupted transport, livelihoods, and local public services [6]. In Chiang Rai, this risk is compounded by increasingly variable rainfall under changing climatic conditions. Although long-term average rainfall remains relatively stable, greater interannual variability has increased the occurrence of extreme rainfall events and the likelihood of sudden, severe flooding, particularly in mountainous catchments and flood-prone lowlands [7]. Recent evidence also shows repeated flood impacts in the province, including seven incidents between July and October 2024 and an upward trend in annual rainfall [8]. Together with dispersed settlements, short lead times, and infrastructure interruptions, these conditions complicate warning delivery, evacuation, emergency logistics, and access to assistance. Chiang Rai therefore provides a relevant setting for examining last-mile early warning effectiveness, particularly the extent to which warnings can be translated into feasible community-level action [8].

Despite policy attention to early warning systems (EWS), empirical evidence in Thailand explaining last-mile enablers and barriers—especially evidence linking organizational capacity to the warning-to-action pathway—remains limited [9]. Local government organizations (LGOs) are central to last-mile delivery through coordination, local networks, warning channels, and preparedness/response [10,11] identifying their strengths and gaps can clarify why warnings do or do not translate into action and what investments best close the last-mile gap.

To address this gap, we examined local EWS conditions in Chiang Rai approximately one year after the 2024 flood events. During this post-flood period, some LGOs participated in capacity-strengthening activities as part of ongoing local EWS practice, although these activities did not cover all LGOs in the province. Rather than evaluating those activities directly, the present study uses a cross-sectional survey to assess broader post-flood patterns of preparedness attentiveness and warning-to-action arrangements across LGOs. Within this broader context, LGOs were engaged through a "municipality produces, community expands" model, in which municipalities standardize warning-to-action processes and community leadership extends reach, inclusiveness, and implementation. We then administered the survey across all LGOs in Chiang Rai (144 total), obtaining 50 complete responses collected between 1 December 2025 and 31 January 2026. Guided by the last-mile evidence synthesis, we conceptualize actionability as a decision chain—Receive → Understand → Trust → Act [12] and examine how institutional capacity and community-linked preparedness mechanisms shape the warning-to-action pathway in practice [4]. Accordingly, this study addresses two research questions:

RQ1: What is the current level of LGOs EWS capacity across the four EWS pillars in Chiang Rai?

RQ2: Which enablers and barriers most strongly shape whether warnings translate into community action along the Receive → Understand → Trust → Act chain?

2. Conceptual Framework: From Warning to Action at the Last Mile

These frameworks are used as complementary lenses in this study. IBFWS explains how warnings become operationally usable by linking hazard information to likely impacts and feasible protective action (Potter et al., 2021). The core outcome is last-mile actionability, defined here as the warning-to-action chain—Receive → Understand → Trust → Act [2,12–14]. The interrelated components in the *Disaster Resilience Scorecard for Cities: Multi-Hazard Early Warning Systems Addendum* by the United Nations Office for Disaster Risk Reduction (UNDRR) [15] are used as the main capacity domains through which this process is examined. Across these domains, cross-cutting enablers and barriers shape whether warnings are trusted and acted upon in practice [5].

2.1. Impact-Based Forecast and Warning Services (IBFWS)

We align this lens with the shift toward Impact-Based Forecast and Warning Services (IBFWS) [16] which emphasizes communicating expected impacts and recommended actions not just hazard information [14] and linking technical forecasts with exposure, vulnerability, and real-world decision needs [5]. This framing is reinforced by the Early Warnings for All (EW4All) agenda, which highlights people-centered, multi-channel systems that enable timely and feasible action, especially for at-risk groups [17].

Conceptually, warning to action is not a single step but a decision process shaped by cognition, trust, and capacity constraints. Protective behavior depends on how warnings are interpreted, whether the source is credible, and whether recommended actions are feasible under time and resource limits [18]. The Protective Action Decision Model (PADM) explains how warning information and social cues shape attention, comprehension, risk and efficacy perceptions, and protective action [12]. Accordingly, even well-designed impact-based warnings may not lead to action if households and local authorities lack preparedness, resources, or implementation pathways. This study therefore treats last-mile action as the outcome of an interconnected capacity chain—governance, monitoring, communication, and preparedness—rather than warning dissemination alone [19].

2.2. Core Outcome: Last-Mile Actionability (Warning → Action)

Last-mile actionability refers to the extent to which warnings are translated into timely and feasible protective action at the community level. In this study, it is treated as the core outcome of early warning performance, emphasizing not only warning dissemination but also whether warnings can be interpreted, accepted, and acted upon under real constraints of time, resources, and local response capacity [4].

A foundational account of this process is provided by *Communication of Emergency Public Warnings*, which describes warning response as a staged process of hearing, understanding, believing, personalizing, and responding, with confirmation often occurring along the way [18]. Lindell and Perry [12] extend this logic through the *Protective Action Decision Model* (PADM), showing that warning response is shaped by predecision processes such as reception, attention, and comprehension, followed by perceptions of threat, protective actions, and stakeholders, all of which influence protective action decision making under situational facilitators and impediments. In this sense, warning response is not a single behavioral step, but a sequence of psychological and perceptual processes linking message receipt to action.

Subsequent studies support and refine this perspective in applied warning contexts. Parker et al. [2] show that behavioural response to flood warnings depends not only on message transmission, but also on access, comprehension, confirmation, and the ability to convert warning information into preparedness or response. Casteel [14] demonstrates that impact-based warnings can improve risk interpretation by communicating likely consequences more clearly. Weyrich et al. [13] further find that warnings are more effective when they combine hazard information, impact meaning, and behavioural recommendations. Together, these studies indicate that effective warning communication depends on clear meaning, credible content, practical guidance, and consistency across channels and providers.

Drawing these strands together, this study summarizes last-mile actionability as the chain Receive → Understand → Trust → Act. This formulation is used as a synthesized analytical sequence rather than as a standalone model from a single source. It captures the common insight across the literature that warnings must first reach people, then be understood, regarded as credible, and finally translated into feasible protective action. The chain therefore provides a concise way to operationalize the warning-to-action process in a manner that remains grounded in both classic warning-response theory and more recent evidence on impact-based and people-centered early warning systems.

2.3. Interrelated Components as Capacity Domains

This study draws on the UNDRR MHEWS Addendum (UNDRR, 2024) and last-mile EWS literature [4] as the conceptual basis for organizing local early warning capacity. The UNDRR framework identifies five interrelated components of effective early warning systems: governance, disaster risk knowledge, detection, monitoring and forecasting, dissemination and communication, and preparedness and response capacity. In the UNDRR presentation, these components are linked to the Ten Essentials for Making Cities Resilient: governance to Essentials 1, 3, 4, and 6; disaster risk knowledge to Essential 2; detection, monitoring and forecasting to Essentials 4, 5, and 8; dissemination and communication to Essentials 7 and 9; and preparedness and response capacity to Essentials 9 and 10 [16]. For the purposes of this survey-based analysis, however, these components are adapted into four capacity domains.

In this adaptation, Governance and Disaster Risk Knowledge are combined into a single domain because the survey focuses specifically on local government capacity. In local government practice, risk knowledge is not treated as a standalone function; rather, it is generated, organized, interpreted, and used through institutional arrangements such as roles and responsibilities, Standard Operating Procedures (SOPs), coordination structures, and decision thresholds. This adaptation does not replace the original distinction in the source frameworks; instead, it re-specifies these elements for an institutional capacity assessment of warning-to-action performance.

Accordingly, the four survey-based domains used in this study are: (1) Governance and Disaster Risk Knowledge, (2) Detection, Monitoring and Forecasting, (3) Dissemination and Communication, and (4) Preparedness and Response Capacity. Although adapted for an institutional capacity survey, these domains remain aligned with the four EWS pillars identified by Tozier de la Poterie et al. [4]: understanding risk, observing and forecasting hazards, communicating warnings, and enabling protective action. More specifically, disaster risk knowledge concerns understanding hazards, exposure, vulnerability, and community coping capacity, including likely threats and their potential impacts on lives, livelihoods, and assets. Detection, monitoring and forecasting concerns observing, tracking, and predicting hazards, including timely information on when, where, and how severe impacts may occur. Dissemination and communication concerns ensuring that clear and timely warnings reach those at risk through accessible and context-appropriate channels. Preparedness and response capacity

concerns whether people and communities have the knowledge, resources, and time needed to act on warnings and protect themselves from hazard impacts.

Within this structure, the first domain combines governance and disaster risk knowledge to capture how local institutions organize and use risk information for warning and decision making, including roles and responsibilities, Standard Operating Procedures (SOPs), Emergency Operations Center (EOC) or equivalent coordination structures, and processes that support timely and legitimate warning-to-action transitions. The second domain assesses the capacity to generate timely and reliable hazard information. The third examines whether warnings can be communicated clearly and accessibly to those at risk. The fourth focuses on whether communities and institutions are prepared to translate warnings into feasible protective action.

In this study, these four domains are treated as the main domains of local institutional capacity. By contrast, cross-cutting factors—such as trust, participation, redundancy, and resources—are not treated as separate domains, but as enabling or constraining conditions that operate across all domains and influence whether capacity in each domain can be translated into feasible local action.

2.4. Cross-Cutting Enablers and Barriers

Last-mile evidence points to a set of cross-cutting enablers and barriers that shape whether local capacity can be translated into trusted, inclusive, and actionable warning-to-action performance. In the Thai LGO context, the most important are inclusive participation, trust-building, adequate resources beyond hardware, multi-channel redundancy, and two-way feedback and learning. These are not treated as separate pillars, but as institutional and operational conditions that influence all components of the warning system; when present, they enable effective performance, and when weak or absent, they become barriers [4,5].

For Pillar 1: Disaster Risk Knowledge, Tozier de la Poterie et al. [4] show that community-level enablers include participation, training, local and Indigenous knowledge, and the meaningful sharing of risk information, while barriers arise when communities are excluded or risk knowledge is poorly communicated. In the Thai LGO context, these conditions depend heavily on institutional support. This study therefore considers whether LGOs provide the governance and coordination, plans and SOPs, and budgetary support needed to organize risk mapping, training, and the co-production of risk knowledge.

For Pillar 2: Monitoring and Forecasting, community-level enablers include adequate monitoring systems, usable data, technical capacity, and links between forecasts and local impacts, while barriers include weak infrastructure, poor data quality, limited staff capacity, and fragmented coordination. In the Thai LGO context, local governments are not necessarily the producers of forecasts, but they are key users and local translators of monitoring information. This study therefore focuses on staff technical capacity and monitoring-related infrastructure as the institutional conditions that make forecasting information usable for warning and response.

For Pillar 3: Warning Dissemination and Communication, Tozier de la Poterie et al. [4] highlight trust, community involvement, clear and accessible messages, and multiple channels as key enablers, while barriers include delayed delivery, fragile channels, jargon, and low credibility. In the Thai LGO context, these findings translate into three practical considerations: community participation in warning arrangements, exercises and after-action review (AAR) to improve communication procedures, and multi-channel communication that combines official channels with community networks and redundant tools.

For Pillar 4: Preparedness to Respond, the main community-level conditions are knowing what to do, being willing to act, having the resources and time to act, and being involved in preparedness planning. Barriers emerge when people lack knowledge, confidence, resources, or practical arrangements for action. In the Thai LGO context, this is reflected in two linked concerns: confidence in the effectiveness of protective action and the practical state of preparedness and response. This study therefore examines whether LGOs support drills, evacuation planning, vulnerable-group support, and response procedures that make action both credible and feasible.

Taken together, Tozier de la Poterie et al. [4] suggest that no single pillar alone determines warning-to-action performance. However, Preparedness to Respond (Pillar 4) emerges as the most proximate driver of action, because even timely and credible warnings will fail when people lack time, resources, confidence, or practical means to act. At the same time, preparedness depends on the cumulative performance of the other pillars: risk knowledge supports understanding, monitoring supports timeliness and relevance, and dissemination supports clarity and trust.

3. Methods

3.1. Study Design and Sampling

This study employed a cross-sectional survey to assess LGO capacities for last-mile early warning systems (EWS) in Chiang Rai Province, Thailand. The analysis focused on identifying enablers and barriers that shape the warning-to-action pathway from warning issuance to community-level protective action, consistent with last-mile EWS evidence synthesis [4,5].

The survey covered all 144 LGOs in Chiang Rai. Respondents were typically LGO officials responsible for disaster prevention and mitigation, emergency coordination, or related administrative functions. The questionnaire was distributed through local project coordinators and designated focal persons, with follow-up reminders issued during the collection period to encourage participation and reduce incomplete returns.

Data were collected between 1 December 2025 and 31 January 2026, after capacity-strengthening activities had been implemented as part of ongoing local disaster risk reduction efforts. Of the 144 LGOs, 50 provided complete responses. Returned questionnaires were reviewed for completeness before inclusion in the analysis. However, because the survey was cross-sectional and did not include a baseline or comparison group, the analysis reports perceived capacity patterns and associations at the time of measurement rather than attributable impacts of those activities.

Because participation was voluntary and the study did not use probability sampling, the study constitutes a nonprobability sample and the findings may be affected by response bias. In particular, LGOs that were more active, more engaged in EWS-related activities, or more institutionally prepared may have been more likely to respond than weaker or less engaged organizations. The results should therefore be interpreted as descriptive and exploratory rather than statistically representative of all LGOs in the province, and are intended to identify broad patterns of institutional capacity, enablers, and barriers rather than to produce province-wide population estimates.

3.2. Study Area Setting

Chiang Rai was selected as the study area because it is a high-risk flood-prone province where recurrent hydro-meteorological hazards intersect with geographic and social conditions that complicate last-mile warning. The province recorded the highest average rainy-season rainfall among the study stations, a peak of 1719.90 mm, a significant upward trend in annual precipitation, and seven flood events between July and October 2024, indicating repeated flood exposure and an increasing need for timely, actionable warning systems [8].

This need is heightened by the province's mountainous, borderland, and rural character, where ethnically diverse communities often live in dispersed settlements and rely heavily on agriculture, making warning dissemination, evacuation, and access to assistance more difficult during severe weather events [20]. At the same time, flood risk in lower-lying areas and difficult terrain in upland areas can together constrain response under hazardous conditions, making Chiang Rai an important setting for examining last-mile early warning, where the effectiveness of warnings depends not only on message delivery but also on whether at-risk communities can act in time under difficult local conditions [8,20,21].

3.3. Survey Instrument

The questionnaire assessed perceived LGO capacity across four EWS pillars adapted from Tozier de la Poterie et al. [4] and UNDRR [5]. The survey items were derived from the main functional components of effective early warning systems identified in these frameworks and were translated into observable questions suitable for local government practice. In this study, the domains of disaster risk knowledge, governance, and standard operating procedures (SOPs) were operationalized through questions on whether LGOs had clearly assigned roles and responsibilities, defined command and coordination arrangements, and formal plans or SOPs that could guide action in actual warning and response situations. Monitoring and decision support were translated into items on access to rainfall and water-level data, monitoring coverage, thresholds, and the use of information for local decision making. Dissemination and communication were measured through items on communication channels, message delivery, clarity, and confirmation of receipt, while preparedness and response were measured through items on drills, evacuation planning, support for vulnerable groups, and post-event review.

For clarity and transparency, Table 1 presents the mapping between each survey domain, its underlying construct, the relevant item numbers, the number of items, and an example item. This mapping helps demonstrate how the conceptual components drawn from Tozier de la Poterie et al. [4] and UNDRR [5] were translated into measurable indicators of local warning-to-action capacity.

Table 1. Capacity Domain, Item and Example Question by domain.

Latent Variable	Observe Variables	Item No.	No. of Items	Example Item
Governance and disaster risk knowledge	L1: Governance and coordination	1–3	3	The LGO has clearly defined roles, responsibilities, and chains of command for warning and response.
	L2: Plans and SOPs	4–6	3	The LGO has clear warning thresholds, alert levels, and SOPs for different hazard scenarios.
	L8: Budget and support	22–24	3	The LGO has a regular budget for maintaining hazard monitoring and warning equipment.
Monitoring and decision support	L3: Staff technical capacity	7–9	3	The LGO has staff who can use information systems or dashboards for decision-making and communication.
	L6: Monitoring and infrastructure	16–18	3	The LGO can access near-real-time and reliable hazard data from meteorological and telemetry stations.
Dissemination and communication	L4: Community participation	10–12	3	The LGO conducts joint drills with village residents to strengthen understanding of local response roles.
	L5: Exercises and AAR	13–15	3	Over the past year, the LGO has conducted post-drill reviews and used the lessons learned to improve plans and SOPs.
	L7: Multi-channel communication	19–21	3	The LGO communicates warning signals, alert levels, and warning criteria clearly and consistently to the public.
Preparedness Action	L9: Outcome 1: confidence/effectiveness	25–27	3	The LGO issues warnings that are clear, easy to understand, and practical to follow.
	L10: Outcome 2: preparedness/response	28–30	3	The LGO ensures that most households know what actions to take when a warning is issued.
Actionability gap	Staffing constraints	31–33	3	The LGO does not have enough disaster management staff to monitor hazards and issue warnings across the whole subdistrict.
	Technical and decision-support limitations	34–36	3	Current warning thresholds and dashboards do not provide enough village-level detail for local decision-making.
	Institutional authority and decision constraints	37–39	3	Local officials often wait for provincial confirmation because warning thresholds are not clear enough to support local decisions.
	Budget and equipment constraints	40–41	2	The LGO lacks sufficient budget to strengthen subdistrict-level warning capacity in line with local risk.
	Communication coverage and equipment limitations	42–44	3	Villages within the LGO area still lack basic warning devices, such as PA systems, sirens, or radios.
	Response feasibility and vulnerable-group evacuation constraints	45–47	3	Villages within the LGO area still lack clear and systematic evacuation plans for vulnerable groups, including older persons, children, persons with disabilities, and bedridden patients.

These items were designed to capture not only the presence of institutional arrangements, but also whether they could support the practical outcome of warning-to-action at the local level. Additional items assessed perceived gaps and barriers, including staffing, budget adequacy, public response, and institutional limitations. All items were rated on a five-point Likert scale: 1 = strongly disagree, 2 = somewhat disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. For descriptive interpretation, mean scores were classified into five levels: low (1.00–1.80), low–moderate (1.81–2.60), moderate (2.61–3.40), moderate–high (3.41–4.20), and high (4.21–5.00).

3.4. Operationalization of Constructs

3.4.1. Pillar Scores

For descriptive analysis, survey items were first summarized into ten reporting dimensions (L1–L10), which served as subdimensions of the broader four-pillar EWS framework. Specifically, L1, L2, and L8 mapped to governance and disaster risk knowledge; L3 and L6 to monitoring and decision support; L4, L5, and L7 to dissemination and communication; and L9 and L10 to preparedness action. Composite scores for each EWS pillar

were then calculated as the mean of items mapped to that pillar. An overall capacity score was computed as the mean across all pillar items, enabling comparison of relative strengths and weaknesses across pillars.

3.4.2. Enablers and Barriers

To identify enablers and barriers, survey items were interpreted using a rule-based approach aligned with last-mile EWS themes [4]. Enablers were defined as items with consistently high mean scores, indicating established or routine capacity, such as functioning coordination mechanisms and multiple dissemination channels. Barriers were defined as items with low mean scores and/or high agreement with constraint statements, indicating actionability gaps that may interrupt the warning-to-action pathway.

Items were further categorized into cross-cutting last-mile dimensions, including participation and inclusion, trust, resource adequacy, multi-channel redundancy, message clarity, and the feasibility of protective action. For example, items on joint drills and community involvement were classified under participation and inclusion, while items on staffing, budget, and equipment were classified under resource adequacy.

3.5. Data Analysis

Analysis proceeded in three stages:

(1) Descriptive analysis of LGO characteristics, hazard profiles, and pillar scores was conducted using IBM SPSS Statistics, Version 19, and is reported as means and proportions.

(2) Comparative analysis was conducted in IBM SPSS Statistics, Version 19. Independent-samples t-tests were used to compare municipalities and SAOs on key outcomes and contextual variables, reflecting the expectation that the two LGO types may differ in administrative scope and resource conditions relevant to last-mile EWS performance. Results are reported as n, mean, SD, Δ(SAO−Muni), t(df), p (two-tailed), and 95% confidence intervals.

(3) CB-SEM (Covariance-Based Structural Equation Modeling) was conducted in IBM SPSS Amos, Version 24, to examine the relationships between the four EWS pillars and the warning-to-action pathway. Because bootstrapping was not performed, the structural results are interpreted descriptively based on the direction and magnitude of standardized path coefficients (β), R^2 values, and model fit indices. Measurement quality was assessed using standardized factor loadings obtained from Amos, from which composite reliability (CR) and average variance extracted (AVE) were derived, together with Cronbach's alpha calculated in IBM SPSS Statistics. These indicators are reported in a supplementary table to support the reliability and convergent validity of the constructs.

3.6. Ethical Considerations

Participation was voluntary. No personally identifiable information was collected, and results are reported in aggregated form at the organizational level. The study posed minimal risk to participants and focused on institutional capacity rather than individual behavior.

4. Results

4.1. Respondent Profile and Hazard Context

Survey responses were obtained from 50 of the 144 LGOs in Chiang Rai Province, yielding a 34.0% response rate. The responding LGOs comprised 29 municipalities and 21 subdistrict administrative organizations (SAOs). In this provincial context, SAOs often operate in more rural and remote areas, where settlements are dispersed, physical access is more difficult, and local communities may face greater exposure to water-related hazards together with more limited resources. Municipalities, by comparison, are generally located in relatively more urbanized areas with stronger infrastructure and revenue bases. These differences provided an analytical basis for comparing the two LGO types, on the expectation that they may differ in institutional capacity and operational conditions relevant to last-mile EWS performance.

4.2. Local EWS Capacity Scores (L1–L10) and Perceived Warning Gaps

Table 2 presents descriptive results for the ten reporting dimensions (L1–L10), providing a more detailed view of local EWS capacity across subdimensions. Overall, LGOs reported a moderate–high level of perceived EWS capacity ($\bar{x}$ = 3.91). The highest score was observed for governance and coordination (L1; $\bar{x}$ = 4.34, high), while

exercises and after-action review (L5; $\overline{x}$ = 3.51, moderate–high) received the lowest score. These results suggest that governance and communication functions were relatively stronger than practice-based preparedness functions.

Table 2. Local EWS capacity and outcome scores by dimension (L1–L10; items 1–30) (n = 50).

Dimension	Capacity Domain	Items	Mean ($\overline{x}$)	Level	SD
L1	Governance and coordination	1–3	4.34	high	0.65
L2	Plans and SOPs	4–6	4.09	moderate–high	0.83
L3	Staff technical capacity	7–9	3.93	moderate–high	0.82
L4	Community participation	10–12	3.77	moderate–high	0.97
L5	Exercises and AAR	13–15	3.51	moderate–high	1.10
L6	Monitoring and infrastructure	16–18	3.82	moderate–high	0.94
L7	Multi-channel communication	19–21	4.17	moderate–high	0.75
L8	Budget and support	22–24	3.75	moderate–high	0.88
L9	Outcome 1: confidence/effectiveness	25–27	3.92	moderate–high	0.86
L10	Outcome 2: preparedness/response	28–30	3.76	moderate–high	0.95
	Overall EWS capacity	1–30	3.91	moderate–high	

Table 3 presents perceived gaps affecting warning-to-action across items 31–47. Overall, LGOs reported a moderate level of perceived gap/constraint ($\overline{x}$ = 2.86). The highest score was observed for insufficient disaster management staff to monitor and issue warnings across the subdistrict (item 31; $\overline{x}$ = 3.44**,** moderate–high). By contrast, the lowest scores were observed for the lack of local risk zoning data for monitoring (item 34; $\overline{x}$ = 2.42, low–moderate) and the need to translate provincial warnings into local language, with risks of delay or misinterpretation (item 36; $\overline{x}$ = 2.42, low–moderate).

These results indicate that staffing shortages were the most strongly perceived constraint among the surveyed LGOs, while local risk zoning information and the translation of official warning language into more accessible forms were seen as less significant barriers. One possible reason is that the respondents, as LGO personnel, viewed constraints mainly from the perspective of day-to-day work at the subdistrict level, where staff shortages are immediately visible in routine monitoring and warning tasks. By contrast, local risk information and language adaptation may have appeared less problematic because local officials often see their role mainly as passing on centrally produced information through existing procedures. However, based on the researchers' training and field engagement, both localized risk information and locally understandable warning language remained important practical gaps in last-mile implementation.

Table 3. Perceived gaps affecting warning-to-action (items 31–47) (n = 50).

Item	Gap/Constraint Statement (Short Form)	Mean ($\overline{x}$)	Level	SD
31	Insufficient disaster management staff to monitor and issue warnings across the subdistrict	3.44	moderate–high	1.39
32	Limited confidence using hydro-meteorological data and risk maps to decide warning levels/areas	3.08	moderate	1.31
33	Limited confidence in risk communication so residents understand and comply	2.54	low–moderate	1.22
34	No local risk zoning data (hotspots, historic flood levels, vulnerable groups) for monitoring	2.42	low–moderate	1.16
35	Existing thresholds/dashboards lack village-level granularity for spatial decisions	2.90	moderate	1.25
36	Need to translate provincial warnings into local language; risk delays or misinterpretation	2.42	low–moderate	1.20
37	Fear of issuing wrong warnings due to unclear thresholds; wait for provincial confirmation	2.88	moderate	1.30
38	Focus on reporting upward rather than proactive local warning issuance	2.58	low–moderate	1.33
39	Perceived lack of authority to command or issue village-level warnings	2.52	low–moderate	1.33
40	Insufficient budget to develop subdistrict EWS capacity (training, data, warning equipment)	3.20	moderate	1.37
41	Insufficient budget to build community preparedness and response capacity	3.18	moderate	1.29
42	Lack of communication channels/equipment covering all villages (PA systems, vehicles, digital)	2.74	moderate	1.32

Table 3. *Cont.*

Item	Gap/Constraint Statement (Short Form)	Mean ($\bar{x}$)	Level	SD
43	Residents must interpret warning info themselves without clear guidance; confusion or errors	2.62	moderate	1.21
44	Villages lack basic warning devices (PA, sirens, radios), delaying warnings in risk areas	2.86	moderate	1.39
45	No systematic plan for evacuating vulnerable groups (older adults, children, PWD, bedridden)	3.02	moderate	1.38
46	Residents evacuate late despite warnings; wait to see actual water level	3.32	moderate	1.38
47	Large/complex terrain and connectivity gaps prevent comprehensive warning coverage	2.96	moderate	1.44
	Overall Gap/constraint	2.86	moderate	

4.3. Comparative Analysis across LGO Types and Contextual Variables

Independent-samples t-tests were conducted to examine whether early warning system (EWS) capacities and perceived warning-to-action gaps differed between municipalities (n = 29) and subdistrict administrative organizations (SAOs; n = 21) (Table 4). This comparison was analytically relevant because the two LGO types operate under different institutional and territorial conditions.

In Chiang Rai, municipalities generally operate in more urbanized areas with relatively stronger infrastructure, communication systems, and revenue bases, whereas SAOs often cover larger rural areas with dispersed and harder-to-reach settlements. These differences may shape staffing, resources, communication coverage, and the feasibility of warning dissemination and evacuation, making the comparison relevant to both EWS capacity and perceived warning-to-action gaps.

Table 4 shows that municipalities had slightly higher mean scores than SAOs in all four capacity domains: governance, monitoring and decision support, dissemination and communication, and preparedness/response. However, these differences were small in magnitude and not statistically significant. For governance capacity, municipalities (M = 4.0843, SD = 0.6477) and SAOs (M = 4.0317, SD = 0.7455) did not differ significantly, $t(48) = 0.2660$, $p = 0.7920$, $\Delta = 0.0526$, 95% CI [−0.3450, 0.4501]. Similarly, no significant differences were observed for monitoring capacity, $t(48) = 0.8930$, $p = 0.3760$, dissemination, $t(48) = 0.6450$, $p = 0.5220$, or preparedness, $t(48) = 0.6570$, $p = 0.5140$, with all confidence intervals crossing zero. In contrast, SAOs reported higher perceived warning-to-action gaps than municipalities (M = 3.1036 vs. 2.6897; $\Delta = -0.4140$), although this difference also did not reach statistical significance, $t(48) = -1.5440$, $p = 0.1290$, 95% CI [−0.9530, 0.1252].

Table 4. Independent-sample t-test comparisons between municipalities and SAOs.

Variable	Municipal $\bar{x}$, (SD)	Subdistrict $\bar{x}$, (SD)	Δ	t (df)	*p* Sig. (2-tailed)	95% CI
Governance (items 1–6,22–24)	4.0843 (0.6477)	4.0317 (0.7455)	+0.0526	0.2660 (48)	0.7920	[−0.3450, 0.4501]
Monitoring (items 7–9, 16–18)	3.9655 (0.7998)	3.7540 (0.8622)	+0.2116	0.8930 (48)	0.3760	[−0.2650, 0.6876]
Dissemination (items 10–12, 13–15, 19–21)	4.0345 (0.7174)	3.8889 (0.8761)	+0.1456	0.6450 (48)	0.5220	[−0.3080, 0.5992]
Preparedness (items 25–30)	3.8046 (0.8114)	3.6296 (1.0729)	+0.1750	0.6570 (48)	0.5140	[−0.3600, 0.7104]
Actionability gap (items 31–47)	2.6897 (0.9279)	3.1036 (0.9470)	−0.4140	−1.5440 (48)	0.1290	[−0.9530, 0.1252]

These results suggest that overall EWS capacity levels were broadly comparable across the two LGO types, despite some directional differences. This may partly reflect the fact that municipalities and SAOs share broadly similar formal responsibilities in local disaster prevention and mitigation, including planning, coordination, warning, and response action [22]. In practice, however, they operate under different local conditions: municipalities generally serve more urbanized areas with relatively stronger infrastructure, communication systems, and revenue bases, whereas SAOs more often cover rural jurisdictions with dispersed settlements, harder-to-reach villages, and more constrained resource conditions [23]. Under such conditions, formal capacity scores may appear similar, while differences are more likely to emerge in operational reach and the practical difficulty of turning warnings into timely protective action [24].

4.4. EWS Capacity and Pathway to Actionability

4.4.1. Reliability and Convergent Validity Analysis

The reliability and convergent validity of the measurement model were assessed using standardized factor loadings, Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE). In general, standardized factor loadings above 0.70 indicate acceptable indicator reliability, Cronbach's alpha values above 0.70 indicate acceptable internal consistency, CR values above 0.70 indicate satisfactory construct reliability, and AVE values above 0.50 indicate adequate convergent validity. As shown in Table 5, all constructs met these recommended thresholds. Standardized factor loadings ranged from 0.717 to 0.893, indicating acceptable to strong indicator reliability. Cronbach's alpha values ranged from 0.891 to 0.953, indicating good to excellent internal consistency across all constructs. CR values ranged from 0.750 to 0.910, confirming satisfactory to excellent construct reliability, while AVE values ranged from 0.600 to 0.751, indicating adequate convergent validity for all constructs. Overall, these results support the reliability and convergent validity of the constructs used in this study.

Table 5. Test results of Cronbach's Alpha, AVE, and CR.

Latent Variable	Observation Variable	Standardization Factor Loading	Cronbach's Alpha	CR	AVE	Overall Interpretation
Governance and disaster risk knowledge	L1	0.722	0.901	0.829	0.618	Excellent reliability; acceptable validity
	L2	0.818				
	L8	0.815				
Monitoring and decision support	L3	0.840	0.891	0.858	0.751	Good reliability; good validity
	L6	0.893				
Dissemination and communication	L4	0.887	0.929	0.898	0.746	Excellent reliability; good validity
	L5	0.882				
	L7	0.821				
Preparedness action	L9	0.814	0.953	0.750	0.600	Excellent reliability; acceptable validity
	L10	0.734				
Actionability gap	Vulnerable	0.764	0.943	0.910	0.629	Excellent reliability; acceptable validity
	Communicate	0.826				
	Budget	0.743				
	Authority	0.717				
	Tech	0.831				
	Staff	0.869				

4.4.2. Structural Model and Pathway to Actionability

This section addresses RQ1 and RQ2 by examining both the current pattern of LGO early warning system (EWS) capacity across the four pillars and the structural pathway linking these capacities to warning-to-action performance. For RQ1, the findings indicate that EWS capacity in Chiang Rai is uneven across the four pillars: Governance and Dissemination appear comparatively stronger, Monitoring is moderate, and Preparedness remains the weakest pillar. Overall, this suggests that Chiang Rai LGOs are stronger in organizing, monitoring, and communicating warnings than in community preparedness for action.

For RQ2, the Receive → Understand → Trust → Act sequence provides the behavioral logic underlying the structural model, while Governance → Monitoring → Dissemination → Preparedness → Actionability gap represents the organizational pathway that supports it in practice. Although the two sequences are not directly equivalent, they are conceptually aligned. In this model, Governance structures how LGOs receive, interpret, and disseminate risk information from national agencies, thereby supporting local preparedness action.

Having established this conceptual interpretation, the next step is to assess whether the proposed pathway is supported by the empirical data. As shown in Table 6, the model demonstrates excellent overall fit ($\chi^2 = 0.618$, df = 2, CMIN/DF = 0.309, RMSEA = 0.000, PCLOSE = 0.761, CFI = 1.000, TLI = 1.028, NFI = 0.998), indicating that the hypothesized relationships are broadly consistent with the observed data. The very low CMIN/DF and RMSEA, together with the high incremental fit indices (CFI, TLI, and NFI), suggest that the proposed structural model fits the sample data closely. However, these fit statistics should still be interpreted cautiously because the model has very low degrees of freedom.

Table 6. Model fit indices and standardized structural coefficients.

Section	Statistic/Path	Value	Criterion/Note	Interpretation
A. Model fit	χ^2	0.618	non-significant preferred	Good fit
	df	2	-	Very low df
	CMIN/DF	0.309	<2–3	Excellent
	RMSEA	0	<0.06–0.08	Excellent
	PCLOSE	0.761	> 0.05	Good fit
	CFI	1	≥ 0.95	Excellent
	TLI	1.028	≥ 0.95	Excellent
	NFI	0.998	≥ 0.90	Excellent
B. Standardized structural coefficients as direction/ magnitude	Governance → Monitoring	0.744	<0.10 = very weak, 0.10–0.29 = weak, 0.30–0.49 = moderate, ≥0.50 = strong	Strong positive
	Monitoring → Dissemination	0.587		Strong positive
	Dissemination → Preparedness	0.538		Strong positive
	Monitoring → Preparedness	0.396		Moderate positive
	Preparedness → Governance	0.041		Very weak positive
	Actionability gap → Dissemination	0.068		Very weak positive
	Preparedness → Actionability gap	-0.364		Moderate negative
C. Squared multiple correlation (R^2) as explanatory power	Monitoring	0.573	0.75 = substantial, 0.50 = moderate, 0.25 = weak	Moderate
	Dissemination	0.700		Moderate to high
	Preparedness	0.835		Substantial
	Actionability gap	0.109		Very low
	Governance	0.062		Very low

As shown in Figure 1, the model suggests a largely sequential capacity pathway. Governance was positively associated with Monitoring (β = 0.744), indicating that stronger institutional arrangements were linked to stronger local risk monitoring and decision support. Monitoring was in turn positively associated with Dissemination (β = 0.587), suggesting that LGOs with stronger monitoring capacity were also better able to communicate and disseminate disaster risk information. Dissemination was positively associated with Preparedness (β = 0.538), indicating that stronger warning communication capacity was linked to greater readiness for protective action. In turn, Preparedness was negatively associated with the Actionability gap (β = -0.364), suggesting that stronger preparedness was linked to fewer perceived constraints in translating warnings into timely protective action. By the way, a very weak reverse path was also observed from the Actionability gap to Dissemination (β = 0.068), suggesting limited feedback. Moreover, the small path from preparedness to governance (β = 0.041) is not treated as a central finding. The main interpretation remains the sequential pathway from governance to monitoring, dissemination, and preparedness, which is more consistent with the conceptual framework and prior literature.

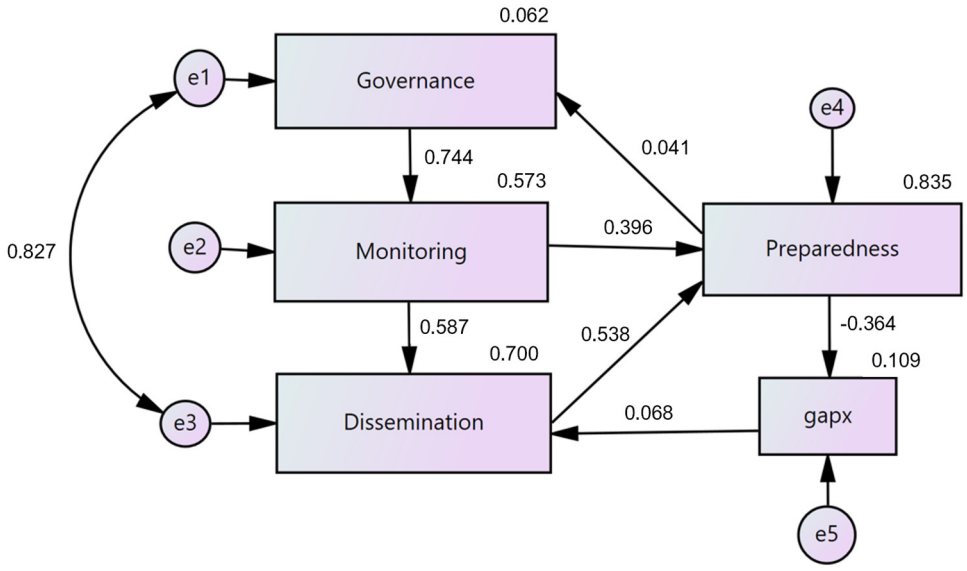

Figure 1. Pathway from EWS capacity to last-mile actionability with CB-SEM standardized solution.

The model explained Preparedness most strongly (R^2 = 0.835), followed by Dissemination (0.700) and Monitoring (0.573), indicating good explanatory power along the intermediate organizational capacity pathway. By contrast, the Actionability gap had low explanatory power (R^2 = 0.109), suggesting that the final transition from warning to community action is also shaped by factors outside the model. The low R^2 for Governance does not contradict its strong effect on Monitoring, because path coefficients and R^2 reflect different aspects of the model. Governance appears to function primarily as an upstream institutional condition that shapes downstream capacities, especially monitoring, rather than as an endogenous construct with high explanatory power in its own right.

Taken together, these results provide a direct answer to RQ2. The strongest enablers of warning-to-action performance are the upstream organizational capacities that support the chain from Governance to Monitoring, Dissemination, and especially Preparedness, with preparedness emerging as the most proximate condition for reducing the actionability gap. At the same time, the findings also point to important barriers, particularly those that lie beyond formal warning capacity alone. These likely include staffing limitations, transport and evacuation feasibility, support for vulnerable groups, household decision constraints under short lead times, and terrain or connectivity barriers. Thus, warnings are more likely to translate into community action when institutional capacity is paired with practical preparedness and feasible response conditions.

5. Discussion

The results show that Preparedness has a very high R^2 (0.832), indicating that anticipatory action is central to the warning-to-action mechanism. Although Governance, Monitoring, and Dissemination all show relatively strong positive effects, these converge on Preparedness, where practical anticipatory measures remain limited. This suggests that the main constraint lies less in the absence of upstream institutional capacity than in the difficulty of converting that capacity into concrete pre-disaster action for social protection under Thailand's regulatory and operational constraints [25,26]. Because the analysis is based on self-reported assessments, however, the findings should also be interpreted with caution, as respondents may have portrayed their organizations more positively than actual implementation would suggest [27].

In the Thai context, the weak implementation of prevention-oriented preparedness-particularly for protecting vulnerable groups and reducing losses before impact-does not appear to stem simply from a lack of funding under the Disaster Prevention and Mitigation Act, B.E. 2550 [28]. Rather, it reflects constraints on anticipatory spending, uncertainty over which pre-disaster expenditures are legally supportable, and concern that such spending may later be questioned by audit and oversight bodies. Thailand has not yet institutionalized a full anticipatory action framework with clearly defined trigger thresholds, risk levels, and procedural safeguards for situations in which warnings are issued but hazards do not occur or are less severe than expected. Although the Ministry of Finance's regulation on contingency advances for emergency disaster assistance allows preventive spending when a disaster is expected in the immediate term and urgent action is necessary [29], this framework remains narrower than a broader preparedness or risk-reduction approach and is geared mainly toward urgent short-term prevention rather than systematic anticipatory action.

These legal and procedural conditions also shape how local governments make decisions in practice. Guidance from the Department of Local Administration [30] provides channels for public assistance and, under certain conditions, the use of reserve funds. At the same time, however, these rules reinforce procedural requirements and approval expectations, making many local actors cautious about committing funds before visible impact occurs. As a result, LGO personnels may hesitate to use reserve or accumulated funds for anticipatory measures when they are uncertain whether such expenditures will withstand later scrutiny, especially if the hazard does not materialize or proves less severe than anticipated.

This helps explain why even hazard-specific standard operating procedures (SOPs) do not automatically translate into anticipatory action in practice. Measures such as pre-evacuation support for vulnerable groups, advance shelter activation, early contracting to clear drainage routes, pre-positioning relief items, or early investment in communication infrastructure may all be difficult to justify before impact is visible. In effect, the institutional system makes post-disaster spending administratively safer than pre-disaster action. This helps explain why early warnings in flood-prone last-mile settings do not always lead to timely protective action, even when warnings are issued. In the present study, this is reflected in the finding that preparedness remained the weakest pillar despite formal responsibilities under Thailand's Disaster Prevention and Mitigation Act and the National Disaster Prevention and Mitigation Plan (2021–2027) [31] of the Department of Disaster Prevention and Mitigation [DDPM]. Taken together, the findings suggest that the main constraint is not the absence of warning messages, but the difficulty of translating warnings into timely [32] and feasible action under existing legal, procedural, and accountability arrangements.

These findings are broadly consistent with evidence synthesized by the GDPC in Tozier de la Poterie et al. [4], which draws on 15 studies across 14 countries and four types of last-mile populations: rural and geographically isolated communities (Bangladesh, the Philippines, Albania, and Namibia); economically vulnerable groups (Kenya, Malawi, Eswatini, Nigeria, and India–fishers); gender and socially marginalized groups (India–women, Ethiopia, and Brazil); and people with disabilities or health-related vulnerabilities (Vietnam, Nepal, and Indonesia). Across these settings, Pillar 4 shows that preparedness remains constrained not simply by the existence of warnings, but by five recurring barriers: limited knowledge of what to do, weak willingness to act, insufficient resources, inadequate time to respond, and limited community involvement in preparedness planning. For example, Bangladesh, Nepal, and Eswatini highlighted the importance of clear, actionable guidance; Nigeria and India showed how livelihood trade-offs reduced willingness to act; Bangladesh, Brazil, Ethiopia, Indonesia, and Nepal pointed to transport and support needs for vulnerable groups; and Albania, Brazil, Malawi, Nepal, Nigeria, Indonesia, and Eswatini reported that warnings often arrived too late for meaningful action. The report also identifies more positive examples, such as actionable heat alerts in Nigeria, anticipatory support linked to early warnings, and community-driven trigger systems in the Philippines that helped connect warnings to concrete actions such as opening shelters or moving livestock. This broader evidence reinforces the present finding that preparedness is often the weakest part of the warning-to-action chain because people may receive and understand warnings but still be unable, unwilling, or unsupported to act in time.

The findings are also consistent with the Protective Action Decision Model, which suggests that people act not only when they receive warnings, but when they trust them and believe they can carry out the recommended actions [12]. However, the low explained variance in the actionability gap outcome (R^2 = .109) indicates that barriers to action are also shaped by factors beyond institutional capacity, especially household risk perception and decision-making under uncertainty and short lead times [33]. Although municipalities and SAOs did not differ significantly in formal capacity scores, SAOs reported higher average gaps, suggesting lower practical actionability at the last mile. This underscores the importance of the municipal–community interface, where formal institutional capacity must be translated into locally actionable support, especially for vulnerable households [34].

6. Recommendations: Toward Systemic Strengthening of Last-Mile EWS

The findings indicate that last-mile early warning effectiveness is shaped by a capacity chain rather than any single technical component. In the structural model, governance strengthens monitoring, monitoring strengthens dissemination, and both contribute to preparedness. Preparedness is the most proximate capacity associated with fewer perceived actionability gap (Figure 1; Table 6). This is consistent with last-mile evidence [4] showing that warnings often fail to translate into timely protection because people face practical constraints that make early action difficult under real-world conditions.

Accordingly, the recommendations proposed here are organized into two groups. Recommendations 1–3 are derived primarily from the structural path coefficients, which identify the strongest downstream leverage points in the capacity chain, particularly the pathway from monitoring to dissemination to preparedness. Recommendations 4–5 are derived primarily from the very low explained variance in the actionability gap outcome (R^2 = .109), which suggests that important barriers remain beyond the institutional capacity pathway, especially at the municipal–community and household implementation interface.

(1) Prioritize preparedness as the primary leverage point for actionability. Because preparedness is directly associated with fewer constraints (Table 6), it should be financed and managed as a standing function rather than an ad hoc activity. This is especially important given the budget constraints identified in Items 40–41, which show that many LGOs lack sufficient resources to strengthen local warning capacity. A minimum preparedness package should include staged actions linked to triggers, shelter readiness, transport and logistics options, and routine drills with after-action updates. This directly addresses the feasibility bottleneck highlighted in last-mile evidence [4].

(2) Co-produce locally actionable guidance tied to thresholds and time windows (impact-based orientation). This recommendation addresses the gaps identified in Items 44–46, including limited warning devices in some villages, the lack of systematic evacuation plans for vulnerable groups, and delayed evacuation despite warnings. LGOs should therefore work with village leaders and community actors to link warning levels to locally relevant risk thresholds and short action scripts—such as prepare, assist priority groups, move assets, and evacuate—so that warnings can be translated into timely action and community-level support for vulnerable groups [35]. This is consistent with WMO [5] guidance on moving from hazard-focused warnings toward impact-based services designed to support decision-making and action.

(3) Build redundancy and confirmation into dissemination, not only message issuance. This recommendation responds to the gap in Item 42 and 47 which indicates incomplete communication coverage across villages. LGOs should therefore strengthen redundant channels, trusted local intermediaries, and escalation steps when primary channels fail, so that warning communication remains functional during crises at the community level [4].

(4) Institutionalize the municipal–community interface with clear operational roles. The very low explained variance in the actionability gap suggests that smoother implementation at the local interface is essential for improving warning-to-action performance and strengthening preparedness. Clear roles should therefore be defined across LGO officers, village leaders, and volunteers for receipt confirmation, household outreach, assistance to vulnerable groups, evacuation coordination, and shelter operations. This can improve speed and clarity under short lead times and people-centered warning delivery [4].

(5) Target feasibility support where constraints remain highest. Given the low explained variance in constraints (R^2 = 0.109) (Table 6), practical "last-mile feasibility" support should be prioritized—especially for vulnerable households and lower-resourced local administrations—through transport arrangements, buddy systems, shelter accessibility checks, and assistance protocols [36]. In the Thai context, such measures are not entirely new, as comparable forms of assistance were previously emphasized during the 2011 major flood response. However, over time, local personnel have often become more reluctant to apply them in routine practice because doing so may require the use of their own agency budgets to support affected households or other groups beyond narrowly defined routine expenditures. Uncertainty over whether such spending is fully permissible, together with concern that it may later be questioned by audit and oversight bodies, can discourage proactive use of these measures.

Overall, the updated findings support a shift from "warning as information" to "warning as implementable protection," where upstream capacity produces protective value primarily when it strengthens preparedness and makes early action feasible at the community interface [4,5].

7. Conclusions

This study shows that last-mile early warning performance in flood-prone Chiang Rai is shaped by a cumulative capacity structure rather than by warning dissemination alone. The four capacity domains used in this study, adapted from the UNDRR and last-mile EWS literature, provide an institutional lens for understanding warning-to-action performance in flood-prone local contexts. Across 50 LGOs, overall EWS capacity was moderate to high, with governance and dissemination comparatively stronger, monitoring moderate, and preparedness the weakest pillar. The structural results further suggest a sequential pattern in which governance strengthens monitoring, monitoring strengthens dissemination, and these downstream capacities support preparedness.

Within this structure, the main gap lies in preparedness. Preparedness was the most proximate capacity associated with fewer warning-to-action constraints, indicating that last-mile EWS depends not only on whether warnings are issued, but on whether communities have feasible, practiced, and supported options for acting on them. At the same time, the very low explained variance in the actionability gap suggests that important barriers remain beyond the institutional capacity chain, particularly at the municipal–community and household interface.

Taken together, these findings suggest that strengthening last-mile EWS should focus less on warning transmission alone and more on preparedness as an operational function, actionable guidance, reliable dissemination under failure conditions, and municipal–community arrangements that make early action feasible.

Future research should build on these findings through longitudinal evaluation of whether capacity strengthening improves preparedness and actionability over time, community behavior surveys on how households interpret and respond to warnings, analysis of how real-time hazard information is used in local decision-making, and mixed-method comparison between LGO and community perspectives to identify gaps between institutional readiness and actual household experience.

Author Contributions

S.S.: conceptualization, methodology, design of data collection, formal analysis, interpretation of findings, synthesis of policy recommendations, writing—original draft preparation, and writing—review and editing. M.S.: spatial data collection for disaster-affected areas, coordination with government agencies to compile responses from local administrative organizations, investigation, resources, and writing—review and editing. Both authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

This research was reviewed and classified as exempt by the Institutional Review Board of Institutional Review Board, Chiang Mai Rajabhat University, Thailand (project code IRBCMRU 2026/002.06.01, date of approval 23 February 2026). The study was conducted in accordance with applicable international ethical principles, national laws, and relevant regulations, and was deemed appropriate to be conducted in accordance with the approved research proposal.

Informed Consent Statement

All participants were informed about the purpose of the study and voluntarily agreed to participate.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used AI-assisted tools only to support translation and improve the academic language of the manuscript. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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